DEVELOPMENT OF ECOFRIENDLY HYBRID MODEL FOR WASTEWATER TREATMENT

Thesis

Submitted to

G. B. Pant University of Agriculture & Technology, Pantnagar U.S. Nagar-263145, Uttarakhand, INDIA.

By

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M.Sc. (Environmental Science & Technology)

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Doctor of Philosophy

(ENVIRONMENTAL SCIENCE)

August, 2018

ACKNOWLEDGMENT

After an intensive period of three years in GBPUA&T Pantnagar, today is the day: writing this note of thanks while compiling my doctoral research work in the form of this thesis, which is one of the most wonderful and memorable experience of my life. It has been a period of intense learning for me, not only in the environmental field but also on a personal level. Writing this thesis has had a big impact on me. Though only my name appears on the cover of this research work, lots of peoples have contributed to its creation. I owe my gratitude to all those peoples who have made this possible and because of whom my Ph.D. experience has been one that I will cherish forever. I bow my head with reverence to Almighty that has showered the blessings on me to get through the whole task of my Ph.D. work and brought this thesis to a logical end.

*I raise my heart in gratitude, and thank Almighty, to be blessed with most loving, supporting and caring Parents Sri **Jagdish Solanki** & Smt. **Lali Solanki**. Thank you both for giving me the strength to reach for the stars and chase my dreams. This thesis is dedicated to my parents as for the education of their children's was the first and foremost thing in life and they left no stone unturned in raising and supporting me throughout their entire life. My fiancee Ms. **Neha** and sister's **Jyoti** and **Lalita** deserve my wholehearted thanks as well.*

*The period of Ph.D. involves an enriching experience in terms of both personal and professional growth; I express my sincere gratitude to my fiancée Ms. **Neha** for her unforgettable and unconditional support throughout this period.*

*My sincere thanks to my advisor, Dr. **R. K. Srivastava**, Professor and chairman of my Advisory Committee. I have been amazingly fortunate to have an advisor who gave me the freedom to explore on my own and at the same time the guidance to recover when my steps faltered. Dr. **R. K. Srivastava** taught me how to question thoughts and express ideas. His patience and support helped me to overcome many crisis situations and finish this thesis work.*

*I am also very much grateful to members of my advisory committee, Dr. **A. K. Shukla**, Professor and Dean College of Basic Sciences and Humanities, Dr. **A. S. Nain**, Professor, and Head, Department of Agrometeorology and Dr. **Vir Singh**, Professor Department of Environmental Science, I am grateful to them for their salutary advice, kind co-operation and congenial discussion on an array of topics.*

*A big Thank You to Dr. **J. P. N. Rai**, Professor and head Environmental Science and Dr. **Uma Melkania**, Professor for their kind co-operation and constant encouragement during the pursuit of the present study.*

Since this research work was a part of R&D project entitled "Integrated Technology System for Phytoremediation of Domestic Wastewater with Floating Rafts (Floating Wetland):

R&D and Pilot Testing" therefore I express my sincere thanks to Ministry of Drinking Water Supply & Sanitation, Govt. of India and IIT Delhi for funding the project.

I would like to extend my thanks to Dr. ***Padma Vasudevan****, Dr.* ***P. K. Sen****, Dr.* ***Mohan Lal Sehgal****, Professors from Indian Institute of Technology, Delhi for their help and support to me in my thesis work.*

I also wish to express my gratitude to Dean, Post Graduate studies and Dean, College of Basic Science and Humanities, Direct Experiment station, Registrar and University Librarian, GBPUA&T for providing me all the necessary facilities needed to conduct the study.

I sincerely acknowledge the motivation, encouragement, and support which I received from my seniors Dr. ***Anil Shankwar****, Dr.* ***Shobhika Parmar****, Dr.* ***Sarita Joshi*** *and Mr.* ***Amit Kumar Rabha*** *and Mr.* ***Aporv Pant*** *without their support I would not have been able to complete this thesis on time. Doing research and attaining innovative research ideas is not only challenging but also most often very stressful. Many friends have helped me to stay sane through these difficult years. Their support and care helped me to overcome setbacks and stay focused on my Ph.D. study. I greatly value their friendship and I deeply appreciate their belief in me. I was lucky to have batchmates; Ms.* ***Maitreyie Narayan****, Ms.* ***Hina Khatoon****, Ms.* ***Surindra Negi*** *and Mr.* ***Shiv Singh Meena*** *for their companionship and non-stop encouragement kept my research momentum going on. I also would like to thank my loving juniors namely Ms.* ***Priyanka****, Ms.* ***Rashmi****, Ms.* ***Sampda*** *and Mr.* ***Shivam*** *for their love and support. I cannot list all the names here, but you are always in my heart, thank you all friends.*

I am also thankful to ***Jitender bhaiyya*** *and* ***Bimlesh Didi*** *for always providing a helping hand in my work. Great thanks to system staff who maintained all the machines in the laboratory so efficiently that I never had to worry about viruses, losing files, creating backups or installing software. I feel that they are the greatest system administrators in the world. Kudos to* ***Akram bhaiyya*** *and* ***Neeraj bhaiyya****, thanks to department office people* ***Manoj bhaiyya****,* ***Kamla didi****,* ***Gupta Ji****,* ***Jugat Ram Ji****,* ***Lal Ji*** *and the rest of the team.*

Thank You ***Lord****, for always being there for me.*

This thesis is only a beginning of my journey.

Pantnagar
August, 2018

(Praveen Solanki)
Author

CERTIFICATE

This is to certify that the thesis entitled "**DEVELOPMENT OF ECOFRIENDLY HYBRID MODEL FOR WASTEWATER TREATMENT"** submitted in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** with major in **Environmental Science** and minor in **Agrometeorology** of the college of Post Graduate Studies, G. B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. Praveen Solanki, Id. No. 49630**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigation and source of literature have been duly acknowledged.

Pantnagar
August, 2018

(R. K. Srivastava)
Chairman
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CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Mr. Praveen Solanki, Id. No. 49630** a candidate for the degree of **Doctor of Philosophy** with major in **Environmental Science** and minor in **Agrometeorology,** agree that the thesis entitled **"DEVELOPMENT OF ECOFRIENDLY HYBRID MODEL FOR WASTEWATER TREATMENT"** may be submitted in partial fulfilment of the requirements for the degree.

(R. K. Srivastava)
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(A. S. Nain)
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Ex-officio Member
Head of the Department

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% red.	:	Percentage reduction of pollutants
µS/cm	:	Micro semen's per centi meter
AAS	:	Atomic adsorption spectrophotometer
As	:	Arsenic
BCF	:	Bioconcentration factor
BIS	:	Bureau of Indian standards
BMP	:	Best management practice
BOD	:	Biochemical oxygen demand
Cd	:	Cadmium
CD	:	Critical difference
COD	:	Chemical oxygen demand
Conc.	:	Concentration
CPCB	:	Central pollution control board
Cr	:	Chromium
CV	:	Coefficient of variation
CW	:	Constructed wetland
EC	:	Electrical conductivity
EPA	:	Environmental protection act
EPI	:	Environmental performance index
FRT-I	:	Floating raft tank-I
FRT-II	:	Floating raft tank-II
FRWTS	:	Floating raft wastewater treatment system
H	:	Hours
Hg	:	Mercury
HRTs	:	Hydraulic retention time
HS-1	:	Hybrid system-1 (FRT-I + FRT-II)
HS-2a	:	Hybrid system-2a (FRT-I + OP)
HS-2b	:	Hybrid system-2b (FRT-II + OP)
HS-3	:	Hybrid system-3 (CW + FRT-II)
HS-4	:	Hybrid system-4 (CW + FRT-II + OP)
IIT	:	Indian institute of technology
K	:	Potassium

M^2	:	Meter square
mg/plant	:	Mili gram per plant
MLD	:	Million liters per day
N/A	:	Not applicable
Na	:	Sodium
NH_4^+-N	:	Ammonia nitrogen
NO_3^-N	:	Nitrate nitrogen
OP	:	Oxidation pond
Pb	:	Lead
PO_4^-	:	Phosphate
ppm	:	Parts per million
R&D	:	Research and development
RCF	:	Root concentration factor
SD	:	Standards deviation
Se	:	Selenium
STPs	:	Sewage treatment plants
TDS	:	Total dissolved solids
TF	:	Translocation factor
TN	:	Total nitrogen
TS	:	Total solids
TSS	:	Total suspended solid
TW	:	Tap water
WP	:	Whole plant
WW	:	Wastewater

Introduction

One of the great ancient Indian scholars, Rahim had addressed the importance of water as "रहिमन पानी राखिए, बिन पानी सब सून । पानी गए न ऊबरे मोती, मानस, चून ।।". This has revealed that water has been one of the most precious assets on the earth which should be preserved if it will vanish out, it will also lead to destroying not only the aquatic life and human beings but the whole world as well. In India, approximately 1.2 billion people had access to only 1820 cubic meter of water per capita per year in 2014, which was 5177 cubic meter per person per year in 1951 **(Bhati *et al*., 2015)**, thus indicating the water crisis of present and upcoming future. Furthermore, only 68 % of Indian population is drinking safe water, and this problem is further becoming worst due to population explosion and rapid industrialization. India's very lower rank, that is 141st in Environmental Performance Index (EPI) for the year of 2016, showed an alarming situation for the protection of human and environmental health on the World map **(Hsu *et al*., 2016)**.

The Central Pollution Control Board **(CPCB, 2015)** has been realized the big gap between sewage generation and its treatment capacity for urban India in 2015 and reported that only a small fraction of about 23277 MLD (37.54 % of total wastewater) out of 62000 MLD (million liters per day) is treated through 816 STPs (sewage treatment plants) across the country. Water demand of industries is also under pressure; therefore many industries have been forced to adopt wastewater recycling systems, and its reuse for different industrial purposes **(WWTI, 2010; Grant, 2011)**. Hence, there is an urgent need to develop low-cost and eco-friendly hybrid model for wastewater treatment, and also to be focused on reuse of this treated water for non-potable purposes such as fertigation, flushing the toilet, thermal cooling tower, iron industries, etc.

Water is our most precious and basically natural resource and a key component for sustainable governance of all ecosystems and further, it is responsible for the great abundance and diversity of life on the earth. However, drastically increasing pollution load in water and simultaneously decreasing in freshwater resources are two most emerging threats to the entire global water cycle. Heavy metals and metalloids, such as Cd, Pb, Cr, Hg, As, Se, etc. are releasing into the water environment by mining, industry and agricultural activities, which leads to threatening environmental and human health **(Dixit *et al*., 2015)**. Due to the acute toxicity of these contaminants, there is an urgent need to develop low-cost, effective and sustainable methods to remove them from the environment or to detoxify them.

These crises of water can mitigate only through the recycling and reuse of industrial and domestic treated and untreated wastewater after certain treatment. For recycling and reuse of wastewater, a proper treatment system is required at large scale, since a huge quantity of wastewater is generating. There are several highly accepted wastewater treatment processes available today. However, the main drawback is that none of these are concurrently followed the 4E concept, i.e., economically viable, efficiently feasible, easily applicable and ecologically suitable at large scale. Hence, the global scientific concern always focused their research orientation towards the eco-friendly, energy-efficient, economic sustain and easy to adoptable (4E) to handle technology for wastewater treatment and recycling.

Floating raft wastewater treatment system (FRWTS) is a manmade ecosystem that mimics natural floating system/habitat **(Solanki *et al*., 2017a)**. At the beginning of the 20th century, this system was used for birds' habitat and fish spawning place as natural habitat. In the 1980s, German scholars designed the modern ecological floating bed and used it to purify polluted water for the first time. In 2012 this technology was tested by **Vasudevan *et al*. (2012)** at Indian Institute of Technology, Delhi and National Institute for Technical Teachers Training and Research, Chandigarh using *Canna indica*. Floating rafts is an efficient and promising wastewater remediation technology for improving surface water quality in wastewater body where vegetation/plants grow on artificial floating platforms. Floating or rafted reed beds with the size of about 1 to 2 m^2 in combination with supporting media (coconut coir or similar) can be used for the tertiary treatment of sewage and also for stormwater treatment **(Vasudevan *et al*., 2011a)**. This technology basically is an application of hydroponics system using artificial floating platforms, where plants grew up and uptake nutrients, organic matter as well as detoxify heavy metals and other pollutants present in the wastewater; furthermore, the overall process will lead to treatment/phytoremediation of wastewater in an eco-friendly manner and cost-effective manner **(Sun *et al*., 2009; Solanki *et al*., 2017b)**.

Due to the shortage of water for irrigation, farmers in peri-urban areas of many developing countries including India are using domestic and other industrial wastewater effluents for raising their crops and often use undiluted wastewater to provide nutrients indirectly as a fertigation **(Keraita and Drechsel 2004; Scott *et al*., 2004)**. This practice can severely harm human health and environment due to associated pathogens, as well as allowing heavy metals and other undesirable constituents from water to entire food chain. Therefore, use of floating raft wastewater treatment system (FRWTS) along with constructed wetland (CW) as a hybrid model for initial treatment of this wastewater could greatly reduce adverse environmental and health impacts from wastewater as it is used for irrigation **(Vasudevan *et al*., 2011b)**. A constructed wetland is a bed or vertical profile of sand, gravel, and pebbles, which is used for wastewater purification. The root system of plants and media (soil and stone) act as filters and support the natural biological growth of biofilms, which help in removing contaminants. In addition, plants utilize nutrients and bioaccumulate contaminants such as metals in their harvestable biomass.

Phytoremediation is a plant-based technology, viz., phytoextraction, rhizofiltration, rhizodegradation, phytovolatilization, phytostabilisation, etc. which is relatively inexpensive since they are performed in-situ and natural-driven **(Duan *et al*., 2016)**. Since plants play a crucial role in this method of wastewater remediation as reported by **Solanki *et al*. (2017a),** can improve water quality by accumulate metals in their harvestable biomass (phytoextraction), to release certain metals in volatile form (phytovolatilization), to degrade complex compounds into simpler compounds (phytodegradation), filtering the metals through their roots (rhizofiltration) and so on. The selection and indigenous availability of suitable plant species according to types and concentration of the pollutant to be removed are very crucial **(Solanki *et al*., 2017a)**. FRWTS may represent a comparatively low cost and sustainable engineered best management practice (BMP) for reducing pollution load from wastewater **(Wilson *et al*., 2006)**.

The eco-friendly management of wastewater can also be done by the process called phytoremediation; in which wastewater is used as irrigation source, and up to some extent it is also called as "fertigation" **(Shankhwar and Srivastava 2015)** as it contains several essential nutrients as well as organic matter which is required for healthy plant growth **(Matheyarasu *et al*., 2016; Plaza *et al*., 2007)**. Most part of available freshwater, approximately 79 % is used in irrigation across the country, hence for sustainable use of water resources and to reduce extreme water scarcity in future, it is very necessary to reuse the domestic and industrial wastewater for irrigation or fertigation purpose after a certain treatment **(Zaidi, 2007)**. Localized treatment of wastewater for irrigation would not only mitigate wastewater disposal problem but also meet the water and nutrients need of plants as it will be utilized for fertigation **(Vasudevan *et al*., 2011a)**.

The plants, viz. Canna (*Canna indica* L.), Pistia (*Pistia stratiotes* L.), Water lily (*Nymphaea* sp.) and American aloe (*Agave americana*), were used in this research work for phytoremediation of domestic wastewater and heavy metals scavenging from the synthetic polluted water.

Keeping in view the above facts, present research work had been planned to achieve the following objectives:-

1. Characterization of domestic wastewater collected from the University Campus, Pantnagar.
2. Development of eco-friendly hybrid model using Floating Raft Tank (FRT), Constructed Wetland (CW) and Oxidation Pond (OP).
3. Assessment of heavy metals scavenging potential of *Canna indica* L. and *Pistia stratiotes* L. for Chromium (Cr), Cadmium (Cd) and Lead (Pb) removal in Laboratory condition.
4. Assessment of hybrid model for purification of domestic wastewater in natural environmental condition.

Review of Literature

2.1 Water for sustainability: present and future

Water is the most important natural resource on the earth which plays an essential role in human as well as in animal life. Water has several applications in our life, i.e., for domestic uses, industries, agricultural utility and many more. But increasing industrialization, urbanization and human population etc. degrading the water quality and quantity of both surface and groundwater resources. Indiscriminate use of agrochemicals in agriculture is also the main factor contributing to the deterioration of water quality. In India, 70 per cent of surface water resources and a growing percentage of groundwater reserves are getting contaminated **(CPCB, 2015)**. Many industrial wastewater are highly contaminated with different types of biological waste, toxic, organic, and inorganic pollutants. Drinking water degradation with heavy elements, metal ions, and harmful microorganisms is one of the major threats to public health causing various types of waterborne diseases **(Gupta, 2009)**. According to the World Health Organization, about 80% of all the diseases in human beings are caused due to polluted water **(UNWWDR, 2018).** Therefore, it is necessary to monitor the quality of water at regular intervals.

Water is a highly valuable renewable resource on the planate earth considering its properties and kind of applications **(Kumar *et al*., 2005).** Being one of the most precious resources **(Nalina and Puttaiah, 2006)**, it is significant to keeping stability and sustenance of plants, living organisms and human civilizations **(Ekhaisi and Anayasi, 2005).** During the current scenario, the value of drinking water whether it is surface or groundwater, degrading due to human activities likes industrialization and unethical over-extraction of water from the groundwater reservoirs.

In recent times, with the increase in pollution input, it has become mandatory to monitor and measure the levels of metal build up in water periodically **(Dundar and Altundag, 2007).** While considering the quality of drinking water, other parameters are also precious which include pH, Electrical Conductivity (EC), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Nitrogen (TN), Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended

Solid (TSS), Phosphate (PO_4^-), Potassium (K), Sodium (Na), Nitrate (NO_3^-), Ammonia (NH_4^+), Heavy metals (Cr, Cd, and Pb) etc.

2.2 Need for wastewater recycling and water quality criteria

Environmental pollution is one of the major challenges of today's civilization **(Kaushik *et al*., 2012)**. In India, it is found that one-third of total water pollution caused by the industrial effluent discharge, solid wastes, hazardous wastes and rest is due to municipal wastewater, agricultural run-off, etc. Wastewater from these all sources presents a potential hazard to the natural water system **(Deepali, 2012)**. This wastewater contains many inorganic and organic matters, which are toxic to the various life forms of the ecosystem **(Spina *et al*., 2012)**.

Several research investigations have shown the worldwide occurrence of pollutants in wastewater, surface water and groundwater quality **(Heberer, 2002; Debska *et al*., 2004)**. The increasing pollution load of pollutants from industrial water as well as domestic wastewater has also caused great harm to the rivers, lakes, springs, and other water bodies, posing major health risks on either direct bathing or drinking **(Seth *et al*., 2013)**. Moreover, domestic and industrial demands for water requirement are increasing as these sectors are growing rapidly day by day. It is estimated that water demand is expected to increase from 688 Km^3 to 1072 Km^3 for the agriculture sector, 12 Km^3 to 63 Km^3 for the industrial sector and 56 Km^3 to 102 Km^3 for domestic sector for drinking water from year 2010 to 2050 **(Shankhwar *et al*., 2016)** as given in **Table 2.1**.

Table 2.1 Increment in freshwater demand from the year 2010 to 2050

Sector	Water demand increment	
	2010	**2050**
Agriculture sector	688 km^3	1072 km^3
Domestic sector	56 km^3	102 km^3
Industrial sector	12 km^3	63 km^3

Water is one of the most crucial elements, which is required every day by human beings as well as entire living biosphere for their survival. Without the adequate availability of hygienic water, the existence of the entire biosphere would be under crisis and will lead to the collapse of various living and non-living ecosystems on the earth. The global scarcity of freshwater is a strong challenge for sustainable development. In India also freshwater scarcity has been found in several states, as the groundwater continues to exhaust more than its recharging rate **(Mandal and Priti 2015).** As per Indian Standards (IS:1172-1963), i.e. 135 liters per person per day (LPD) is required for various domestic purposes throughout the day, however, the daily wastewater generation is around 64 % of 135 LPD **(Shankhwar *et al*., 2016).**

Besides this, population explosion is boosting up wastewater generation in manifold ratio. Globally in 2013, the unsafe drinking water leads to approximately 2 % (~1.24 million) of deaths, and their access to freshwater has been drastically decreased by approximately half from 960 million in 2000 to 550 million people in 2016 **(Hsu *et al*., 2016).** Thus, the reuse of this huge wastewater for irrigation purpose such as "fertigation" **(Shankhwar and Srivastava 2015),** is an emerging issue to manage the increasing freshwater demand for human consumption. The sources of wastewater generation, particularly from the non-point sources of wastewater are multiple in nature as well as they are very tedious to assess the exact point from where the pollutants are entering into the water body **(Wagener *et al*., 2010; Destouni *et al*., 2013).**

Quantitatively wastewater generation is also very tedious to assess, as it completely depends upon human, industrial, socioeconomic and cultural activities at the different times throughout the day **(Zhoua *et al*., 2000).** Wastewater generation varies from season to season, day to day and even it is changing on an hourly basis as well **(Henze *et al*., 2000),** which creates hurdle in the preparation of wastewater treatment strategy. Due to the lack of wastewater treatment facility, e.g., only 60 % of industrial and approximately 26 % of domestic wastewater is currently treated in India **(Bhati *et al*., 2015).** As well as due to inactive strong policies, most of the domestic wastewater and industrial effluent water are directly discharged into the vicinity rivers and other water bodies, resulting in approximately 75 % contamination of all freshwater resources across the country **(CPHEEO, 2012).**

Human interference for unsustainable instant benefits and inappropriate use of water leads to more pollution load into most of the water sources. Hence, it is very necessary to develop low-cost and eco-friendly; phytoremediation based wastewater treatment methodologies which will be more efficient and less time-consuming in managing and reusing this huge quantity of wastewater. **Table 2.2** represents the discharge standards of wastewater on Inland surface water, public sewer, land for irrigation and marine coastal area.

The reuse of municipal wastewater has become an economic issue with increasing water demand for human consumption and agricultural production **(Shankhwar and Srivastava, 2012)**. Therefore, the secondary application of wastewater, as well as grey water, have been emerged as an integral part of wastewater management which is promoting the preservation and conservation of high-quality freshwater, additionally reducing both environmental pollution and overall supply costs **(Al-Hamaiedeh and Bino, 2010; Matos *et al*., 2012).** For many countries, wastewater reuse has been now a major part of their overall water management plan. For example, in Israel, more than 70% of its treated wastewater is reused for agricultural irrigation (**Mekorot, 2007**). Wastewater treatment and recycling of useful products (i.e., water, nutrients, and organic matter) mitigate water shortages and environmental pollution. Along with secondary application and reuse of wastewater as sources of irrigation will leads understanding to the potential environmental impacts of this practice.

Table 2.2 Discharge standards for treated sewage water in ppm (developed from CPHEEO, 2012)

Sl. No.	Parameters	Inland surface water	Public Sewer	Land for irrigation	Marine coastal area
1	SS (suspended solids)	100	600	200	100
2	TDS (total dissolved solids)	2100	2100		2100
3	pH	5.5-9.0			
4	Temperature °C	(A)			(A)
5	Oil & Grease	10	20	10	20
6	Total Residual Chlorine	1			1
7	Ammonia Nitrogen as N	50	50		50
8	Total Kjeldahl Nitrogen as N	100			100
9	Free Ammonia	5			5
10	BOD (biological oxygen demand)	30	350	100	100
10	COD (biochemical oxygen demand)	250			250
11	Dissolved phosphorous as P	5			
12	Nitrate Nitrogen as N	10			20
	Fecal Coliform (by courtesy of **NRCD, 2010)**				
		Discharge onto land		Discharge onto water	
		Desirable	Max Permissible	Desirable	Max Permissible
13	Fecal Coliform (MPN/100ml)	1000	10000	1000	10000

(A) – the temperature of the receiving water body shall not exceed above 5°C

2.3 Potential sector for reuse of treated and untreated wastewater

Wastewater is comprised of two types of water, i.e., grey water and black water with approximately 7:3 ratio of grey and black water respectively **(Pandey *et al*., 2014)**. Grey water comes from bathroom, kitchen, washing and so on, whereas the black water comes from the toilets. The nutritional value of sewage water at Gangneung City, South Korea has been reported by **Choi and Lee (2015)** as total phosphorus (9.24 ppm), PO_4 (8.19 ppm) and total nitrogen (40.02 ppm), which shows the agricultural potential of sewage water.

The manurial potential of grey water was also assessed at GBPUA&T, Pantnagar where the total above ground biomass (AGB) production of *Eucalyptus* hybrid (clone K-413) revealed 34.19 kg/tree in grey water treated plots as compared to 25.69 kg/tree in control plots (irrigated with well water) **(Shankhwar *et al*., 2016)**. More presence of microorganisms indicates the higher nutrient level of water, sewage from residential areas and biodegradable waste from industrial discharge has shown relatively higher microbial biomass **(Kumar and Pal, 2015)**.

In India, 75 % effluents discharge from paper and pulp mill emerging as wastewater **(Kumar *et al*., 2014)**, and widely used for irrigation. Furthermore, this wastewater contains several essential plant nutrients, viz., nitrogen (N), potassium (K), sulfur (S), phosphorus (P), calcium (Ca), etc. **(Jais *et al*., 2017; Hultberg and Bodin 2017)**. Wastewater can be the best option to irrigate turfgrass of golf courses as an alternative to freshwater since it contains some essential nutrients, however, the electrical conductivity can be limiting one **(Beltrao *et al*., 2014)**. Globally it is also observed that rapid increase in the concentration of phosphorus (P) and nitrogen (N) in wastewater, leads to accelerating eutrophication of receiving water bodies **(Conley *et al*., 2009)**.

Presence of different plant nutrients, viz. N, P, K, Na, Mg, Zn, Co, Mo etc. in various types of wastewater makes it more economically viable for agricultural production, since it works as 'fertigation' (sources of fertilizer as well) which reduces the recommended dose of fertilizer **(Fatta-Kassinos *et al*., 2011; Adrover *et al*., 2012; Shankhwar and Srivastava 2015)**. Millions of farmers in urban areas of developing countries having no alternative rather than reuse of wastewater for cropping in off rainy season, moreover this could reduce the irrigation cost, improve soil physico-chemical properties as well as reduce environmental damages by direct discharging of wastewater into the freshwater bodies **(Solanki *et al*., 2017c)**.

Physico-chemical properties of wastewater from textile industry of Savar, Bangladesh have been reported by **Shammi *et al*. (2016)** as pH of 8.15, EC 7390 µS/cm, Ca 8.63 ppm, Mg 3.83 ppm, Zn 0.13 ppm and safely used in a pot culture experiment for Malabar spinach. Addition of plant nutrients through wastewater lead to changes in soil aggregates and microhabitats which further affects the soil microbial community **(Torsvik and Ovreas 2002)**. In general, wastewater with high organic matter (OM), improve soil physical properties, i.e., soil aggregation, water holding capacity (WHC), soil organic carbon (SOC) and soil structure as well **(Baldock and Nelson 2000; Sparks 2003)**.

Plant nutritional capacity of wastewater (applied @ 5000 m^3/ha/year) for deposition of N, P and K into the soil can reach as high as 250, 50 and 150 kg/ha, respectively **(Pescod, 1992)**. The composition of major plant nutrients, i.e. N, P and K in wastewater also reported by **Mojid *et al*. (2012)** accordingly 17.50, 3.70 and 10.30 ppm, which shows its potential application in agricultural production. Wastewater application also plays a significant role in bio-geochemical cycles of different elements, i.e. C, N, P, K, S, etc. through the wastewater-soil-plant system.

Use of wastewater for irrigation particularly in arid zones, where the freshwater has been scarce and reuse of wastewater for irrigation and other non-potable purposes, could significantly reduce the use of potable water up to 50 % **(DHWA, 2001)**. In some, arid and semiarid areas, municipal water consumption typically increased by 40-60 % in summer months due to landscape irrigation **(Eriksson *et al*., 2002)**. However, the secondary application as reuse and treatment of wastewater which is collected as grey water sources alone has been observed particular interest for urban and peri-urban reuse possibly due to low pollution loading and high quantitative availability **(Jefferson *et al*., 1999)**. **Anirudhan and Sreekumari, (2011)** reported that treatment of gray water from bathroom source alone could be sufficient to meet the on-site reuse requirements and thereby significantly reduce the potable water consumption by 28.5 %.

2.4 Domestic wastewater phytoremediation

Some plants are more capable for the accumulation of heavy metals and trace elements (hyperaccumulators) into their different body parts such as roots, stems and leaves; which have been intensively characterized, identified and studied since the beginning of 20th century **(Gałuszka *et al*., 2015)**. These plants are extensively used for remediation of the polluted environment through the process called phytoremediation **(Rasico and Navari 2011; Ali *et al*., 2013)**, however, different plant shows different types of mechanisms for remediation of pollutants from polluted as well as contaminated water **(Zabłudowska *et al*., 2009)**.

Heavy metals and metalloids, such as Cd, Pb, Cr, As and Se are releasing into the environment by mining, industry, and agriculture which threatening environmental and human health **(Mishra and Maiti, 2017)**. Due to the acute toxicity of these contaminants, there is an urgent need to develop low-cost, effective and sustainable methods to remove them from the environment or to detoxify them. Floating rafts, a plant based technique, called phytoremediation, which is relatively less expensive since it performed in-situ and solar-driven **(Duan *et al*., 2016)**. Since plants play a major role in remediation of wastewater, they can be used to accumulate metals and another pollutant into their harvestable biomass (phytoextraction) and to release certain metals in a volatile form into the atmosphere (phytovolatilization).

Heavy metals present in drinking water may affect human health unfavorably and adversely. The increasing contamination of food chain and drinking water with the elevated, toxic concentrations of heavy metals is posing a startling situation into the human being. They may exist in the environment naturally in higher concentrations or as a consequence of anthropogenic activities. Drinking water source may be groundwater (including tube-wells and hand-pumps) or surface water (including rivers, lakes, ponds, and streams). More than three billion people of the world are dependent on groundwater as a source of drinking water **(Fry, 2005)**.

Phytoremediation of heavy metals refers to the use of pollutant-accumulating plants to extract and accumulate contaminants into their harvestable parts and is increasingly being considered as an environmentally friendly, easy to adopt, and cost-effective solution to clean up soils and wetlands contaminated through heavy metals **(Salt *et al*., 1998; Yu and Gu 2007; Solanki *et al*., 2017b)**.

Hyperaccumulating plants, which have unique abilities to tolerate, accumulate and detoxify metals at high concentration, represent an important method that could be enhanced phytoremediation process **(Arora *et al*., 2006).** Phytoremediation activities done by the plant are depicted in **Fig. 2.1**. They comprise a complex ecosystem of plants and several microbes into their root hair zone and organic loads that together act as a biogeochemical filter, efficiently removing contaminants from the very large volume of wastewater **(Augustynowicz *et al*., 2010)**. Plants support microbial mediated transformations of contaminants by supplying fixed-carbon as an energy source for microbes and by altering the chemical as well as the microbial environment in their rhizosphere **(Say *et al.*, 2001)**. **Table 2.3** represents some examples of phytoremediation plants along with target pollutants to be removed by them.

Table 2.3 Examples of selected plants for phytoremediation of different contaminants

Plant species	Contaminant	Reference
Salix alba	Cd	**Weyens *et al.*, (2013)**
Sedum alfredii	Zn	**Chen *et al.*, (2014)**
Brassica juncea	Ni and Cr	**Kumar *et al.*, (2009)**
Ricinus communis	Ni, Cu, and Zn	**Rajkumar and Freitas (2008)**
Brassica napus	Pb and Cd	**Sheng *et al.*, (2008)**
Pisum sativum	2,4-D	**Germaine *et al.*, (2004)**
Arabidopsis thaliana	Atrazine	**Wang *et al.*, (2005)**
Populus deltoids	Hg	**Che *et al.*, (2003)**
Nicotiana glauca	Cd, Pb, Cu, and B	**Martinez *et al.*, (2006)**

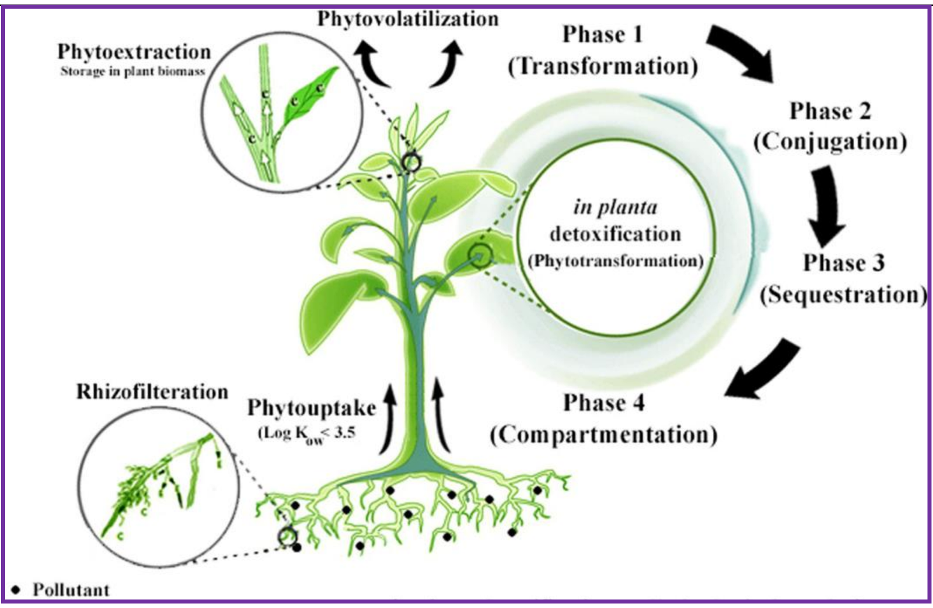

Fig. 2.1 Mechanisms of hyperaccumulator plant for detoxification of contaminants (Aken *et al.*, 2009)

Normally, heavy metals cause toxic effects by forming organic complexes with organic compounds. The solubility of the metal ions mainly depends on the pH of the water or soil solution, Dissolved Oxygen (DO), and total hardness **(Barlas, 1999)**. The decrease in pH and increase in acidity can increase the solubility of heavy metals and further their availability to the aquatic and terrestrial plants **(Hellawel, 1988)**.

2.4.1 Floating Raft Wastewater Treatment System (FRWTS)

Floating raft wastewater treatment system (FRWTS) is a combined eco-technological model, developed using ecological principals involving aquatic macrophytes and colonization of various microorganisms developed into their root hair biofilms for phytoremediation of wastewater **(Gustavo *et al*., 2008; Sun *et al*., 2009; Faping and Xiaoyi 2013; Duan *et al*., 2016; Solanki *et al*., 2017a; Solanki *et al*., 2017b)**. Aquatic macrophytes are key component of FRWTS and play a crucial role in pollutants removal through the various processes such as rhizofiltration, rhizodegradation, root induced chemicals, bacterial mechanisms, phytoaccumulation etc, thus promoting efficient functioning of FRWTS **(Korboulewsky *et al*., 2012; Li *et al*., 2013; Das *et al*., 2014; Rodrigues *et al*., 2017)**. In addition, selected plants for FRWTS should have a large rhizosphere, high bio-concentration factor (BCF) and translocation factor (TF), high adaptation and fast growth rate in various climatic conditions, high tolerance with respect to pollution load **(Qin *et al*., 2011; Vesely *et al*., 2012; Chattoraj *et al*., 2014; Yan *et al*., 2017)**. Therefore, the selection of plant species significantly affects the phytoremediation efficiency of FRWTS's **(Madera-Parra *et al*., 2013; Solanki *et al*., 2017b)**.

In the recent scenario, application of floating rafts/floating wetlands (which is supported with rooted and free aquatic floating plants) and facultative ponds treating domestic as well as industrial wastewater, have been observed to gain considerable attention because of these techniques offer an ecofriendly approach **(Chang *et al*., 2012; Pan *et al*., 2012; Avila *et al*., 2013; Mburu *et al*., 2013)**. The mechanisms of pollutants removal in floating rafts/wetlands involve an "interaction between the bacterial metabolism, plant uptake and accumulation of pollutants into their physiological biomass" **(Osem *et al*., 2007)**.

The oxygen produced by the process called photosynthesis by floating plants was released into water through the plant's submersed leaves **(Chen *et al*., 2003)**, then many oxic and aerobic areas were formed around the root rhizosphere zone to intensify both aerobic microbe’s and anaerobic microbe’s for their growth and reproduction, to promote microbe’s constant absorption and utilization of organic pollutants in water and to increase its degradation efficiency of organic and inorganic matters, thus achieving the purpose of removing organic matters. Plant’s roots also release a large number of enzymes and organic acids to enhance the decomposition and degradation of the macromolecular or toxic pollutants/substances in wastewater and improve the bioavailability of nitrogen and phosphorus to the plant roots.

Experiment on a floating bed grown canna was also conducted by **Sun *et al*. (2009)** for wastewater phytoremediation which was collected from Pearl River in Guangzhou, China. The initial characteristics of wastewater were ranged as total nitrogen (8.61 – 8.86 ppm), ammoniacal nitrogen (2.38 – 2.96 ppm), nitrate nitrogen (2.46 – 2.79 ppm), nitrite nitrogen (0.28 – 0.76 ppm), chemical oxygen demand (36.2 – 41.6 ppm), dissolved oxygen (5.12 – 5.61) and pH (6.50 – 7. 00). Reduction in these pollutants by canna planted floating bed system after 5 days retention time were by 50.4 % for total nitrogen, 100 % for ammonical nitrogen, 22.4 % for nitrate nitrogen, 5.3 % for nitrite nitrogen and 39.9 % for chemical oxygen demand.

The working concept behind FRWTS

The following activities occur during phytoremediation in FRWTS:-

a. Organic matter degradation through various types of microorganisms such as bacteria, actinomycetes, and fungi on plant root surfaces (rhizosphere).

b. Plant uptake organic as well as inorganic substances such as nutrients, heavy metals etc. through the process called phytoextraction.

c. The root hair zone (rhizosphere) of floating aquatic plant promotes flocculation and sedimentation of various suspended materials and filters out various sediments and associated pollutants through root hair filtration which is called as rhizofiltration.

d. During the degradation process of remaining dried plant material, the trapped organic matter will release soluble carbon which further allows for their natural denitrification which occurs in oxygen-limited conditions.

2.4.2 Constructed Wetland (CW)

A constructed wetland is a man-made wetland system to treat/filter municipal or domestic, industrial wastewater, grey water or black water etc. Constructed wetlands are engineered systems that use natural functions of vegetation in combination with gravel, pebbles and various types of microorganisms to purify wastewater. Depending on the type of wastewater and the level of treatment, the design of the constructed wetland has to be adjusted accordingly **(Maiga *et al*., 2017)**. The constructed wetlands (CW) have been used for the treatment of both on-site as well as centralized wastewater. If the BOD and COD of wastewater are high, which shows a large amount of debris, suspended solids or soluble organic matter (OM) then it will be necessary to run a primary treatment of wastewater prior to feeding into the constructed wetland to reduce the blockage of CW.

Similar to natural wetlands system, the constructed wetland also acts as a biological filter and/or can remove or detoxify different kinds of pollutants and toxic metals (such as nutrients, organic matter, heavy metals, pathogens) from the different types of wastewater **(Hoffmann *et al*., 2011)**. A constructed wetland is a sanitation technology that has not only been designed specifically for removal of various pathogens, but also, it has been designed for removal of other water quality constituents such as nutrients (nitrogen and phosphorus), suspended solids (SS), organic matter etc. (**Cui *et al*., 2010**). All kinds of pathogens (i.e., bacteria, protozoan, viruses, and helminths) are expected to be removed up to some extent through a constructed wetland which planted with various kinds of phytoremediation plants. Sub-surface type of wetland provides greater removal of pathogens as compared to surface wetlands **(Dotro *et al*., 2017)**.

Constructed wetland systems and constructed soil filters were suggested as suitable treatment alternatives owing to their ability to treat highly variable pollutant load with lower operational and maintenance cost, which will be more practically adapted for tropical and developing countries like India. In addition to this, grey water which comes from the kitchen and bathroom source was considered more favorable for its secondary application due to its low concentration of pollutants and contaminants.

Rai *et al*. (2015) also used constructed wetland (horizontal subsurface type) for treatment of urban wastewater to conserve river Ganga at Haridwar, India. This horizontal sub surface type of constructed wetland which was planted with *Phragmites australis*, *Typha latifolia* and *Colocasia esculenta* removed lead by 86 %, Cu by 84.01 %, Zn by 83.48 %, As by 82.23 %, Cr by 81.63 %, Co by 76.86 %, Ni by 68.14 % and Mn by 62.22 % during summer, while in winter, the reduction for various pollutants were in order of Pb (78.59 %) > Cu (72.50 %) > Zn (68.40 %) > Co (65.12 %) > Cr (64.50 %) > As (63.18 %) > Mn (53.34 %) and Ni (51.39 %) at 36 hrs. of treatment period.

2.4.3 Oxidation Pond (OP)

The shallow pond along with floating rafts is an alternative option to the conventional treatment process because of it's low water depth (140-150 mm) comprising with fully matured plant roots which submerged (80-130 mm) to "avoid the anaerobic zone" **(Valipour *et al*., 2009)**. Shallow pond floating raft technique ensures the optimal interactions between the wastewater effluent, plant root zone and microbial biomass in the phytoremediation treatment process. The shallow water pond promotes an attempt to minimize these problems due to the better diffusion efficiency of the oxygen through the roots and accumulation of a larger population of the aerobic bacteria. This is a new biological-plant-based-eco-friendly technique that can be applied to the efficient and reliable elimination of pollutants at a lower hydraulic retention time (HRT) through providing of extra oxygen, as the raft is free floating in nature due to natural air circulation **(Valipour and Singh, 2016; Valipour, 2015)**. However, further improvements in the shallow pond practice as an effective plant-based-remediation tool for purifying municipal/industrial wastewater effluents could be the objective for future research.

2.5 Domestic wastewater characteristics and phytoremediation

Wastewater composition depends on the source, plumbing system, living habits in households, personal hygiene of the users, and the type of pollutants to be disposed **(Badadoost, 1998)**. The grey water quality was found to have a clear-cut seasonal variation **(Shankhwar *et al*., 2016)**. Grey water enables optimum concentration of pollutants to harness nutrients and hold a great potential of recycling and reuse as well. Crops require a high quantity of nutrients to harvest their potential yields, can be treated with wastewater **(Jeet *et al*., 2014)**.

Characteristics of sewage water collected at Shantikunj, Haridwar were reported by **Rai *et al*. (2015)** as pH (6.24), electrical conductivity (0.875 µS/cm), biological oxygen demand (167 ppm), total suspended solids (278 ppm), nitrate (0.840 ppm), phosphate (6.81 ppm) in Winter season, while the values of the above parameters were 6.44, 0.786, 187, 286, 0.755, 7.35, respectively in the Summer season.

Characteristics of treated (vegetative filtration) municipal wastewater of Isfahan municipal wastewater treatment plant, Iran were reported by **Najafi *et al*. (2015)** as pH (7.5). electrical conductivity (1.4 ds/m), sodium absorption ratio (3.3), biological oxygen demand (34.4 ppm), chemical oxygen demand (85.3 ppm), sodium (6.3 meq/l), nitrate (1.28 ppm), ammonia (29.2 ppm), sulphate (2.2 meq/l) and magnesium (2.4 ppm).

Likewise, **Singh *et al*. (2012)** also analyzed the characteristics of sewage wastewater at National Environmental Engineering Research Institute (NEERI), Nagpur (India) and reported as pH (7.3), electrical conductivity (0.78 ds/m), sodium (1.42 ppm), sodium absorption ratio (0.790), calcium (4.76 ppm), potassium (0.31 ppm), iron (83.0 ppm), manganese (22.0 ppm), magnesium (1.69 ppm), copper (2.40 ppm), lead (7.50 ppm), nickel (4.10 ppm), cadmium (2.1 ppm) and chlorides (5.10 ppm).

The physico-chemical properties of domestic sewage were also analyzed at Dharwad, India by **Salakinkop and Hunshal (2014)** and reported as BOD_5 (141.4 ppm), total solids (708.5 g/l), pH (7.54), electric conductivity (0.79 dS/m), chlorides (8.40 meq/l), SO_4 (7.77 meq/l), total Kjeldahl N (29.2 ppm), total P (13.1 ppm), total K (54.7 ppm), Ca (10.85 ppm), Mg (6.38 ppm), Na (47.6 ppm), Zn (0.31 ppm), Mn (0.15 ppm), Cu (0.16 ppm), Fe (1.24 ppm) and toxic heavy metals such as Cr (0.004 ppm) and Pb (0.029 ppm).

2.5.1 pH

The pH shows the acidity or alkalinity of any solution, and usually, the pH value lies between 1 and 14, with 7 being neutral**.** The pH is one of the most important parameters of any wastewater, as it measures the acidity/alkalinity or hydrogen ion concentrations, and also affects most of the other parameters of wastewater such as availability of heavy metals, the activity of ions, chemical oxygen demand, nutrient level, etc. It also shows the characteristic of wastewater, e.g. most of the effluents from dye industries are acidic in nature. Oxidation of sulfides and iron pyrite by bacteria leads to discharge of their acidic leachates into rivers and other water bodies. These leachates also contain dissolved ferric iron that results in sufficient increase the pH of stream water for the precipitation of iron into ferric hydroxides. It leads to blanketing the surface of water bodies and, wiping out several sensitive plant and animal due to insufficient sunlight and oxygen. When the pH of water is below 7.0 (acidic pH), or slightly alkaline, this water would have a property of corrosiveness, as the acid has the potential to rapidly dissolve metals.

2.5.2 Electrical Conductivity (EC)

The Electrical Conductivity (EC) of wastewater is measured as "the ionic compounds dissolved in water" **(Ali *et al*., 2011).** Similar to pH, EC of wastewater is also an important parameter for water quality standards and it is measured in siemens per meter (S/m). In developed countries like the U.S. and Australia, wastewater reclamation is very common, and for that purpose, the EC is known as an important parameter **(EPA, 1999).** The EC is a key parameter for total cations and salinity determination **(APHA, 2012).** It is also used to determine total ionic concentrations as well as ionic salinity **(Zinabu *et al*., 2002).**

2.5.3 Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) is the measure of total organic and inorganic compounds present in wastewater. The COD determination is more preferable, and unlike the BOD test, it is easier and less time consuming, i.e. only two hours reflux at $150^{o}C$ for complete digestion by potassium dichromate

($K_2Cr_2O_7$) as strong oxidising agent using silver sulphate ($AgSO_4$) as catalyst and mercuric sulphate ($HgSO_4$) to avoid interference of chlorides with COD reaction **(Yintao *et al*., 2004).** The value of COD usually expressed in milligram per liter (mg/l or ppm), which is proportional to the consumed potassium dichromate during the digestion. If the wastewater contains only organic or easily biodegradable matter, the COD and BOD are supposed to have approximately equal values. For domestic wastewater the ratio of COD:BOD is 2:1 **(Liu *et al*., 2016),** while for wet market wastewater it is 5:1 **(Zulkifli *et al*., 2012),** however, if this ratio is high (e.g. > 8:1), it shows increased presence of toxic compounds, resulting in death of bacteria which has to lower the BOD value **(Wright, 1987).**

Calamus and Canna floating bed's removal rates for the COD were 36.3 % and 42.3 %, respectively in the period of 5 days treatment **(Cui *et al*., 2010)**.

2.5.4 Biochemical Oxygen Demand (BOD)

The BOD (biological oxygen demand) test is one of the most significant tests to assess the efficiency of any wastewater treatment method, which is simply equal to the amount of oxygen required by the microorganism to degrade the organic compound in the specific incubation period of 5 days and at a controlled temperature of 20±1 ^{o}C. The oxygen saturation level of normal water is very low, i.e. about 10 ppm, however the typical value of BOD for wastewater may be 20 times of saturation level, hence, discharge of this high BOD wastewater into water bodies results in further depletion of available oxygen, that is necessary for aquatic organisms.

Organic pollutant loading of wastewater depends on flow rate, and total pollutant concentration, therefore variations in wastewater generation significantly affect the total pollution load. The organic pollutant loading in wastewater can be calculated by the following formula **(EPA, 1997)**.

$$OL\,(kg/day) = \frac{Q(\,m3/day) \times BOD5\,(mg/l)}{1000}$$

Where, OL = organic loading, Q = daily flow, BOD_5 = biological oxygen demand of wastewater for the incubation period of 5 days at the controlled temperature of 20±1^{o}C. **Fig. 2.2**, represent the consumption of oxygen during the incubation period.

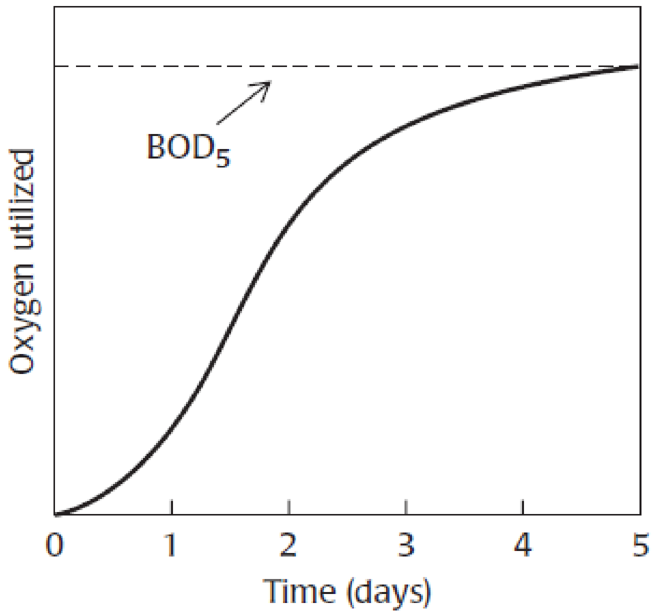

Fig. 2.2 Oxygen consumption curve during the incubation period (Wright, 1987)

The wastewater with high BOD in order to degrade itself requires more oxygen. Enrichment of organic compounds into water bodies results in explosive growth microorganisms and excess growth of algal bloom. This way the oxygen again depletes and leads to the death of the entire aquatic ecosystem due to insufficient oxygen. The value of BOD for domestic wastewater ranges between 200 and 600 ppm, whereas for industrial whey it ranges between 40,000 and 50,000 ppm **(Choi and Lee, 2015).** The BOD test is the most significant parameter in designing of the sewage treatment plants (STP) since the total contribution of BOD is approximately 36 grams per capita per day (g/capita/day) by generated volume of sewage. For example, if a town has a population of 5,50,000 and the volume of generated sewage is 55 MLD than the design for raw sewage BOD can be calculated by following formula **(CPHEEO, 2012).**

$$BOD\ (mg/l) = \frac{Population\ (no.) \times 36 \times 1000}{Generated\ wastewater\ (liter)}$$

$$BOD\ (mg/l) = \frac{550000 \times 36 \times 1000}{55 \times 1000000}$$

$$BOD\ (mg/l) = \mathbf{360}$$

The main ways of removing organic matters by floating rafts were the degradation of organic matter by roots secretion as well as absorption and utilization by microbes. Aquatic plants constantly secreted a great number of macromolecular organics into the environment in the process of growth, such as enzyme, saccharide, organic acid etc. **(Liu *et al*., 2016)**.

2.5.5 Total Nitrogen (TN)

Aquatic plants such as Canna, Water lily etc. have an enormous potential for removing nitrogen and phosphorus elements from the eutrophic water **(Wang *et al*., 2002)**. As the indispensable nutrient, elements in plants growing process, the inorganic form of N and P in water could be absorbed directly by aquatic plants through their roots' absorption (rhizoaccumulation), and then plant protein or organic component was synthesized to facilitate plant's growth and development. Therefore, plants had a strong capacity for fixing N and P as well as other nutrients/pollutants.

In the research conducted by **Zhu *et al*. (2012)** on the water purification mechanism of aquatic plants, it was observed that plants themselves absorb N and P in water, root's microbes' activity is an important way/component of removing N and P in water, mainly because microbe's activity can accelerate the decomposition rate of N and P around root hair zone, enhance other element's activity and improve the bioavailability of N and P to the roots **(Zhu *et al*., 2012)**. Therefore, the exertion of floating rafts technology's purification function not only depends on the plant's absorption of N and P, but a bigger factor is that, floating rafts constructs/develop a micro-ecosystem/ environment which is in favour of microbe's inhabitation so that N and P can be removed effectively in shorter period or HRTs.

2.5.6 Total Solids (TS)

The runoff from agricultural fields and overflow of urban sewage water are major sources of solids in wastewater. The total solids (TS) consist of total dissolved solids (TDS) and total suspended solids (TSS). Total solids are added by natural disasters, viz. floods, typhoons, earthquakes, cyclones, etc. similarly by anthropogenic activities like coal mining, stone cruising, direct throwing of waste into water drain, industrial effluents, etc. **(Pettersson and Lavieille, 2007).** Sewage water or domestic wastewater consists of about 99 % water, which comes from the kitchen, bathing, urine, night soil, laundry and so on. A small portion of solid wastes degrade into solution, and the rest remain as such in colloidal as well as in true suspension form, besides these solids, salts by cooking, bathing, laundry, urine, detergents, etc. are also added **(CPHEEO, 2012).**

2.5.7 Total Dissolved Solids (TDS)

The total dissolved solids (TDS) are the solids that remain as suspension or completely in dissolved form in the water, and do not settle down easily; however, they are filterable in nature. The presence of a significant amount of dissolved solids leads to the reduced aesthetic value of the water body; also the taste, odour and available oxygen of the water are reduced. The TDS of the sample is proportional to the hardness. Some of the dissolved solids are carcinogenic in nature, and to have several adverse impacts on human and aquatic animals. High concentration such as 3000 ppm of TDS can cause distress in animals, scaling in boilers and corrosion of many industrial instruments. These solids also act as an obstacle for oxygen, as they prevent oxygen to reach up to the bottom of the water body, resulted in depletion of photosynthesis by phytoplankton in the deep layers of water body **(Klausmeie *et al*., 2004).**

Total dissolved solids may be any minerals, salts, metals or ions which are dissolved in water. TDS may contain inorganic salts including Ca, Mg, K, Na, bicarbonates, chlorides, and sulfates with small amounts of organic matter; dissolved in water **(APHA, 2012)**.

2.5.8 Total Suspended Solid (TSS)

These are non-filterable in nature and are defined as the residues left over filter paper (2.0 µm or smaller pore size) after complete evaporation at the controlled temperature of 179-181^{0}C. However, the difference between TS and TDS also gives the value of TSS for the same water sample. Suspended solids, those are biologically active in nature also are known disease-causing organisms, and cause many diseases in human beings.

2.5.9 Phosphate (PO_4^-)

Phosphorus found naturally as rocks phosphate and other mineral deposits which degrade very slowly and release phosphorus into the soil as well as the water system. During natural degradation of rocks by the process called weathering, phosphorus release as phosphate ions which are water-soluble. Aquatic plants make the rapid accumulation of biomass (biomagnification) come true in the way of more vegetative reproduction and removal of more pollutants from wastewater. Most of the phosphate in domestic wastewater comes from detergents, soaps, toothpaste etc. Presence of detergents could be problematic due to their poor biodegrability and surface activity **(Justina *et al*., 2009)**.

The research conducted on floating rafts purification in intensive aquaculture pond, water spinach floating beds were observed highest direct absorption rates of total nitrogen (TN) and total phosphorus (TP) on the 100 days as 52.35 and 5.39 ppm dry weight respectively **(Chen *et al*., 2014)**. There was a positive correlation between floating rafts removal rates of nitrogen and phosphorus in wastewater and plant's growth speed, concentration of nitrogen and phosphorus in water (more the concentration of pollutants in wastewater, there was more growth of plants and removal rate of pollutants).

2.5.10 Potassium (K)

Although potassium contents normally found in drinking water are generally low and do not pose health concerns, the high solubility of potassium chloride and its use in treatment devices such as water softeners can significantly increase its concentration **(WHO, 2009)**. Saskatchewan which is the largest production area for potassium chloride in Canada has potassium concentrations ranged up to 51 ppm in its discharged wastewater. **(Health Canada, 2008)**.

2.5.11 Sodium (Na)

The sodium ion is ubiquitous in water. Most of the water supplies system contains less than 20 mg of sodium (Na) per liter, but in some countries, levels were observed beyond 250 mg per liter (ppm). Saline intrusion, mineral deposits, seawater spray, sewage effluents, and salt used in road de-icing contribute a significant amount of sodium to water **(WHO, 1996)**.

2.5.12 Nitrate (NO_3^-)

Health problems like tumours, goitre, oral cancer, colon cancer, lymphoma, and other cancer related to alimentary canal along with methemoglobinemia in babies can be caused by an excess of NO_3^- in drinking water **(Mishra, 1980; Joshi and Seth, 2010)**.

2.5.13 Ammonia (NH_4^+)

Ammonia removal from the wastewater commonly occurs in the constructed wetlands, if they are constructed to achieve the biological removal of nutrients, even for this removal of ammonia no external intensive energy, addition of air (oxygen) are needed, instead this the constructed wetland will drive by solar energy **(Langergraber and Weissenbacher, 2017)**. It is a two-step process including nitrification followed by denitrification. The nitrogen cycle (N-cycle) is completed as follows: first ammonia present in the wastewater is converted into ammonium ions; the aerobic bacterium *Nitrosomonas* sp. which oxidizes ammonium to nitrite; further the bacterium *Nitrobactor* sp. then converts nitrite to nitrate. Under anaerobic conditions, nitrate is reduced to relatively harmless nitrogen gas that enters the atmosphere **(Hallin *et al*., 2015)**.

2.5.14 Heavy metals (Cr, Cd, and Pb)

Inorganic pollutants present in wastewater affects soil health in many ways. The high sodium adsorption ratio (SAR) can imbalance the concentration of Mg^{2+} and Na^{2+} in the soil which results in lower physical properties of soil **(Gupta, 2005)** with high soil salinity **(Klay *et al*., 2010)**. Continuous imbalance application of wastewater could results in more deposition of heavy metals into the soil segment followed by their accumulation into the plant systems **(Gupta *at al*., 2010; Salakinkop and Hunshal, 2014)**.

High electrical conductivity (EC) of wastewater causes soil sodification and salinization, which are most frequently observed drawback of wastewater reuse **(WHO 2006a; EPA 2012)**. Traces of heavy metals had been observed in wheat irrigated with wastewater **(Karatas *et al*., 2006)**. As and Hg accumulation into the soil through wastewater application, has reported the negative impact on soil microbial properties **(Zhang *et al*., 2008)**. A very low-level Cr (0.004 ppm) and Pb

(0.029 ppm) in sewage water of Dharwad, Karnataka reported by **Salakinkop and Hunshal (2014)**. Contrast, relatively high level of Cu (2.40), Pb (7.50), Ni (4.10) and Cd (2.10) were reported by **Singh *et al*. (2012)** in sewage wastewater at Nagpur (NEERI), India.

Normally, heavy metals cause toxic effects by forming organic complexes with organic compounds. The solubility of the metal ions mainly depends on the pH of the water or soil solution, dissolved oxygen (DO), and total hardness **(Barlas, 1999)**. The decrease in pH and increase in acidity can increase the solubility of heavy metals and further their availability to the aquatic and terrestrial plants **(Hellawel, 1988)**.

Heavy metals in wastewater of Shijiazhuang Hebei Province, North China were reported by **Massaquoi *et al*. (2015)** as Arsenic (14.3 ppm), Cadmium (1.3 ppm), Copper (73.9 ppm), Chromium (25.6 ppm), Nickel (38.5 ppm), Lead (38.1 ppm) and Zinc (90.8 ppm).

2.6 International regulatory acts and permissible limits of wastewater

Wastewater application for agricultural production across the world has been observed two major implications; first is changes in soil physico-chemical as well as biological properties, which can affect the soil fertility and productivity; and the second is deposition of different contaminants into the soil-plant-human/animal system, which could lead to serious health issues in human being and others living animals as well **(Mojid *et al*., 2012; Becerra-Castro *et al*., 2015)**. Hence there is a strong need to manage these both implications using wastewater in a sustainable way concerning on its composition with respect to the target application as well as adopting the standards guidelines for application of wastewater in developing countries.

Regulatory frameworks and their enforced governance will also be needed for sustainable application of wastewater particularly for irrigation to the agricultural production. Furthermore, the rules and regulations should also involve the support of local authorities, regional, federal health agencies, environmental protection boards and farmers as well. Laws and norms should also clearly state the water rights, quality and its agricultural restrictions particularly for edible crops, e.g. vegetables, cereals, fruits etc. Concerning to human and animal health risk, new microorganism based pollutants, i.e. endocrine disruptor chemicals (EDCs), protozoa, surfactants, and estrogens should also be included while preparing regulatory acts and laws rather than focusing only to conventional parameters **(Furumai, 2008)**. The wastewater standards for agricultural application in a few developing countries are depicted in **Table 2.4.**

Table 2.4 Wastewater standards for agricultural application in developing countries

Country	pH	BOD*	COD*	DO*	B*	NH_4-N*	TDS*	TSS*	Fe*	F*	Pb*	Zn*	Ni*	CFU[@]	EC[#]	Na*	SAR	Reference
India	5.5-9	30	250	-	2.0	50	2100	100	-	2.0	0.1	5.0	3.0	-	-	-	-	EPA (1986)
Bangladesh	6-9	100	400	5 or <	2.0	75	2100	-	2.0	10	0.1	10	1.0	1000	1200	< 26	-	BECR (1997)
Tunisia	6.5-8.5	30	90	-	3.0	-	2000	30	0.5	3	1.0	5.0	0.2	100	7000	300	-	Bedbabis *et al*. (2010)
Jordan	6-9	30	100	>2	1.0	-	1500	50	5.0	1.5	5.0	5.0	0.2	100	-	230	9.0	WHO (2006b)
Oman	6-9	15	150	-	0.5	5.0	1500	15	1.0	1.0	0.1	5.0	0.1	200	2000	200	10	WHO (2006b)
Brazil	7.2-7.8	77.8	180.5	-	0.2	-	-	-	0.08	-	-	0.02	-	100	860	145	11.9	Fonseca *et al*. (2007)
South Korea	5.8-8.5	< 8	-	-	0.75	-	-	-	-	-	0.1	2.0	0.2	100	<2000	-	-	Korea (2011)
Morocco	6-9	30	100	>2	0.75-1.0	-	2000	50	5.0	1-2	0.2	2-5	0.2	1000	-	230	9.0	ABRI (2009)
Turkey	6.5-8.5	<25	-	-	<0.5	0-5	-	20	5.0	1.0	5.0	2.0	0.2	100	250	200	<10	Kramer and Post (1991)
Egypt	-	<20	-	-	0.75	-	-	<20	5.0	1.0	5.0	2.0	0.2	<1000	-	230	6-9	Elbana *et al*. (2014)

* = ppm, [@] = CFU 100/ml, [#] = µS/cm, BOD = biochemical oxygen demand, COD = chemical oxygen demand, DO = dissolved oxygen, B = boron, NH_4-N = ammonical nitrogen, TDS = total dissolved solids, TSS = total suspended solids, Fe = iron, F = fluoride, Pb = lead, Zn = zinc, Ni = nickel, EC = electrical conductivity, Na = sodium, SAR = sodium absorption ratio

Materials & Methods

3.1 Chemicals and reagents

The chemicals and reagents used in the present research work were of analytical grade (AR) and supplied by standard manufacturers, e.g., Hi-Media Laboratories Ltd., Mumbai; Merck India Ltd., Mumbai; India and Sigma Chem. Pvt. Ltd., U.S.A.; S. D. Fine Chem. Ltd., Mumbai.

3.2 Glass-wares and plastic-wares

All the glass-wares and plastic-wares used in this experimental work were supplied by Borosil, Schott Duran, and Tarsons.

3.3 Instruments used

The following instruments presented in **Table 3.1** were used in the present research work.

Table 3.1 List of the instruments used in the present work and their make

S.No.	Name	Make
1.	Electronic Balance	Mettler Toledo, USA
2.	Hot Plate	Scientronic Instruments Services Pty Ltd, Australia
3.	Atomic-absorption spectrophotometer (AAS)	SensAA DUAL, GBC scientific equipment, Australia
4.	UV-VIS Spectrophotometer	Varian Inc, California
5.	Distillation Apparatus	Borosil Glass Work Ltd, India
6.	pH meter	Khera Instruments Pvt. Ltd., India
7.	EC meter	Khera Instruments Pvt. Ltd., India
8.	BOD Incubator	Sanco Industries Ltd, India
9.	Refrigerator	Zenith Electronics LCC, US
10.	Hot air oven	Metrex Scientific Instruments (P) Ltd. India
11.	COD Digestion Unit	Khera Instruments Pvt. Ltd., India
12.	Kjeldahl Nitrogen Analyzer	Pelican Equipments, India
13.	Flame Photometer	Khera Instruments Pvt. Ltd., India
14.	TDS meter	Khera Instruments Pvt. Ltd., India

3.4 Plant species used

In the present research work, phytoremediation of domestic wastewater and synthetic polluted water was done using four different types of plants. These plants were namely Canna, Pistia, Water lily and Amerian aloe. Details about each plant are given below and the data representation of these plants is depicted in **Fig 3.1**.

3.4.1 Canna (*Canna indica* L.)

Canna indica is also known as Indian shot because its seeds are small, round and hard like birdshot. This is used like pearls in jewelry and also as the mobile elements of the kayamb (musical instrument). The seed also used to make hosho (gourd rattle). The applications of cannas are observed in many cities of southern U.S.A. for the municipal plantation. They are good at taking care of them and add bold stripes of color to road median strips, parks, and other public flower plantings. Worldwide, cannas are one of the popular garden plants as well as many horticultural industries are depends on the plant. The rhizomes of this plant are rich in the starch and additionally the plant has many applications in agricultural sector. Even in some remote areas of India, this plant is fermented to produce alcohol as well as alcohol based other products. In the wetland environment, the cannas are employed to remediates many unwanted pollutants, as it having a relatively high tolerance with respect to the contaminants and various pollutants to absorb into their harvestable biomass.

The Canna is getting much concern as green phytoremediation tool due to its colossal root mass, long root hair biofilms and relatively more root concentration factor (RCF). The rhizomes of this plant were collected from National Botanical Research Institute (NBRI), Lucknow, India and initially shifted to the nursery at the experimental site for its growth. Later on, the plant was shifted onto the floating rafts and finally placed into the floating raft tank.

3.4.2 Pistia (*Pistia stratiotes* L.)

Pistia (Water lettuce) is often used in tropical aquariums to provide cover for fry and small fish. Water lettuce is among the world's most productive aquatic plants. In water with high nutrient content (eutrophic water), particularly those that have been contaminated with the loading of human sewage or fertilizers, water lettuce can often exhibit overgrowth behavior. Sometime this plant also helpful to compete with algae regarding nutrients uptake from the water body, thereby it preventing the massive growth of algal blooms. Pistia plants were locally available nearby the experimental site.

	
Canna (*Canna indica* L.)	**Pistia (*Pistia stratiotes* L.)**
	
Water lily (*Nymphaea* sp.)	**American aloe (*Agave americana*)**

Fig 3.1 Pictorial representation of selected plant

3.4.3 Water lily (*Nymphaea* sp.)

The stems of all Water lilies reach deep below the surface of the water and into the muck and mud of the river or pond bottom. The "tough" part of the water lily are capable enough to maintaining and to hold themselves even in the strong current or typhoons and make connect between the flowering portion and the rhizomes on the bottom. The rhizome collects organic and inorganic pollutants/nutrients which are necessary for the development of plant. Water lily contributes food for various kinds of herbivorous animals, in addition to this they provides natural habitat substrate to the other animals as well, such as the long-toed birds which is known as lily-trotters or jacanas. Species of Water lilies provide a beautiful aesthetic to aquatic habitats, which is greatly appreciated by many people. Many species of this family deserve for their economic and esthetic importance as one of the horticultural plants, because of their natural aesthetic of floating leaves and attractive looks of Lotus flowers.

3.4.4 American aloe (*Agave americana*)

Aloes have long been in use for several applications such as alcoholic beverage, fiber handicrafts, and medicinal uses. If the flower stem of aloe is cut without flowering, a sweet liquid called aguamiel (honey water) gathers in the heart of the plant. This may be fermented to produce the drink called pulque (alcoholic beverage). The leaves also yield fibers, which is known as pita, which is suitable for making eco-friendly rope, matting or coarse cloth and is used for embroidery of leather in a technique known as piteado. Both pulque and maguey fiber was important to the economy of pre-Columbian Mexico and other countries. It has also long been in use for several diseases, particularly connected with the digestive system, they have also been used for wounds, burns and skin problems. The term Aloe is stands for a dried juice, which produces from transversely cut bases of its matured leaves. It is the best herbal plant which supports the health as well as provides healing mechanisms to the body because it does not heal instead it feeds the body's own systems in order function optimally and healthy. Pharmacologically it is an immunity booster and detoxifies the system. There are personal care and skin care creams, moisture lotions, shampoos and conditioners prepared from Aloe gel.

3.5 Description of experimental site

The present experimental site was selected for the phytoremediation of domestic wastewater which originated from the University campus. Therefore, the experimental trial for phytoremediation process was started in University campus nearby Mahakaleshwer Temple.

Geographically the site lies in *Tarai* plains about 30 km southwards of the foothill of the Shivalik range of Himalaya at 29^0 1' 49" N latitude, 79^0 29' 52" E longitudes and at an altitude of 243.8 meters above the mean sea level. The study area falls under sub-humid and the subtropical climatic zone which is known as *Tarai* region of Uttarakhand with average annual rainfall of around 1350 mm. The experimental site was situated on the University campus premises, along with the drain which carries domestic wastewater generated from residential colonies of University, Pantnagar, India as shown in **Fig 3.2** and **Fig 3.3**.

At the selected site, an initial survey was done on the basis of the rate of wastewater generation and channels feeding wastewater to treatment tanks. A part of the water was taken up into distribution tank and then further distributed into floating raft tank-I, II, constructed wetland and into their hybrid combination with each other. Necessary construction, inlet/outlet of channels and designing of pipes were done in a manner to utilize the maximum efficiency of floating raft tanks and constructed wetland at different water level depth and flow rate.

3.5.1 Floating raft tanks (FRT)

Floating raft tanks were constructed using cement, concrete, and bricks with the size of 14×2×1.5 (length×width×depth) meters. The relative small depth of floating raft tanks constructed wetland and oxidation pond were chosen in order to ensure plug flow conditions. To get the desired water level in floating raft tanks and constructed wetland, a check/gate valve and a V-notch were used. Maintenance of the floating raft tank and gravel constructed wetland were included the harvesting of plants at various intervals of time and removal of detritus accumulated at the bottom of the tanks. The effective phytoremediation area of each FRT was 27.96 m^2 with the planted zone of two rectangular FRT-I & FRT-II (L=13.70m; W=1.95m; D=1.25m).

3.5.2 Constructed Wetland (CW)

The constructed wetland was in the size of 10×5×0.75 meters and proper lining was done with high-density polyethylene (HDPE) to prevent the percolation and infiltration of wastewater towards the underground. The substrate used in the gravel constructed wetland was consisting gravels of three different sizes such boulders (250-270 mm) at the bottom layer, cobbles (80-90 mm) at middle and pebbles (20-40 mm) at the topmost layers. The effective area for the planted zone of CW was 41.53 m^2 with a rectangular chamber (L=9.75m; W=4.26m; D=1.20m).

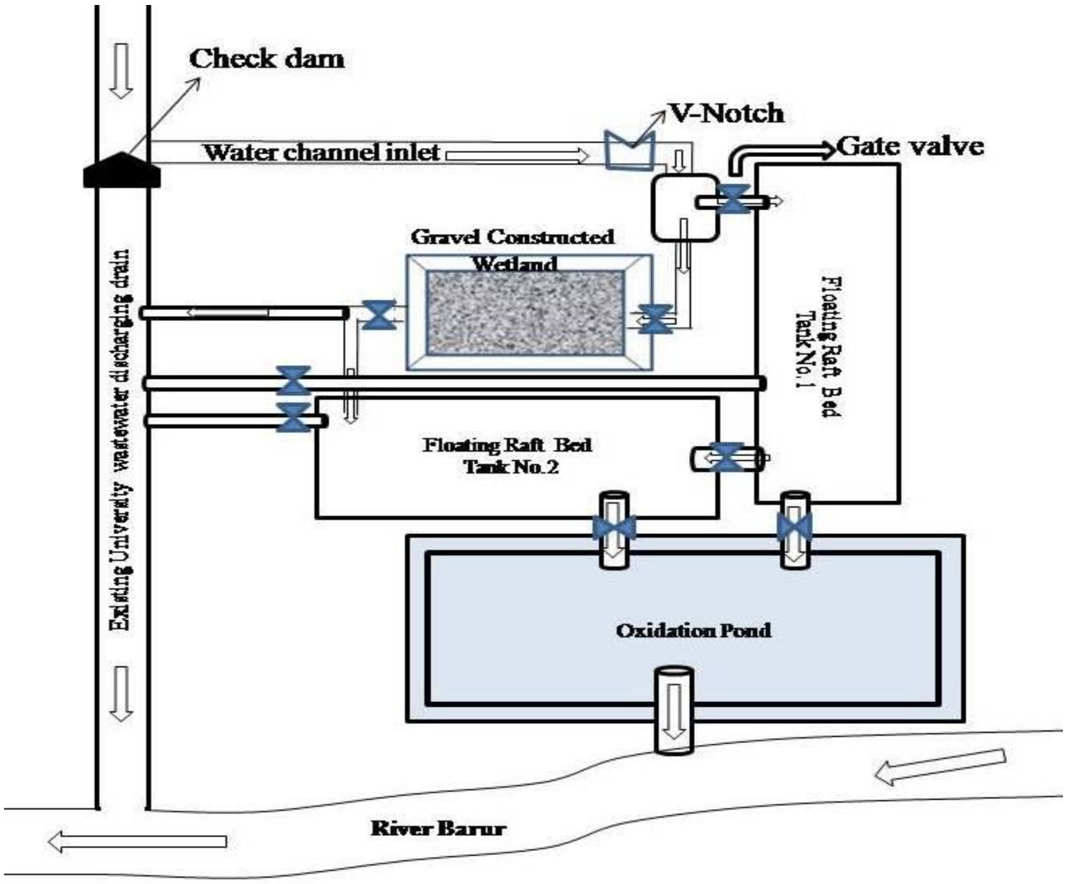

Fig 3.2 Initial layout of experimental model

3.5.3 Oxidation Pond (OP)

The size of oxidation pond was 20×15×1 meters. The total planted zone in OP was 300 m^2 with a rectangular shape pond (L=20 m; W=15 m; D=1.0 m). The flow rate of influent and effluent was controlled with the help of 12 mm diameter check valve and the exact quantity of flowing water was assessed using known volume beaker (1 L) and stopwatch.

3.5.4 Floating rafts

Floating rafts (FRs) in size of 2.1×1.4 meter were prepared using PVC pipe, bamboo, plastic mess and supporting media (coconut coir). "The articulated nature of the bamboo means that it contains sealed chambers of air which is naturally buoyant" **(Headley and Tanner 2006)**. All FRs were allowed freely to float naturally on the water surface for nature-based oxidation (NBO) of different pollutants.

Fig 3.3 Layout of working experimental model

Bamboo and coconut coir were used to develop low cost eco-friendly floating rafts. The open textured coarse peat/soil or coconut coir materials that do not become too anaerobic or heavy once saturated are likely the most suitable growth media for plant establishment on floating raft wetlands system. Plant roots and rhizomes can spread and grow through the matrix (coconut coir/peat), with their roots extending down into the water below. The matrix (growth supporting media) was made with various plant growth materials and potentially also incorporated with reactive/sorptive media to promote contaminants removal efficiency of the system. Step wise pictorial representation of floating raft is given in **Fig 3.4**.

Step I- Adding coconut coir

Step II- Binding with mess & bamboo

Step III- Transplanting Canna

Step IV- Shifted into tank

Step V- Canna at maturity stage

Fig 3.4 Step wise pictorial representation of floating raft

3.6 Phytoremediation of wastewater

3.6.1 Phytoremediation at lab scale

3.6.1.1 Phytoremediation of domestic wastewater

A lab experiment was conducted in the month of August and September 2016 in ambient atmosphere at GBPUA&T Pantnagar. The objective of this study was to standardize the system for phytoremediation of domestic wastewater in floating rafts and constructed wetland and validates the system at laboratory scale before field level study.

Treatments detail:-

TW–100% Tap water

WW–100% Wastewater

3.6.1.2 Phytoremediation of synthetic polluted water

The Canna (*Canna indica* L.) also called 'Indian shoot' **(Talukdar, 2013)** and Pistia (*Pistia stratiotes* L.), were chosen as chromium (Cr), cadmium (Cd) and lead (Pb) scavenger for the present set of experiment. Mature plants of both Canna and Pistia with similar height and health were shifted into 5 L plastic pots and fed with tap water for a period of 10 days for acclimatization in hydroponic condition. Test for initial Cr, Cd and Pb content in plant roots and shoots were negative.

A synthetic chromium, cadmium and lead stock solution of 1000 ppm each separately were prepared and sequentially diluted to 5, 10, 25, 50, 75, 100 and 150 ppm using 4 L Hoagland and Arnold solution **(Hoagland and Arnold 1950)**, while in control only Hoagland and Arnold solution without above metals (4 L) was taken for both Canna and Pistia separately. The nutritive composition of Hoagland and Arnold solution is depicted in **Table 3.2**. There were triplicates for each treatment and each replicate had one Canna and Pistia plant. Throughout the experiment, standard methods are given in **APHA (2012)** were followed. All necessary data were collected and the evapotranspiration loss was compensated using double distilled water.

Table 3.2 Composition of Hoagland and Arnold solution (Hoagland and Arnold 1950)

Components	Concentration
KNO_3	1.02 g/l
$Ca(NO_3)_2$	0.49 g/l
$NH_4H_2PO_4$	0.23 g/l
$MgSO_47H_2O$	0.49 g/l
$MnCl_24H_2O$	1.81 ppm
H_3BO_3	2.86 ppm
$CuSO_45H_2O$	0.08 ppm
$ZnSO_47H_2O$	0.22 ppm
$H_2MoO_4H_2O$	0.09 ppm
$FeSO_47H_2O$	0.60 ppm

Preparation of plant samples:- Harvested samples were rinsed thoroughly using distilled water followed by the separation of the root and shoot portion. Thereafter, the separated root and shoot samples were oven dried at 80°C until a constant weight was achieved. Harvested and dried plant samples (100 mg each) were digested using 5 ml concentrated HNO_3 at 100°C.

Throughout the digestion, the volume of samples was maintained approximately 15 ml using 0.6% HNO_3 **(Rai *et al*., 2015)**; the digested samples were allowed to cool at room temperature and later filtered using Whatman No. 42 (2.5 µm pore size) filter paper. Well filtered samples were fed into the atomic absorption spectroscopy, equipped with air-acetylene flame **(D'Souza *et al*., 2010; Varun *et al*., 2015)** for Cr, Cd and Pb uptake analysis.

Bio-concentration factor (BCF):- BCF in this experiment was calculated using the formula given by **Soda *et al*. (2012)**, which shows the metal uptake potential of the shoot.

$$\mathrm{BCF} = \frac{\mathrm{C.shoot}}{\mathrm{C.aw}}$$

where, C.shoot is the metal concentration in the shoot biomass (ppm DW) and C.aw is the metal concentration in artificial water (ppm).

Root concentration factor (RCF):- RCF was calculated according to the formula given by **Fitz and Wenzel (2002)** and **Mendez and Maier (2008)**.

$$\mathrm{RCF} = \frac{\mathrm{C.root}}{\mathrm{C.aw}}$$

where, C.root represent as the metal concentration in the root biomass (ppm DW).

Translocation factor (TF):- TF in the present work was calculated based on the mathematical formula given by **Rai *et al*. (2015)**, which represent the metal translocation (from root to shoot) efficiency of the plant.

$$\mathrm{TF} = \frac{\mathrm{C.shoot}}{\mathrm{C.root}}$$

where, C.shoot represent the metal concentration in shoot biomass (ppm DW) and C.root represent the metal concentration in root biomass (ppm DW).

3.6.2 Phytoremediation at the field scale

After construction of floating raft tanks, constructed wetland and oxidation pond, floating rafts in size of 2.1 x 1. 4 meter were prepared by PVC pipes and plastic mess, and later on these rafts were planted with Canna and Water lily plant species and placed separately in the floating raft tank-I and floating raft tank-II, respectively. To gets the desired water level in floating raft tanks, a check/gate valve was used. The wastewater analysis was done before and after floating rafts passing water separately with Canna and Water lily species at different Hydraulic Retention Time (HRT).

3.6.3 Phytoremediation by the hybrid model

Analysis of treated water from hybrid systems of floating raft tank I, II, constructed wetland and oxidation pond together were done from October 2016 to September 2017 as detailed given below.

Hybrid system-I (HS-1):- In the Hybrid system-I, two floating raft tanks (I, II) were considered together, where wastewater was passed first to the floating raft tank-I, planted with Canna and then after that it was passed through the floating raft tank-II, planted with Water lily and analyzed for water pollutant reduction at different HRTs.

Hybrid system-II:- In the Hybrid system-II, there were two treatments viz., a & b and relative comparison were done to assess the best one among these two treatments (a & b) for water pollutant reduction. where,

a. **(HS-2a)** floating raft tank-I & oxidation pond
b. **(HS-2b)** floating raft tank-II & oxidation pond

Hybrid system-III (HS-3):- In the Hybrid system-III, constructed wetland planted with *American aloe* was firstly allowed to passed with wastewater and after that this water was diverted to floating raft tank-II for further pollutants reduction.

Hybrid system-IV (HS-4):- In the Hybrid system-IV, untreated wastewater was allowed in the sequence of a constructed wetland, floating raft tank-II and oxidation pond allow steps for overall pollutant reduction measurement.

In each hybrid system, water analysis was done at the different hydraulic retention time (HRT) for remediation of pollutants from wastewater through plant root's uptake by the process called phytoextraction. Relative comparison of all hybrid systems viz., I, II, III and IV, were the prime aim to assess/develop the best one natural wastewater treatment system at minimum HRT.

3.7 Climatic conditions

The climatic condition of the experimental location was sub-humid, sub-tropical with dry hot summer and cold winter. Generally, the monsoon was started in the third or fourth week of June and lasts up to September or first week of October. The weather parameters for the study period (November 2015 to December 2017) were recorded from the meteorological observatory located at Crop Research Centre (CRC) of the University and it is around 3 km away from the experimental trial field. The mean monthly maximum temperature ranged from 20.5^oC to 37.6^oC whereas the mean monthly minimum temperature ranged from 6.5^oC to 26.2^oC. The approximate variation in total monthly precipitation ranged from trace amount 0.0 mm to 17.4 mm. The site has normally relative humidity from 27.7 to 95 % throughout the year. The wind speed during the study period ranged between 2.3 Km/hr to 7.7 Km/hr. The collected weather data is presented in **Table 3.3**.

Table 3.3. Meteorological data during period of experiment from November 2015 to December 2017

Months	Tem. (^oC)		Relative Humidity (%)		Rainfall (cm)	Sunshine (hr)	Wind Velocity (Km/hr)	Evapo-transpiration (mm)
	Max	Min	7.00 AM	2.00 PM				
Nov, 2015	28.1	12.2	91.0	42.0	0.06	6.5	2.4	2.5
Dec, 2015	22.2	7.6	95.0	52.0	0.00	4.1	3.1	1.5
Jan, 2016	20.6	6.5	94.0	52.0	0.00	3.9	3.6	1.5
Feb, 2016	25.3	9.5	89.0	40.0	0.08	5.9	4.9	2.7
Mar, 2016	30.9	14.0	81.0	34.0	0.02	7.8	6.0	4.4
April, 2016	37.6	18.9	67.5	29.7	0.00	9.0	7.7	9.3
May, 2016	35.3	22.7	68.8	41.8	4.36	7.4	7.5	7.7
June, 2016	34.4	26.2	78.1	59.4	5.70	6.2	7.0	5.7
July, 2016	31.5	25.6	90.3	75.2	16.10	3.0	6.5	4.0
Aug, 2016	33.2	26.1	88.4	67.5	6.50	6.3	5.0	4.3
Sept, 2016	32.6	24.3	89.2	67.0	5.54	6.1	4.2	3.6
Oct, 2016	31.7	18.5	86.0	51.8	0.00	6.4	2.4	2.8
Nov, 2016	28.0	11.0	91.3	40.1	0.00	7.1	2.3	2.3
Dec, 2016	22.7	9.3	94.3	55.5	0.36	4.8	2.8	1.5
Jan, 2017	20.5	7.6	93.0	57.1	1.94	5.4	4.4	1.5
Feb, 2017	24.8	9.1	91.8	47.5	0.00	6.9	4.1	2.1
Mar, 2017	28.9	11.2	84.5	39.3	0.11	8.3	5.5	3.7
April, 2017	36.3	19.4	64.6	27.7	0.13	8.5	7.6	7.6
May, 2017	37.4	22.7	63.7	35.5	1.06	9.1	7.5	8.3
June, 2017	37.0	25.2	70.7	49.7	2.43	7.4	7.5	7.9
July, 2017	32.3	25.7	89.7	77.9	17.40	4.6	6.3	4.3
Aug, 2017	32.0	25.7	89.8	74.6	14.50	4.0	5.7	4.2
Sept, 2017	32.5	24.3	89.3	69.2	11.22	6.4	3.5	3.7
Oct, 2017	32.5	19.2	84.8	50.9	0.00	7.5	2.3	2.9
Nov, 2017	27.1	10.9	91.5	46.4	0.00	6.0	2.5	2.1
Dec, 2017	22.7	9.5	94.3	63.6	0.10	5.3	3.1	1.4

3.8 Water flow rate measurements

The quantity of generated wastewater prior to the study area was calculated seasonally at nearby Mahakaleshwar temple with help of V-notch on the basis of following calibration equation **(Shankhwar *et al*., 2016)**. Furthermore, invariably equation of best fitted is derived in the form of

$$Q = {}_{a}H^{b} \quad \ldots\ldots\ldots\ldots\ (1)$$

Where, *Q* represents the flow of the grey water and H is the head over the weir. The coefficients *a* and *b* are experimentally determined by regression coefficients and variable for water flow range. The above formula is known as Cone formula and was applied for accurate water flow rate quantification because it is more reliable than other weir methods due to its simplicity.

$$Q = {}_{1.34}H^{2.48} \quad \ldots\ldots\ldots\ldots\ (2)$$

The values of *a* and *b* were taken as 1.34 and 2.48 respectively and defined on the basis of observations for overhead height H, in range of 0.06 m to 0.13 m.

3.9 Measurement of plant growth parameters

Plant growth parameters such as plant height, root length, no. of roots per plant, no. of leaves per plant etc. were observed at different stages after transplanting the plant species on the floating rafts and constructed wetland.

3.10 Analytical methodology for wastewater

The wastewater samples were thoroughly analyzed for pH, Electrical Conductivity (EC), Total Solids (TS), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS); nutrient load such as total nitrogen, nitrate nitrogen, ammonical nitrogen, phosphate, potassium and sodium, organic load such as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) at different times during the study period as per standard method of **APHA (2012)** and other prescribed methods.

All the collected samples were stored in airtight plastic bottles and were analyzed immediately for above-mentioned parameters. In addition, metal analyses (Cr, Cd, and Pb) were also carried out for synthetic water to assess the heavy metal removal efficacy of Canna and Pistia in laboratory condition by atomic absorption spectrophotometry (AAS, sensAA DUAL) using standardized method **(APHA, 2012)**.

3.10.1 pH

The pH of different samples was measured using digital glass electrode pH meter after calibrating it with different standards of pH (4, 7 and 9 pH) **(APHA, 2012)**.

3.10.2 Electrical Conductivity (EC)

The electrical conductivity of different samples was measured through digital Electrical Conductivity meter after calibrating it with different standards (Potassium chloride) of electrical conductivity **(APHA, 2012)**.

3.10.3 Chemical Oxygen Demand (COD)

COD was analyzed according to the method given in Indian Standard methods of sampling and test (physical and chemical) for water and wastewater **(APHA, 2012)**.

Reagents:-

a) **Standard Potassium Dichromate Solution, $K_2Cr_2O_7$ (0.25N):-** 12.259 g of (oven dried sample at 103°C) $K_2Cr_2O_7$ was dissolved in 1000.0 mL of distilled water.

b) **Sulphuric Acid- Silver Sulphate Reagent, H_2SO_4:-** 22.0 g of $AgSO_4$ was dissolved in 1000.0 mL of concentrated H_2SO_4 (98%).

c) **Ferroin Indicator (Liquid).**

d) **Mercuric Sulphate, $HgSO_4$:-** (used as per requirement).

e) **Ferrous Ammonium Sulphate, Fe $(NH_4)_2$ $(SO_4)_2$ (0.1N):-** 39.0 g of $Fe(NH_4)_2(SO_4)_2.6H_2O$ was dissolved in distilled water and 20.0 mL of concentrated H_2SO_4 (98 %) was added to the solution, made the volume up to 1000.0 mL using distilled water. The solution was standardized by using standard solution potassium dichromate ($K_2Cr_2O_7$).

Standardization:-

10.0 mL of standard $K_2Cr_2O_7$ was diluted to 100.0 mL and 30.0 mL of concentrated H_2SO_4 was added to this solution, kept to cool down the solution. The solution was titrated against ferrous ammonium sulfate ($Fe(NH_4)_2(SO_4)_2.6H_2O$) by using 2-3 drops of ferroin as an indicator.

Normality of ferrous ammonium sulfate was calculated by following formula:

$$N = \frac{10 \text{ x } 0.25}{V}$$

Where,

V = volume of $Fe(NH_4)_2(SO_4)_2$ required for titration in mL.

Procedure:-

In the COD reflux tubes, 0.4 g $HgSO_4$ was taken and 20.0 ml of samples was diluted with 20.0 ml of distilled water and mixed properly. The blank sample was prepared by adding only distilled water. In the COD reflux tubes, 10.0 ml of standard potassium dichromate ($K_2Cr_2O_7$) solution and 30.0 ml of sulphuric acid-silver sulfate reagent was added. After proper mixing, the COD reflux tubes were then connected to the condensers and the solution was refluxed for approximately 2 hours at 150 ± 2^0C.

After refluxing, the COD tubes were removed from digestion unit and cooled at room temperature; later 60.0 ml of distilled water was added to each tube. The solution in the COD tubes was then titrated with standard $Fe(NH_4)_2(SO_4)_2$ using 5-8 drops of ferroin as an indicator. At the termination point of this titration, the color of the solution changes from green-blue to wine red.

Calculation:-

$$\text{COD (mg/L)} = \frac{(B-A) \times \text{Normality of } Fe(NH)_2(SO_4)_2 6H_2O \times 8 \times 1000}{\text{mL of sample taken for estimation}}$$

Where,

A = mL of titrant required for titration (ml) against the sample

B = mL of titrant required for titration (ml) of blank

3.10.4 Biochemical Oxygen Demand (BOD)

BOD was measured according to the Azide Modification of Iodometric method as mentioned in **APHA (2012)**.

Seeding of wastewater:-

The purpose of seed inoculation is to provide the sufficient number/quantity of microorganisms that should having capable of oxidizing the biodegradable organic matter present in the sample. Typically seeding is required where insufficient indigenous microorganisms present, such as in chlorinated effluents from a wastewater treatment plant.

Reagents:-

a) **Manganous Sulphate Solution, $MnSO_4$:-** This solution was prepared by dissolving 480.0 g of $MnSO_4$ in 1000.0 ml distilled water, followed by filtration of the solution using Watman filter paper no. 42.

b) **Concentrated Sulphuric Acid, H_2SO_4:-** Specific gravity: 1.84.

c) **Alkali Iodide Azide Reagent:-** 125.0 g of NaOH and 33.7 g of NaI was dissolved in 250.0 ml distilled water. Then 2.5 g of sodium azide was added in 10 ml distilled water in another flask and finally, both solutions were mixed together properly.

d) **Starch Indicator:-** 2.0 g of starch was dissolved in 100.0 ml of warm distilled water and then cooled to room temperature.

e) **Sodium Thiosulphate Solution (0.025N):-** The solution was prepared by dissolving 6.205 g of sodium thiosulphate in freshly boiled distilled water. This volume was made upto 1000.0 mL and a pellet of sodium hydroxide (NaOH) was added as a preservative.

f) **Phosphate Buffer:-** 8.5 g of KH_2PO_4, 21.75 g of K_2HPO_4, 33.4 g of $Na_2HPO_4.7H_2O$ and 1.75 g of NH_4Cl were dissolved in distilled water and volume was made upto 1000.0 mL, pH of this solution was adjusted to 7.6 using sodium hydroxide (NaOH) or hydrochloric acid solution (HCl).

g) **Magnesium Sulphate:-** 22.5 g of magnesium sulfate-heptahydrate was dissolved in distilled water, and made volume upto the 1000 ml.

h) **Calcium Chloride:-** 27.5 g of anhydrous calcium chloride (CaCl) was dissolved in distilled water, making volume upto 1000 ml of solution.

i) **Ferric Chloride:-** 0.25 g of ferric chloride was dissolved in distilled water, and made volume upto 1000 ml solution.

j) **Dilution Water:-** 1000.0 mL of dilution water was prepared by adding 1.0 mL each of phosphate buffer, magnesium sulfate, calcium chloride and ferric chloride solution and 100.0 mL of distilled water was added to it with finally making up the volume upto 1000.0 mL. The final solution was aerated for half an hour; meanwhile, pH was adjusted to 7.0 by the 1N base (*i.e.* NaOH) or 1N acid (i.e., H_2SO_4).

Procedure:-

The sample was diluted using dilution water according to the expected BOD range. Two sets of replicates of BOD (300 mL) bottles were prepared, one set of bottles was used for analyzing the initial dissolved oxygen (DO) content in the sample and the other set of the bottle was kept in BOD incubator at 20 ± 1^0C (in dark) for 5 days. The dissolved oxygen level of the sample before and after five days of incubation was measured according to the azide modification of the iodometric method.

Azide Modification of Iodometric Method:-

Into the BOD bottle containing the sample, 1 ml of each $MnSO_4$ & alkali azide reagent were added. A brown color precipitate was formed in the bottle containing the sample. When brown precipitate was settled in the BOD bottle then 2.0 ml of concentrated H_2SO_4 was added and mixed uniformly until the precipitate was completely disappeared. Then 20.0 ml of this solution was taken in a separate beaker and titrated with 0.025 $Na_2S_2O_3$ solutions. Few drops of starch solution indicator were added and titration was continued until the end point, i.e., blue color of the sample completely disappear.

Calculation:-

$$BOD_5\,(ppm) = D_1 - D_5 \times D_f$$

Where,

D_1= DO of diluted sample immediately after preparation (ppm).

D_2 = DO of the diluted sample after 5 days of incubation period at 20 ± 1^0C (ppm).

D_f = Dilution factor

3.10.5 Total Nitrogen (TN)

Total nitrogen was estimated by the Kjeldahl method as explained in Physico-Chemical Examination of Water Sewage and Industrial Effluents**.** However, Salicylic acid thiosulphate modification of Kjeldahl method was used to convert all forms of nitrogen to ammonia.

Reagents:-

a) **Salicylic-Sulphuric acid:-** 25.0 gm of salicylic acid was taken and added to 1000.0 ml of concentrated Sulphuric acid. Salicylic acid was used in the place of sulphuric acid, to convert all the forms of nitrogen to ammonia for estimation of total nitrogen through Kjeldahl method.

b) **Copper Sulphate solution 10 %:-** 10.0 g of copper sulfate was taken and dissolved in 100.0 mL of distilled water.

c) **Potassium Sulphate Crystals**

d) **Sodium Thiosulphate**

e) **Phenolphthalein Indicator (Liquid)**

f) **Sodium Hydroxide Solution, 50 %:-** 100.0 g of NaOH was dissolved in 200 ml of distilled water.

g) **The boric acid solution, 2%:-** 10.0 g H_3BO_3 was dissolved in distilled water and volume was made upto 500.0 mL.

h) **Mixed indicator solution:-** 200.0 mg of methyl red indicator was dissolved in 100.0 mL of 95% ethyl alcohol. 100.0 mg of methylene blue was dissolved in 50.0 mL of 95% ethyl alcohol. The two solutions were mixed properly. The endpoint was the color change from pale green to lavender.

i) **Standard Sulphuric acid solution (0.02 N):-** 28.0 ml of concentrated sulphuric acid was placed in 1000.0 ml volumetric flask and volume were made upto the mark of the flask with 1 N sulphuric acid. Then 0.02 N sulphuric acid was prepared by diluting 20.0 ml of 1 N sulphuric acid upto 1000.0 ml with distilled water.

Procedure:-

1. **Digestion:-** 25.0 mL of the sample was taken in the Kjeldahl flask and 25.0 mL of Conc. Salcylic-H_2SO_4 acid, 1.0 mL copper sulfate solution and 5.0 g potassium sulfate and 5.0 g sodium thiosulphate were added in the Kjeldahl flask. The sample was then digested for 3-4 h until the solution became clear.
2. **Distillation:-** The contents of the flask were transferred to a distillation flask. The solution in the flask was made alkaline with sodium hydroxide, using phenolphthalein indicator. The distillation was started after immersing the tip of the condenser in 50.0 mL of boric acid solution in a conical flask. Finally, the distillate was collected in the conical flask.
3. **Titration:-** 0.5 mL of methyl red indicator solution was added to the distillate. It was then titrated against 0.02N H_2SO_4. Titration continues until the endpoint appears i.e. red color appearance.

A blank sample was also taken and all steps starting from the digestion step to final titration were followed.

Calculation:-

$$\text{TN as N (ppm)} = \frac{A - B \times 0.28 \times 1000}{V}$$

Where, A = mL 0.02 N H_2SO_4 for sample

B = mL 0.02 N H_2SO_4 for blank

V = Volume of the sample in ml

3.10.6 Total Solids (TS)

Total solids were analyzed as the residue left after the complete evaporation of unfiltered sample. The analysis was done according to the method given in Chemical and Biological Methods for Water Pollution Studies **(Trivedy and Goel, 1986)**.

Procedure:-

An evaporating porcelain dish of suitable size was taken and weighed as initial weight (A). Then 100.0 ml of unfiltered sample was taken in an evaporating porcelain dish, and after complete evaporation, the dish was again weighed as final weight (B) of porcelain dish.

Calculation:-

$$\text{Total solids (ppm)} = \frac{B - A \times 100}{V}$$

Where, A = Initial weight of dish in mg

B = Final weight of dish in mg

V = Volume of the sample taken in mL

3.10.7 Total Dissolved Solids (TDS)

Total dissolved solids can be explained as the residue left after evaporation of filtered sample through Watman filter paper no. 42. This was according to the method explained in Chemical and Biological Methods for Water Pollution Studies **(Trivedy and Goel, 1986)**.

Procedure:-

An evaporating porcelain dish of suitable size was taken and weighed as initial weight (A). Then 100.0 ml of filtered sample was taken in this evaporating porcelain dish, and after the complete evaporation, the final weight (B) of porcelain dish was measured.

Calculation:

$$\text{Total dissolved solids (ppm)} = \frac{B - A \times 1000}{V}$$

Where A = Initial weight of disk in mg

B = Final weight of disk in mg

V = Volume of the sample taken in mL

3.10.8 Total Suspended Solid (TSS)

Total suspended solids were calculated as the difference between the total solids (TS) and total dissolved solids (TDS) **as mentioned in APHA, (2012)**.

Calculation:-

TSS (ppm) = TS (ppm) – TDS (ppm)

3.10.9 Phosphate (PO_4^-)

Stannous chloride method:-

Apparatus and equipment:-

a. Colorimeter or spectrophotometer for use at 690 nm and 880 nm providing 0.5 cm light path.

b. Nessler tubes, 100mL

Reagents and standards:-

a. **Stock phosphate solution**:- Dissolved 219.5 mg anhydrous KH_2PO_4 in distilled water and dilute to 1000 mL. 1 mL = 50 mg PO_4^{3-}P

b. **Phosphate working solution**:- Diluted 50 mL stock solution to 1000 mL with distilled water. 1 mL = 2.50 mg PO_4^{3-}P

c. **Ammonium molybdate solution**:- Dissolved 25 g of Ammonium molybdate in approximately 175 mL of distilled water. Then added carefully 280 mL of concentrated H_2SO_4 to 400 mL of distilled water. Then cool the solution and added molybdate solution, and finally diluted it to 1000 mL using distilled water.

d. **Strong acid reagent**:- Added 300 mL concentrated H_2SO_4 to 600 mL distilled water. Added 4 mL concentrated HNO_3, cool and diluted to 1000 mL.

e. **Sodium hydroxide 6 N**:- Dissolved 24 g NaOH and diluted to 100 mL.

f. **Phenolphthalein indicator**:- Dissolved 0.5 g in 500 mL 95 % ethyl alcohol. Added 500 mL distilled water. Added dropwise 0.02 N NaOH till faint pink color appears (pH 8.3).

c. **Stannous chloride reagent I**:- Dissolved 2.5 gm fresh $SnCl_2.H_2O$ in 100 mL glycerol. Heated in the water bath to ensure complete dissolution.

d. **Dilute stannous chloride (reagent II)**:- Mixed 8 mL of stannous chloride solution (reagent I) with 50 mL of glycerol and mixed thoroughly.

e. **Potassium antimonyl tartrate solution**:- Dissolved 2.7 g in 800 mL distilled water and diluted to 1000 mL.

f. **Ascorbic acid**:- Dissolved 1.76 g ascorbic acid in 100 mL distilled water. This solution was stable for a week at 4°C.

g. **Combined reagent**:- Mixed 250 mL, 5 N sulphuric acid, 75 mL ammonium molybdate solution and 150 mL ascorbic acid solution. Then added 25 mL potassium antimonyl tartrate solution and mixed well.

Calibration curve:-

a. Into a series of 100 mL, Nessler tubes pipette appropriate amounts of phosphate working solution to cover the range of 5-30 ppm or 0.3-2 ppm P when $SnCl_2$/Ascorbic acid reagent was used as a reducing agent.

b. Added 4 mL of ammonium molybdate followed by 0.5 mL stannous chloride or 8 mL combined reagent and dilute to 100 mL with distilled water and mixed well. Allowed to stand for 10 minutes.

c. Prepared blank using distilled water in the same way.

d. Measured the intensity of blue colored complex at 690 nm or 880 nm between 10 and 12 minutes after the development of the color. The developed plot of absorbance vs. phosphate concentration to give a straight line passing through the origin will help to find out the concentration of unknown samples.

Procedure:-

a. The suitable volume of the sample was taken in a conical flask.

b. Added 1 drop of phenolphthalein indicator.

c. Added strong acid reagent till pink color disappears. Added 1 mL in excess.

d. Boiled for 5 minutes, cooled, filtered. Transferred to Nessler tube and neutralized to phenolphthalein with NaOH.

e. Then proceed as described in the preparation of calibration curve.

f. Measured the intensity of the complex at 690 nm and read the corresponding concentration from the calibration curve.

3.10.10 Potassium (K)

Potassium was measured by Flame Photometric method as described by **Trivedy and Goel (1986)**.

Reagents:-

a. **Stock potassium solution**:- Weighed 1.907 g of KCl dried at 110^0 C for 1-2 h and cooled in the desiccator, it was transferred to 1.0 L of volumetric flask and made volume up to 1.0 L with distilled water; 1 mL = 1.00 mg K.

b. **Intermediate potassium solution:-** 10.0 mL of stock potassium solution was prepared by diluting it with distilled water up to 100.0 mL; 1.0 mL = 0.1 mg of K, the calibration curve was prepared in the range of 1.0 to 10.0 ppm.

c. **Standard potassium solution:-** 10 mL intermediate solution was diluted with distilled water and volume was made up to 100 mL, 1 mL = 10 µg of K, the standard solution of 10.0, 15.0, 20.0, 25.0 and 30.0 ppm were prepared to draw the calibration curve.

Procedure:-

The instrument was calibrated by using the standard potassium solutions and the concentration of potassium in samples was taken directly from the flame photometer after forming calibration curve by using standards through the instrument **Trivedy and Goel (1986)**.

3.10.11 Sodium (Na)

In the present experiment sodium was estimated through flame photometer, while procedure given in **APHA, (2012)** was followed.

Reagents:-

a. **Stock sodium solution:-** 2.542 g of NaCl was dried at 140.0^0 C and cooled in desiccator. Weight was measured again and dissolved in distilled water making up the volume upto 1.0 L (1 mL = 1.00 mg Na).

b. **Intermediate sodium solution:-** 10.0 mL stock solution of sodium was diluted with distilled water upto 100.0 mL; 1.0 mL = 0.1 mg Na, calibration curve was prepared in the range of 1.0 to 10.0 ppm.

c. **Standard sodium solution:-** 10.0 mL of intermediate solution was taken and diluted with distilled water upto 100.0 mL, 1.0 mL = 10 µg Na, the standard solution of 10.0, 15.0, 20.0, 25.0 and 30.0 ppm were prepared to draw the calibration curve.

Procedure:-

The instrument was calibrated by using the standard solutions of sodium and then the concentration of sodium in samples was measured directly from the flame photometer after calibration of the instrument.

3.10.12 Nitrate (NO_3^-)

UV spectrophotometer method:- (APHA, 2012)

Apparatus and equipment:-

a. **Spectrophotometer**, for use at 220 nm and 275 nm with matched silica cells of 1cm or longer light path.

b. **Filter paper**:- 0.45 µm membrane filter, and appropriate filter assemble.

c. **Nessler tubes**, 50 mL volume.

Reagents and standards:-

a. **Distilled water**:- use distilled water for the preparation of all solutions and dilutions.

b. **The stock nitrate solution**:- dissolved 721.8 mg of anhydrous potassium nitrate and diluted it to 1000 ml using distilled water. 1 mL of this solution was equal to 100 µg N or 443 µg NO_3^-.

c. **Standard nitrate solution**:- diluted 100 mL stock nitrate solution to 1000 mL with distilled water. 1 mL = 10 µg NO_3^- N = 44.3 µg NO_3^-.

d. **Hydrochloric acid** solution: HCl, 1N.

e. **Aluminium hydroxide suspension**:- dissolved 125 g potash alum in 1000 mL distilled water. Warmed to 60°C, add 55-60 mL NH_4OH and allow standing for 1 h. Decant the supernatant and washed the precipitate a number of times till it was free from Cl, NO_2, and NO_3. Finally after setting, decant off as much clean liquid as possible, leaving only the concentrated suspension.

Calibration curve:-

Prepared nitrate calibration standards in the ranged from 0 to 350 µg N by diluting 1, 2, 4, 7…..35 mL of the standard nitrate solution to 50 mL. Then treated the nitrate standards in the same manner as the samples.

Procedure:-

The absorbance or transmittance was readied against distilled water and set the instrument at zero absorbance or 100% transmittance. For this a wavelength of 220 nm is applied to obtain the nitrate reading and, if necessary, take a reading at the wavelength of 275 nm to avoid interference due to dissolved organic matter (OM).

Calculation:-

For correction of dissolved organic matter, subtracted 2 times the reading value at 275 nm from the reading value at 220 nm to obtain the absorbance due to nitrate. Then converted this absorbance value into equivalent nitrate concentration by comparison between absorbance and the nitrate concentration value from the standard calibration curve.

Nitrate N (ppm) = mg nitrate-N/mL of sample

NO_3 (ppm) = Nitrate N ppm x 4.43

3.10.13 Ammonia (NH_4^+)

Nesslerisation method:- (APHA, 2012)

Apparatus and equipment:-

a. **Spectrophotometer**:- spectrophotometer having a measurement range of 300 to 700 nm.

b. **Nessler tubes** or 100 mL capacity volumetric flasks.

Reagents and standards:-

a. **Zinc sulfate**:- dissolved 10 g $ZnSO_4.7H_2O$ in distilled water and diluted to 100 mL.

b. **Sodium hydroxide**, **6 N**:- dissolved 24 g NaOH and diluted to 100 mL.

c. **EDTA reagent**:- dissolved 50 g EDTA in 60 mL water containing 10 g NaOH. Cool and diluted to 100 mL.

d. **Rochelle salt solution**:- dissolved 50 g potassium sodium tartarate in 100 mL. Removed ammonia by boiling off 30 mL solution, cool and diluted to 100 mL.

e. **Nessler reagent**:- mixed well 100 g Hgl_2 and 70 g Kl. Dissolved in the small quantity of water. Added this mixture to a cooled solution of 160 g NaOH in 500 mL water. Diluted to 1000 mL. Then keep the solution overnight and store the supernatant in the colored bottle.

f. **Standard ammonium solution**:- dissolved 3.819 g NH_4Cl dried at 100°C in distilled water and diluted to 1000 mL using distilled water. Diluted 10 mL of the solution to 1000 mL. 1 mL = 10 µg NH_3.

Calibration curve:-

Prepared a calibration curve using suitable aliquots of standard solution in the range of 5 to 120 µg/100 mL for reference following the same procedure as a. to e. but using the standard solution in place of sample.

Procedure:-

a. Taken 100 mL of sample. Added 1 mL $ZnSO_4$ solution and 0.4 or 0.5 mL NaOH to obtain the pH of 10.5. Allowed to settle and filter the supernatant through 42 No. Whatman filter paper.

b. Taken the suitable aliquot of sample.

c. Added 3 drops of Rochelle salt solution or 1 drop of EDTA mixed well.

d. Added 3 mL Nessler reagent if EDTA is used or 1 mL if Rochelle salt solution is used. Made up to 100 mL.

e. Then mixed well the solution and read the percent transmission after 10 minutes (for color development) at 410 nm along with a blank prepared in the same way by taking distilled water instead of the sample.

Calculation:-

The concentration was obtained directly from the prepared standard graph.

3.10.14 Heavy metals

Nitric acid digestion, method was used for digestion of water samples and plant samples for heavy metal analysis. 50.0 ml of acid preserved water sample was mixed with 5.0 ml concentrated HNO_3. The beaker was placed on a hot plate and heated till volume was reduced to 50%. After cooling, 5.0 ml of conc. HNO_3 was added to the digested water sample and again heated till the content of the beaker was reduced to 5.0 ml. Later the volume of solution was made upto 50 ml of distilled water and the contents were filtered with Watman filter paper no. 42. The filtered solution was directly aspirated and concentration of the trace metals was analyzed through Atomic Absorption Spectrophotometer (AAS). Specific hollow cathode lamps were used for analysis of different metals. The elements chosen for analysis were Chromium (Cr), Cadmium (Cd) and Lead (Pb) because these are ubiquitous pollutants **(APHA, 2012)**.

3.11 Statistical analysis of data

All the data collected for different experiments recorded during the study period were compiled and analyzed for statistical interpretation using the Microsoft Excel. The replicates were analyzed for the mean and standard deviation, while the software OPSTAT was used to prove the level of significance among different treatments.

Results & Discussion

4.1 Wastewater characteristics

The wastewater for the present experiment was collected from one of the drain of GBPUA&T, Pantnagar nearby Mahakaleshwer Temple. The initial concentrations of wastewater for various parameters along with their discharge permissible limits (BIS) are depicted in the **Table 4.1**. Among different parameters total suspended solids (244.5 ppm), biochemical oxygen demand (64.75 ppm), chemical oxygen demand (277.25 ppm), phosphate (11.03 ppm) and nitrate (11.44 ppm) were found beyond their discharge permissible limits as per the **EPA Rules 1986** and the rest parameters were found within permissible limits. The wastewater characteristics varied with different seasons and for this experimental work the samples were collected between August, 2016 to February, 2018, therefore the values presented in the **Table 4.1** are the mean of 20 samples ± standard deviation (SD). The pH of the collected wastewater was found to be 7.3 which were slightly alkaline in nature. The electrical conductivity was about 624.1 µS/cm. The potassium and sodium of wastewater were 11.5 and 25.67 ppm, respectively. While, the total solids, total dissolved solid and total suspended solids were accordingly 767.62 ppm, 527.12 ppm and 244.5 ppm. The BOD and COD content were about 64.75 ppm and 277.25 ppm, respectively. If the value of COD is high, then it might be due to more oxidisable organic compounds present in the effluent. The values of both BOD and COD were beyond their discharge permissible limits. The values of phosphate, ammonical nitrogen, nitrate nitrogen and total nitrogen were 11.03 ppm, 12.73 ppm, 11.44 ppm and 25.73 ppm, respectively.

Similar characteristics of municipal wastewater in the city of Jaslo, located in south-eastern Poland was also reported by **Mikosz (2015)** as 290 ppm BOD, 222 ppm COD, 19 ppm ammonical nitrogen, 38 ppm total nitrogen and 7.3 ppm total phosphorus.

Table 4.1 Wastewater characteristics and discharge permissible limits as per EPA Rules 1986 (BIS)

Parameters	*Wastewater Conc.	permissible limits
pH	7.3±0.36	5.5 to 9.0
EC (µS/cm)	624.1±54.25	500
K (ppm)	11.5±1.32	-
Na (ppm)	25.67±2.31	-
TS (ppm)	767.62±61.3	-
TDS (ppm)	527.12±61.7	2100
TSS (ppm)	244.5±35.94	100
BOD (ppm)	64.75±11.54	30
COD (ppm)	277.25±38.5	250
PO_4^- (ppm)	11.03±1.83	5.0
NH_4^+-N (ppm)	12.73±1.92	50
NO_3^--N (ppm)	11.44±1.69	10
TN (ppm)	25.73±3.53	-

* = Mean (no. = 20) ± Standard deviation

Nutrient content of wastewater is a valuable resource if used for irrigation but if wastewater discharged to other water body then nutrient content may lead to eutrophication of water body with consequent ecological damage **(Reddy and D'Angelo, 1997; Scott et al., 2004)**.

Bu and Xu (2013) also reported characteristics of the Linjiang River, a tributary in Jiangjin of Chongqing, China, where the chemical oxygen demand (COD) varied from 6.53 to 18.45 ppm, total nitrogen (TN) from 6.82 to 12.25 ppm and total phosphorus (TP) from 0.65 to 1.64 ppm.

4.2 Phytoremediation of wastewater under lab condition

Initially a lab experiment was conducted in ambient environmental condition at Department of Environmental Science GBPUA&T, Pantnagar in the months of August and September, 2016 for assessment of phytoremediation efficiency of Canna and Pistia plants under hydroponic condition. The objective of this study was to standardize the system for phytoremediation of domestic wastewater in floating rafts and constructed wetland to validate the system at laboratory scale before field level study.

The initial characteristics of wastewater and tap water for the various parameters viz. pH, EC, COD, BOD, TS, TDS, TSS, TN, TP, TK and Na were 8.86, 552, 380, 50.4, 425, 280, 145, 36.5, 7.42, 2.30 and 8.84 ppm for wastewater and 7.70, 251, 6.38, 3.95, 281, 161, 120, 1.71, 1.37, 0.95 and 4.68 ppm for tap water, respectively. Both wastewater and tap water were treated with Canna and Pistia at 5, 10 and 15 days HRTs.

4.2.1 Phytoremediation by Canna

At 5 days hydraulic retention time, the concentration of pH, EC (µS/cm), COD (ppm), BOD (ppm), TS (ppm), TDS (ppm), TSS (ppm), TN (ppm), TP (ppm), TK (ppm), Na (ppm) were reduced to 8.10, 466, 292, 39.7, 340, 213, 127, 29.3, 6.23, 1.93, 7.43 ppm, respectively from wastewater and 7.51, 213, 4.94, 3.12, 220, 117, 103, 1.42, 1.25, 0.87, 3.94 ppm, respectively from the tap water by Canna. While, after 10 days hydraulic retention time, the concentration for the same above mentioned parameter were reduced to 7.7, 448, 276, 34.6, 322, 199, 123, 22.1, 5.92, 1.62, 6.37 ppm, respectively from wastewater and 7.4, 204, 3.49, 2.89, 197, 98, 99, 1.21, 0.93, 0.62, 2.21 ppm, respectively from the tap water by the same plant Canna. Further, after 15 days hydraulic retention time, the concentration for the same parameters were reduced to 7.5, 412, 213, 28.7, 284, 170, 114, 16.5, 4.31, 0.98, 4.35 ppm, respectively from wastewater and 7.2, 192, 2.74, 2.01, 172, 79, 93, 0.92, 0.67, 0.41, 1.78 ppm, respectively from the tap water by the same plant Canna. Comparatively pollutants concentrations along with their percentage reduction by Canna are depicted in **Table 4.2** and **Fig. 4.1 to Fig. 4.9**.

4.2.2 Phytoremediation by Pistia

At 5 days hydraulic retention time, the concentration of pH, EC (µS/cm), COD (ppm), BOD (ppm), TS (ppm), TDS (ppm), TSS (ppm), TN (ppm), TP (ppm), TK (ppm), Na (ppm) were reduced to 8.37, 472, 302, 40.9, 353, 224, 129, 31.6, 6.74, 2.01, 7.24, respectively from wastewater and 7.62, 209, 5.01, 3.2, 225, 121, 104, 1.53, 1.32, 0.89, 4.16, respectively from the tap water by Pistia plant. While, after 10 days hydraulic retention time, the concentration for the same above mentioned parameter were reduced to 7.9, 457, 284, 36.5, 315, 212, 103, 24.8, 6.19, 1.73, 6.85, respectively from wastewater and 7.5, 200, 3.94, 2.96, 211, 110, 101, 1.32, 1.01, 0.53, 2.95, respectively from the tap water by the same plant Pistia. Further, after 15 days hydraulic retention time, the concentration for the same parameters were reduced to 7.6, 416, 208, 32.6, 265, 187, 78, 18.7, 4.93, 1.29, 3.12, respectively from wastewater and 7.1, 196, 2.97, 2.23, 182, 92, 90, 1.12, 0.79, 0.47, 1.01, respectively from the tap water by the same plant Pistia. Comparatively pollutants concentrations along with their percentage reduction by Pistia at 5, 10 and 15 days HRT are depicted in **Table 4.3** and **Fig. 4.1 to Fig. 4.9**.

Table 4.2 Comparison of pollutants concentration to assess the phytoremediation efficiency of Canna at 5, 10 and 15 days HRTs

Parameters	Initial Concentration		Pollutants reduction by Canna											
			Pollutants concentration after 5 days				Pollutants concentration after 10 days				Pollutants concentration after 15 days			
	TW	WW	TW	% red.	WW	% red.	TW	% red.	WW	% red.	TW	% red.	WW	% red.
pH	7.70	8.86	7.51	2.47	8.10	8.58	7.4	3.90	7.7	13.09	7.2	6.49	7.5	15.35
EC (µs/cm)	251	552	213	15.14	466	15.58	204	18.73	448	18.84	192	23.51	412	25.36
COD (ppm)	6.38	380	4.94	22.57	292	23.16	3.49	45.30	276	27.37	2.74	57.05	213	43.95
BOD (ppm)	3.95	50.4	3.12	21.01	39.7	21.23	2.89	26.84	34.6	31.35	2.01	49.11	28.7	43.06
TS (ppm)	281	425	220	21.71	340	20.00	197	29.89	322	24.24	172	38.79	284	33.18
TDS (ppm)	161	280	117	27.33	213	23.93	98	39.13	199	28.93	79	50.93	170	39.29
TSS (ppm)	120	145	103	14.17	127	12.41	99	17.50	123	15.17	93	22.50	114	21.38
TN (ppm)	1.71	36.5	1.42	16.96	29.3	19.73	1.21	29.24	22.1	39.45	0.92	46.20	16.5	54.79
TP (ppm)	1.37	7.42	1.25	8.76	6.23	16.04	0.93	32.12	5.92	20.22	0.67	51.09	4.31	41.91
TK (ppm)	0.95	2.30	0.87	8.42	1.93	16.09	0.62	34.74	1.62	29.57	0.41	56.84	0.98	57.39
Na (ppm)	4.68	8.84	3.94	15.81	7.43	15.95	2.21	52.78	6.37	27.94	1.78	61.97	4.35	50.79

HRTs = hydraulic retention time, TW = tap water, WW = wastewater, % red. = percentage reduction of pollutants

Table 4.3 Comparison of pollutants concentration to assess the phytoremediation efficiency of Pistia at 5, 10 and 15 days HRTs

Parameters	Initial Concentration		Pollutants reduction by Pistia											
			Pollutants concentration after 5 days				Pollutants concentration after 10 days				Pollutants concentration after 15 days			
	TW	WW	TW	% red.	WW	% red.	TW	% red.	WW	% red.	TW	% red.	WW	% red.
pH	7.70	8.86	7.62	1.04	8.37	5.53	7.5	2.60	7.9	10.84	7.1	7.79	7.6	14.22
EC (µs/cm)	251	552	209	16.73	472	14.49	200	20.32	457	17.21	196	21.91	416	24.64
COD (ppm)	6.38	380	5.01	21.47	302	20.53	3.94	38.24	284	25.26	2.97	53.45	208	45.26
BOD (ppm)	3.95	50.4	3.2	18.99	40.9	18.85	2.96	25.06	36.5	27.58	2.23	43.54	32.6	35.32
TS (ppm)	281	425	225	19.93	353	16.94	211	24.91	315	25.88	182	35.23	265	37.65
TDS (ppm)	161	280	121	24.84	224	20.00	110	31.68	212	24.29	92	42.86	187	33.21
TSS (ppm)	120	145	104	13.33	129	11.03	101	15.83	103	28.97	90	25.00	78	46.21
TN (ppm)	1.71	36.5	1.53	10.53	31.6	13.42	1.32	22.81	24.8	32.05	1.12	34.50	18.7	48.77
TP (ppm)	1.37	7.42	1.32	3.65	6.74	9.16	1.01	26.28	6.19	16.58	0.79	42.34	4.93	33.56
TK (ppm)	0.95	2.30	0.89	6.32	2.01	12.61	0.53	44.21	1.73	24.78	0.47	50.53	1.29	43.91
Na (ppm)	4.68	8.84	4.16	11.11	7.24	18.10	2.95	36.97	6.85	22.51	1.01	78.42	3.12	64.71

HRTs = hydraulic retention time, TW = tap water, WW = wastewater, % red. = percentage reduction of pollutants

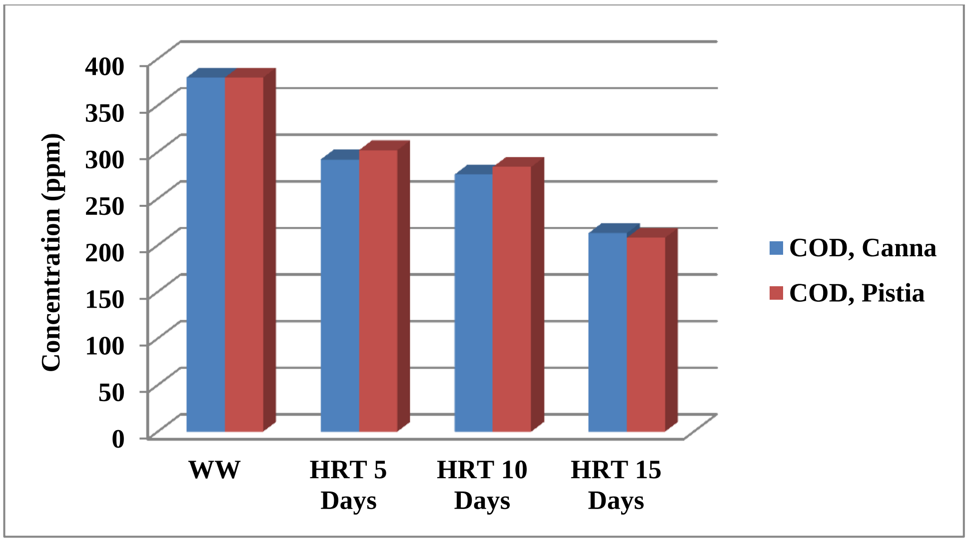

Fig. 4.1 COD reduction by Canna and Pistia at different HRTs

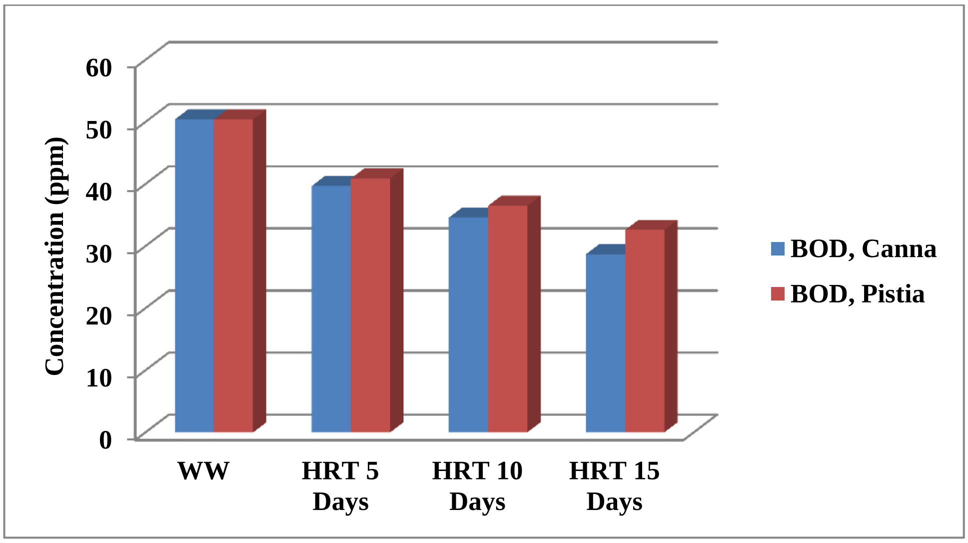

Fig. 4.2 BOD reduction by Canna and Pistia at different HRTs

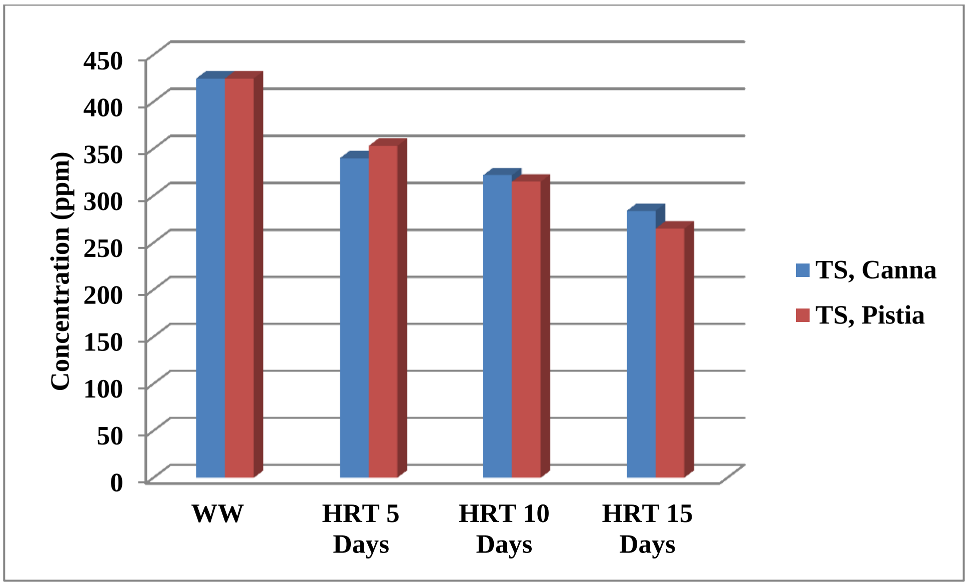

Fig. 4.3 TS reduction by Canna and Pistia at different HRTs

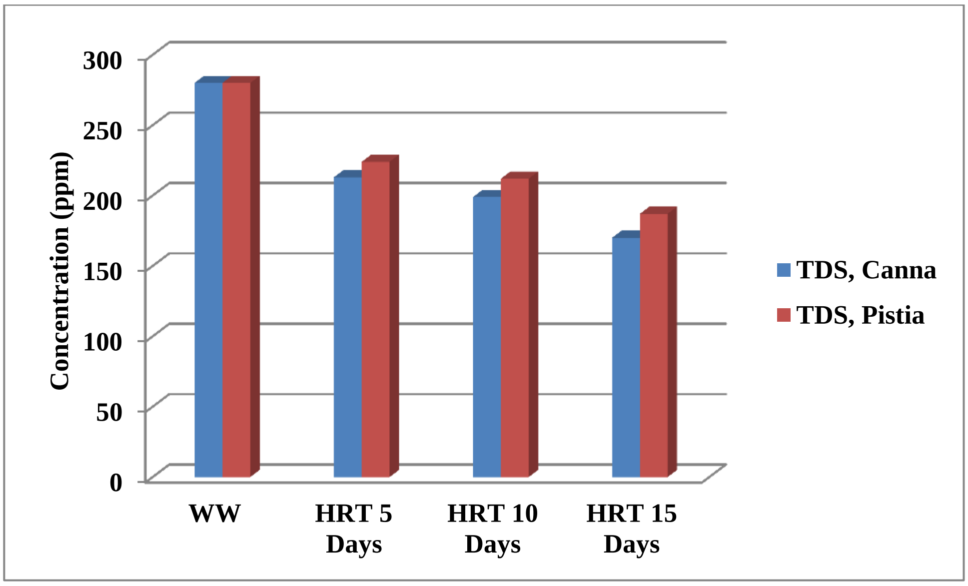

Fig. 4.4 TDS reduction by Canna and Pistia at different HRTs

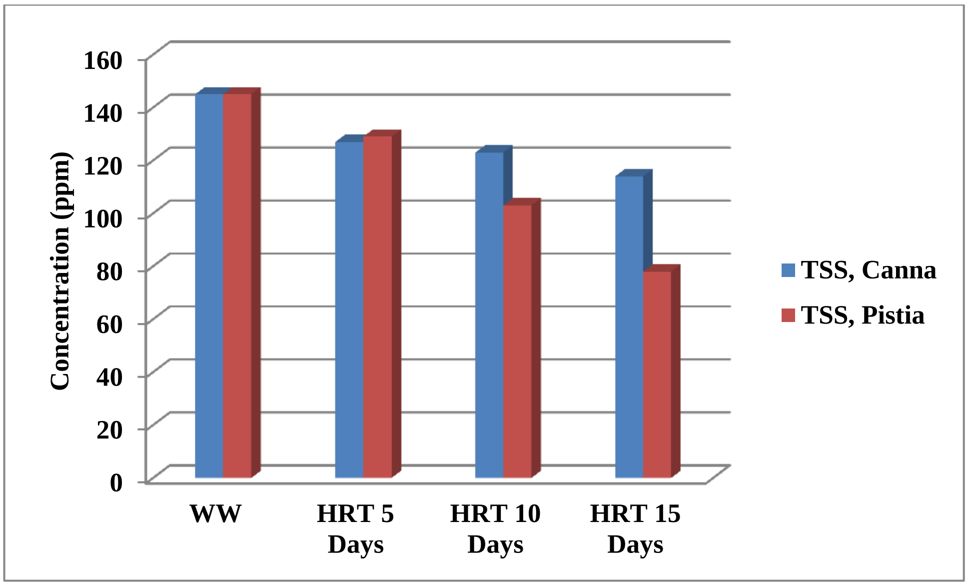

Fig. 4.5 TSS reduction by Canna and Pistia at different HRTs

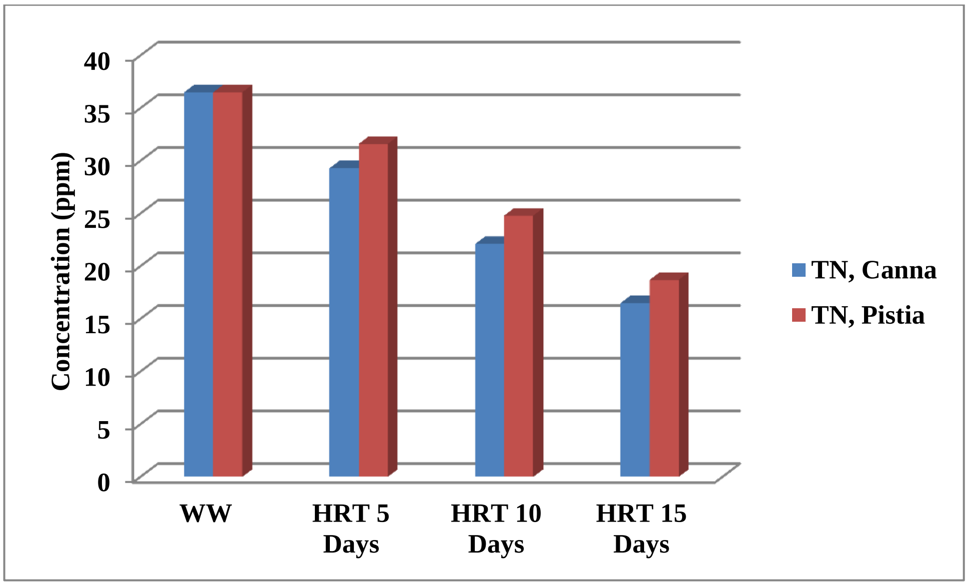

Fig. 4.6 TN reduction by Canna and Pistia at different HRTs

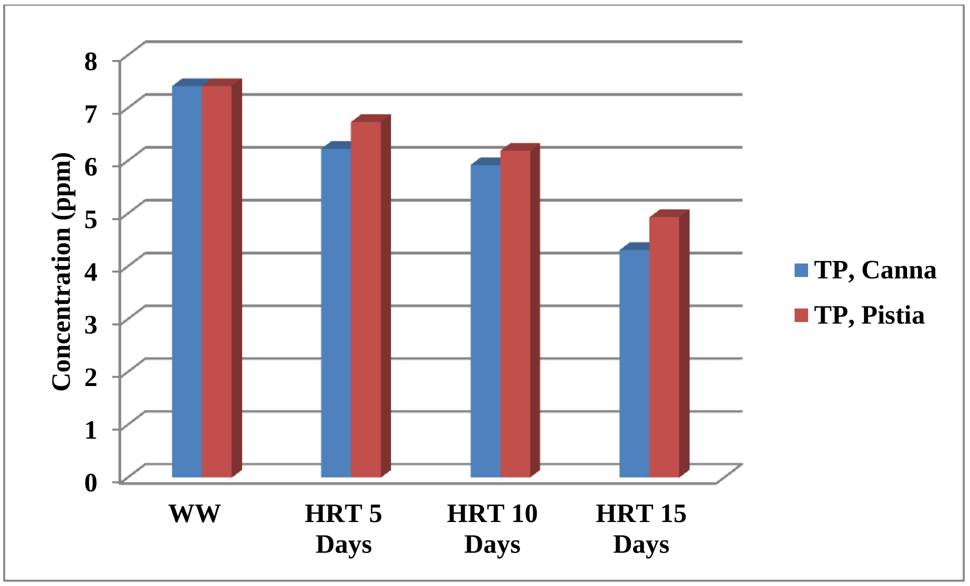

Fig. 4.7 TP reduction by Canna and Pistia at different HRTs

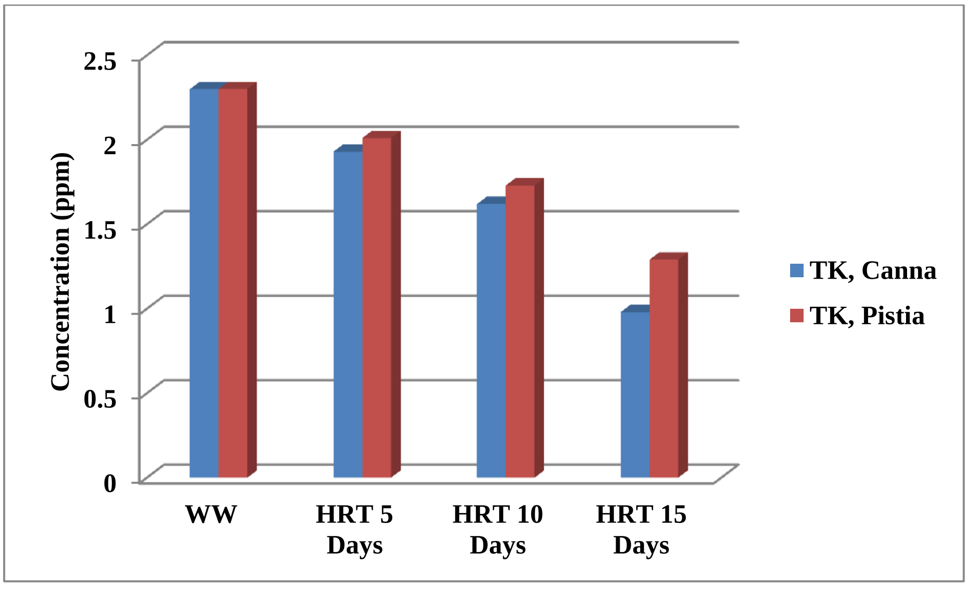

Fig. 4.8 TK reduction by Canna and Pistia at different HRTs

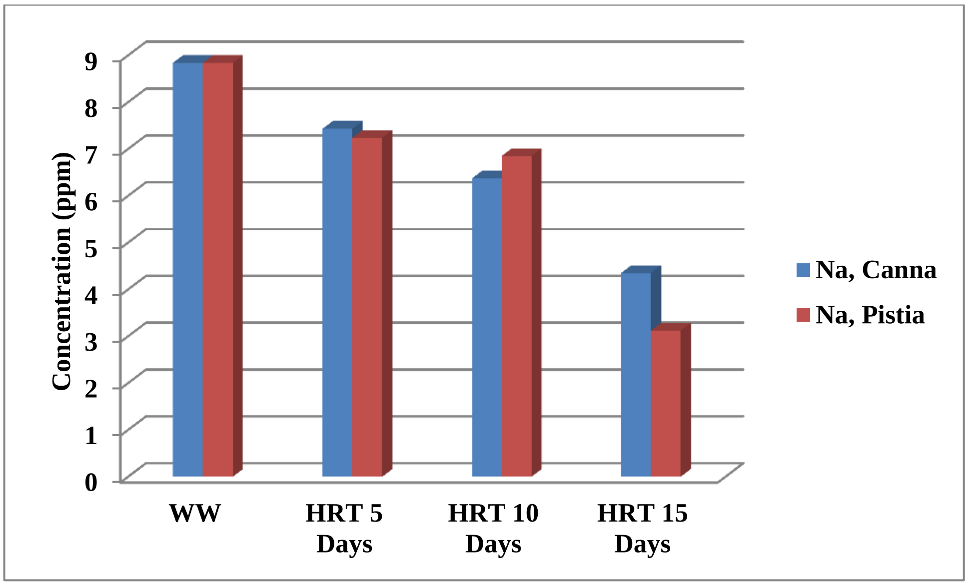

Fig. 4.9 Na reduction by Canna and Pistia at different HRTs

4.3 Phytoremediation of wastewater under field condition

After validation of floating raft concept in hydroponic condition at lab level experiment, a field level experiment was also conducted nearby Mahakaleshwer Temple, Pantnagar. This experiment was conducted from October 2016 to September 2017, at 6, 12, 24 and 48 h hydraulic retention time (HRT). This field level experiment was constituted with two floating raft tanks, one constructed wetland and one oxidation pond individually as well as in combination with each other to develop a hybrid model for wastewater treatment as mentioned in the Chapter 3 (Materials and Methods).

4.3.1 Phytoremediation at 6 h HRTs

At 6 h hydraulic retention time, the initial concentration of pH, EC (µS/cm), K (ppm), Na (ppm), TS (ppm), TDS (ppm), TSS (ppm), BOD (ppm), COD (ppm), PO_4^- (ppm), NH_4^+-N (ppm), NO_3^--N (ppm), TN (ppm) were 7.63, 622.62, 12.0, 24.25, 767.24, 510.12, 257.75, 69.75, 283.75, 10.32, 13.62, 13.25 and 33.54, respectively. After 6 h HRT time under various hybrid model, maximum pollutants reduction were observed by hybrid system-1 (HS-1) which was combined with two floating raft tanks such as floating raft tank-I planted with Canna and floating raft tank-II planted with Water lily. Concentration of pollutants after 6 h HRT was 7.2, 581, 8, 14, 515, 346, 169, 53, 170, 6.34, 9.94, 9.39 and 26.43, respectively in case of HS-1 and 7.1, 7.33, 25, 25.77, 19.19, 18.65, 20.47, 28.32, 22.47, 24.32, 33.63, 29.28 and 30.02, respectively in case of HS-4. Pollutants concentrations along with their percentage reduction by various models at 6 h HRT are depicted in **Table 4.4** and **Fig. 4.10 to Fig. 4.20**.

Table 4.4 Phytoremediation of wastewater after 6 h HRT through different hybrid models

Parameters	Initial Conc. (Mean±SD)	FRT-I		FRT-II		CW		HS-1		HS-2a		HS-2b		HS-3		HS-4	
		Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.
pH	7.63±0.25	7.4	3.01	7.2	5.64	7.63	0.00	7.2	5.64	7.2	5.64	7.63	0.00	7.5	1.70	7.1	6.95
EC (µS/cm)	622.62±65.7	620	0.42	610	2.03	490	21.30	581	6.68	511	17.93	599	3.79	577	7.33	558	10.38
K (ppm)	12.0±3.0	9	25.00	8	33.33	10	16.67	8	33.33	8	33.33	9	25.00	9	25.00	8	33.33
Na (ppm)	24.25±4.7	23	5.15	23	5.15	16	34.02	14	42.27	12	50.52	17	29.90	18	25.77	17	29.90
TS (ppm)	767.24±79.4	492	35.87	606	21.02	611	20.36	515	32.88	588	23.36	546	28.84	620	19.19	402	47.60
TDS (ppm)	510.12±38.4	332	34.92	397	22.18	408	20.02	346	32.17	395	22.57	366	28.25	415	18.65	260	49.03
TSS (ppm)	257.75±25.3	160	37.92	209	18.91	203	21.24	169	34.43	193	25.12	180	30.16	205	20.47	142	44.91
BOD (ppm)	69.75±18.54	56	19.71	48	31.18	52	25.45	53	24.01	51	26.88	60	13.98	50	28.32	50	28.32
COD (ppm)	283.75±26.4	210	25.99	250	11.89	230	18.94	170	40.09	210	25.99	210	25.99	220	22.47	150	47.14
PO_4^- (ppm)	10.32±2.65	10.26	0.58	10.02	2.91	8.99	12.89	6.34	38.57	6.98	32.36	9.3	9.88	7.81	24.32	6.12	40.70
NH_4^+-N (ppm)	13.62±3.73	11.66	14.39	11.06	18.80	9.68	28.93	9.94	27.02	10.12	25.70	9.64	29.22	9.04	33.63	9.88	27.46
NO_3^--N (ppm)	13.25±3.68	11.07	16.45	11.35	14.34	10.06	24.08	9.39	29.13	11.5	13.21	9.21	30.49	9.37	29.28	8.95	32.45
TN (ppm)	33.54±5.32	30.45	9.21	28.32	15.56	27.10	19.20	26.43	21.19	25.39	24.29	24.79	26.08	23.47	30.02	22.81	31.99

h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), Conc. = concentration, % red. = percentage reduction of pollutants

Similar experiment was also conducted by **Bu and Xu (2013)** for the treatment of the River, Linjiang, a tributary in Jiangjin of Chongqing, China, where the removal of COD, TN and TP was ranged between 15.3 % - 38.4 %, 25.4 % - 48.4 % and 16.1 % - 42.1 %, respectively using floating bed planted with *Canna indica*, *Accords calamus*, *Cyperus alternifolius* and *Vetiveria zizanioides*.

Bu and Xu (2013) also reported characteristics of the Linjiang River, a tributary in Jiangjin of Chongqing, China, where the chemical oxygen demand (COD) varied from 6.53 to 18.45 ppm, total nitrogen (TN) from 6.82 to 12.25 ppm and total phosphorus (TP) from 0.65 to 1.64 ppm

Bu and Xu (2013) also conducted an experiment using *Canna indica*, *Accords calamus*, *Cyperus alternifolius*, *Vetiveria zizanioides* and observed that floating bed was a viable alternative for treating eutrophic river water, especially for inhibiting algae growth.

Vymazal (2010) compiled data on treatment efficiencies of a large number of CWs and found average removal efficiencies for BOD (by 73, 75 and 90 %, respectively), TSS (72, 75 and 89 %, respectively), total nitrogen (48, 38 and 43 %, respectively), ammoniacal nitrogen (45, 35 and 73 %, respectively) and total phosphorus (40,50 and 56 %, respectively) by FWS-CW (free water surface constructed wetland), HF-CW (horizontal flow constructed wetland) and VF-CW (vertical flow constructed wetland), respectively.

4.3.2 Phytoremediation at 12 h HRTs

At 12 h hydraulic retention time, the initial concentration of pH, EC (µS/cm), K (ppm), Na (ppm), TS (ppm), TDS (ppm), TSS (ppm), BOD (ppm), COD (ppm), PO_4^- (ppm), NH_4^+-N (ppm), NO_3^--N (ppm), TN (ppm) were 7.56, 618.37, 10.12, 26.12, 772.48, 513.75, 256.25, 73.62, 288.87, 9.83, 13.33, 13.59 and 31.7, respectively. The average trend for phytoremediation efficiency of various hybrid models for domestic wastewater after 12 h hydraulic retention time was HS-4> HS-1> HS-2a> HS-3> HS-2b> FRT-I> FRT-II and CW. Pollutants concentrations along with their percentage reduction by various models at 12 h HRT time are depicted in **Table 4.5** and presented in **Fig. 4.10 to Fig. 4.20**.

Table 4.5 Phytoremediation of wastewater after 12 h HRT through different hybrid models

Parameters	Initial Conc. (Mean±SD)	FRT-I		FRT-II		CW		HS-1		HS-2a		HS-2b		HS-3		HS-4	
		Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.
pH	7.56±0.32	7.6	-0.53	7.3	3.44	7.3	3.44	7.1	6.08	7.5	0.79	7.1	6.08	7.7	-1.85	7.2	4.76
EC (µS/cm)	618.37±68.62	608	1.68	530	14.29	510	17.53	509	17.69	485	21.57	585	5.40	512	17.20	504	18.50
K (ppm)	10.12±2.03	5	50.59	5	50.59	8	20.95	4	60.47	3	70.36	5	50.59	4	60.47	4	60.47
Na (ppm)	26.12±3.60	9	65.54	14	46.40	15	42.57	7	73.20	10	61.72	14	46.40	10	61.72	11	57.89
TS (ppm)	772.48±56.58	491	36.44	479	37.99	497	35.66	337	56.37	361	53.27	461	40.32	441	42.91	316	59.09
TDS (ppm)	513.75±25.79	328	36.16	319	37.91	329	35.96	217	57.76	246	52.12	302	41.22	291	43.36	210	59.12
TSS (ppm)	256.25±11.54	163	36.39	160	37.56	168	34.44	120	53.17	115	55.12	159	37.95	150	41.46	106	58.63
BOD (ppm)	73.62±4.17	44	40.23	50	32.08	54	26.65	33	55.18	31	57.89	45	38.88	41	44.31	30	59.25
COD (ppm)	288.87±19.67	198	31.46	190	34.23	220	23.84	180	37.69	170	41.15	150	48.07	160	44.61	140	51.54
PO_4^- (ppm)	9.83±1.79	7.84	20.24	6.82	30.62	7.46	24.11	5.6	43.03	6.78	31.03	8.84	10.07	6.17	37.23	3.81	61.24
NH_4^+-N (ppm)	13.33±2.12	10.81	18.90	11.4	14.48	9.74	26.93	5.53	58.51	8.66	35.03	9.13	31.51	7.31	45.16	5.15	61.37
NO_3^--N (ppm)	13.59±2.96	9.84	27.59	11.6	14.64	10.44	23.18	6.68	50.85	7.76	42.90	9.41	30.76	7.29	46.36	4.43	67.40
TN (ppm)	31.7±3.85	25.85	18.45	27.26	14.00	27.33	13.78	18.15	42.74	20.29	35.99	22.35	29.49	19.32	39.05	14.36	54.70

h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), Conc. = concentration, % red. = percentage reduction of pollutants

The lower phytoremediation efficiency of HS-2a (floating raft tank-I + oxidation pond) followed by HS-2b (FRT-II + OP) was due to oxidation pond which was planted with Pistia. Since in this experiment the oxidation pond was naturally managed (not lined properly with cement concrete) in this condition the harvesting of dead Pistia plants was very tedious, therefore these dead plants get decomposed in the oxidation pond which lead to decreased its phytoremediation efficiency of oxidation pond.

Sun *et al*. (2009), conducted an experiment with river water and shown that floating bed system of ornamental Canna plants removed 50.4 % of total nitrogen, 22.4 % of the nitrate nitrogen, 5.3 % of nitrite nitrogen, 39.9 % of COD and 100% ammonical nitrogen in 5 days. Whereas this efficiency was improved considerably using immobilized bacteria along with aeration process. Then the removal percentage of total nitrogen was increased to 72.1 %, nitrate nitrogen to 75.8 %, nitrite nitrogen to 95.9 % and COD to 94.6 % in 5 days retention time with ammonical nitrogen oxidation by 100 %.

4.3.3 Phytoremediation at 24 h HRTs

At 24 h hydraulic retention time, the initial concentration of pH, EC (µS/cm), K (ppm), Na (ppm), TS (ppm), TDS (ppm), TSS (ppm), BOD (ppm), COD (ppm), PO_4^- (ppm), NH_4^+-N (ppm), NO_3^--N (ppm), TN (ppm) were 7.38, 622.82, 10.75, 27.25, 765.5, 509.87, 255.75, 70.5, 281.25, 9.61, 13.59, 12.86 and 34.3, respectively. The average maximum percentage reduction in various pollutants was observed in case of HS-4 (in which the above mentioned parameters were reduced by 3.79, 17.79, 72.09, 77.98, 59.11, 59.79, 57.77, 70.21, 50.22, 77.11, 74.32, 74.73 and 63.76 %, respectively) followed by HS-1 (in which the above mentioned parameters were reduced by 0.00, 8.48, 62.79, 77.98, 68.91, 68.03, 70.67, 73.05, 60.89, 77.52, 70.86, 64.46 and 58.25 %, respectively) and HS-2a (in which the above mentioned parameters were reduced by 3.79, 3.18, 72.09, 63.3, 58.33, 59.4, 56.21, 68.79, 46.67, 33.09, 57.76, 50.62 and 52.27 %, respectively). The data collected at 24 h HRT are presented in **Table 4.6** and depicted in **Fig. 4.10 to Fig. 4.20**.

Table 4.6 Phytoremediation of wastewater after 24 h HRT through different hybrid models

Parameters	Initial Conc. (Mean±SD)	FRT-I		FRT-II		CW		HS-1		HS-2a		HS-2b		HS-3		HS-4	
		Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.
pH	7.38±0.30	7.2	2.44	7.5	-1.63	7.2	2.44	7.38	0.00	7.1	3.79	7.1	3.79	7.2	2.44	7.1	3.79
EC (µS/cm)	622.82±85.92	549	11.85	603	3.18	588	5.59	570	8.48	603	3.18	477	23.41	492	21.00	512	17.79
K (ppm)	10.75±1.66	5	53.49	6	44.19	8	25.58	4	62.79	3	72.09	4	62.79	4	62.79	3	72.09
Na (ppm)	27.25±3.49	11	59.63	16	41.28	11	59.63	6	77.98	10	63.30	10	63.30	9	66.97	6	77.98
TS (ppm)	765.5±97.01	433	43.44	388	49.31	382	50.10	238	68.91	319	58.33	371	51.53	471	38.47	313	59.11
TDS (ppm)	509.87±64.75	291	42.93	258	49.40	260	49.01	163	68.03	207	59.40	245	51.95	312	38.81	205	59.79
TSS (ppm)	255.75±32.58	142	44.48	130	49.17	122	52.30	75	70.67	112	56.21	126	50.73	159	37.83	108	57.77
BOD (ppm)	70.5±7.69	35	50.35	31	56.03	40	43.26	19	73.05	22	68.79	36	48.94	30	57.45	21	70.21
COD (ppm)	281.25±21.00	170	39.56	170	39.56	200	28.89	110	60.89	150	46.67	170	39.56	150	46.67	140	50.22
PO_4^- (ppm)	9.61±1.51	8.64	10.09	8.53	11.24	6.54	31.95	2.16	77.52	6.43	33.09	6.21	35.38	3.66	61.91	2.2	77.11
NH_4^+-N (ppm)	13.59±2.76	8.27	39.15	9.61	29.29	10.03	26.20	3.96	70.86	5.74	57.76	6.83	49.74	5.06	62.77	3.49	74.32
NO_3^--N (ppm)	12.86±2.29	9.32	27.53	8.94	30.48	9.97	22.47	4.57	64.46	6.35	50.62	6.78	47.28	4.62	64.07	3.25	74.73
TN (ppm)	34.3±3.71	26.36	23.14	27.98	18.42	28.85	15.85	14.32	58.25	16.37	52.27	17.13	50.05	15.42	55.04	12.43	63.76

h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), Conc. = concentration, % red. = percentage reduction of pollutants

In an Australian Project **(Ash and Troung, 2004)** conducted by Veticon using Vetiver System (VS) for treatment of wastewater of Toogoolawah sewage treatment plant, the wastewater quality showed improvement with respect to nutrient loads. The total phosphorous level for the plant influent varied between 10-20 ppm and in the effluent it dropped to between 1-3 ppm. Similarly the total N in the influent was 30-80 ppm and was reduced to 4-6 ppm in the effluent, while 5 days BOD influent came down from 130-300 ppm to 7-11 ppm in the effluent. Suspended solids dropped from 200-500 ppm to 11-16 ppm and Dissolved oxygen (DO) increased from 0-2 ppm in influent to 8.1-9.2 ppm in effluent. Thus results showed that the Vetiver grass wetlands can improve the effluent quality **(Ash and Troung, 2003)**.

4.3.4 Phytoremediation at 48 h HRTs

At 48 h hydraulic retention time, the initial concentration of pH, EC (µS/cm), K (ppm), Na (ppm), TS (ppm), TDS (ppm), TSS (ppm), BOD (ppm), COD (ppm), PO_4^- (ppm), NH_4^+-N (ppm), NO_3^--N (ppm), TN (ppm) were 7.5, 620.1, 10.5, 26.37, 770.62, 517.12, 253.5, 65.75, 281.25, 10.03, 13.73, 12.48 and 29.79, respectively. After the 48 h HRT time, the maximum pollutants were reduced to 7.5, 520, 2.0, 6.0, 262, 173, 89, 9.0 70, 2.09, 2.87, 2.83 and 7.42, respectively by HS-4 followed by HS-1 (in which pollutants were reduced to 7.1, 490, 3.0, 6.0, 262, 180, 82, 14.0, 80.0, 2.1, 3.18, 3.36 and 8.35, respectively) and HS-2b (7.2, 492, 4.0, 10.0, 248, 169, 79, 23, 140, 4.48, 5.36, 5.46 and 10.56, respectively) as presented in **Table 4.7** and depicted in **Fig. 4.10 to Fig. 4.20**.

Similar result was also reported by **Vymazal (2010)** in case of horizontal surface flow constructed wetland to reduce pollutant load with performance efficiency (% removal) in the range of 70-90 % for biological oxygen demand (BOD), 70-80 % for total suspended solids (TSS), 40-50 % for total phosphorus (TP), 33-43 % for total nitrogen (TN) and 30-40 % for ammonical nitrogen (NH4N) in the residential time of wastewater for 1-2 days. Beside these, they also reduce pathogens, toxic metals and organic pollutants as well.

Table 4.7 Phytoremediation of wastewater after 48 h HRT through different hybrid models

Parameters	Initial Conc. (Mean±SD)	FRT-I		FRT-II		CW		HS-1		HS-2a		HS-2b		HS-3		HS-4	
		Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.	Conc.	% red.
pH	7.5±.36	7.3	2.67	7.2	4.00	7.2	4.00	7.1	5.33	7.4	1.33	7.2	4.00	7.3	2.67	7.5	0.00
EC (µS/cm)	620.1±64.25	520	16.14	580	6.47	535	13.72	490	20.98	595	4.05	492	20.66	557	10.18	520	16.14
K (ppm)	10.5±1.32	4	61.90	4	61.90	5	52.38	3	71.43	4	61.90	4	61.90	3	71.43	2	80.95
Na (ppm)	26.37±2.41	6	77.25	13	50.70	14	46.91	6	77.25	6	77.25	10	62.08	8	69.66	6	77.25
TS (ppm)	770.62±81.3	409	46.93	365	52.64	401	47.96	262	66.00	275	64.31	248	67.82	329	57.31	262	66.00
TDS (ppm)	517.12±63.7	273	47.21	246	52.43	265	48.75	180	65.19	182	64.81	169	67.32	216	58.23	173	66.55
TSS (ppm)	253.5±45.94	136	46.35	119	53.06	136	46.35	82	67.65	93	63.31	79	68.84	113	55.42	89	64.89
BOD (ppm)	65.75±13.54	27	58.94	30	54.37	35	46.77	14	78.71	14	78.71	23	65.02	22	66.54	9	86.31
COD (ppm)	281.25±48.5	150	46.67	120	57.33	150	46.67	80	71.56	110	60.89	140	50.22	120	57.33	70	75.11
PO_4^- (ppm)	10.03±1.83	5.93	40.88	6.29	37.29	6.84	31.80	2.1	79.06	4.51	55.03	4.48	55.33	3.83	61.81	2.09	79.16
NH_4^+-N (ppm)	13.73±2.14	6.53	52.44	7.16	47.85	8.48	38.24	3.18	76.84	4.76	65.33	5.36	60.96	3.71	72.98	2.87	79.10
NO_3^--N (ppm)	12.48±2.19	7.34	41.19	7.17	42.55	9.04	27.56	3.36	73.08	4.75	61.94	5.46	56.25	4.62	62.98	2.83	77.32
TN (ppm)	29.79±3.26	12.76	56.16	13.52	54.61	15.16	49.11	8.35	71.79	9.87	66.86	10.56	64.55	11.84	60.25	7.42	75.09

h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), Conc. = concentration, % red. = percentage reduction of pollutants

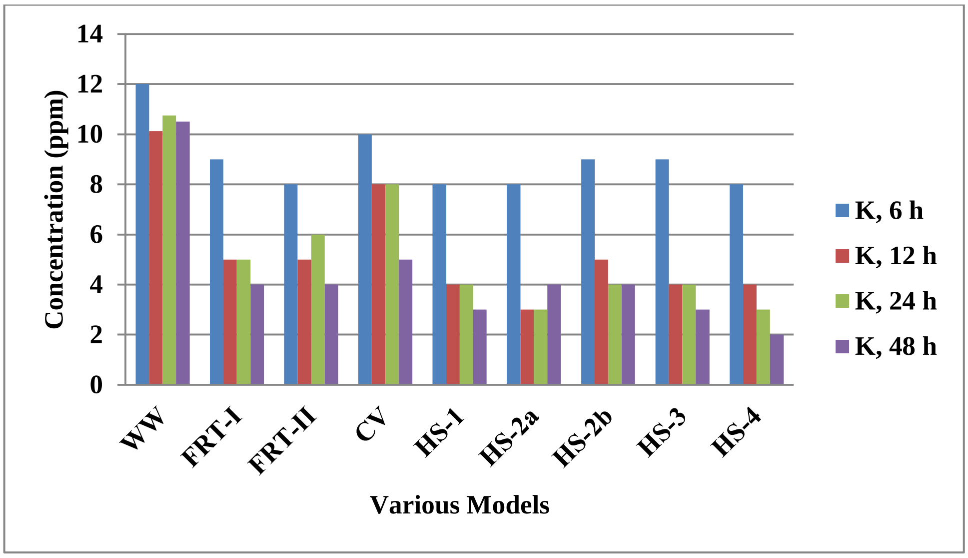

Fig. 4.10 K reduction by various models at different HRTs

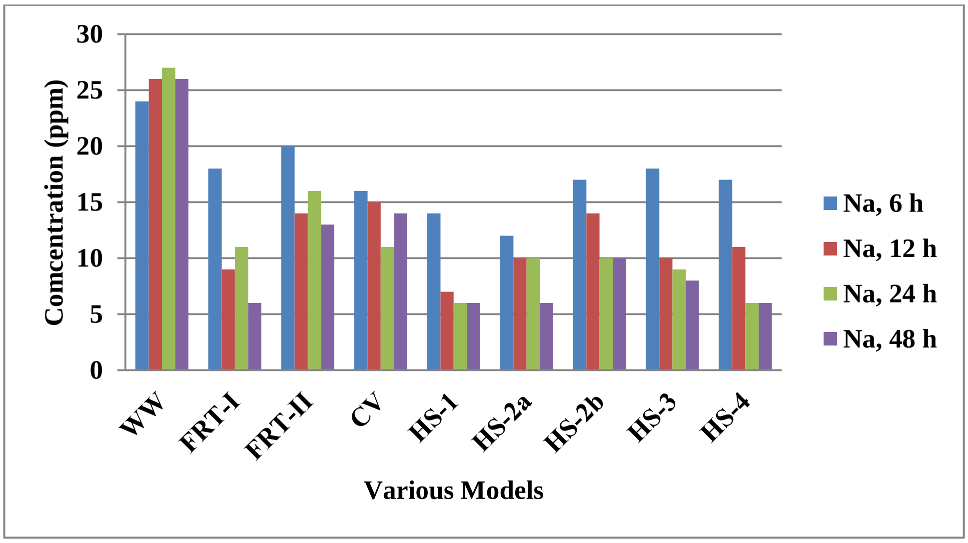

Fig. 4.11 Na reduction by various models at different HRTs

K = potassium, h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), Na = sodium

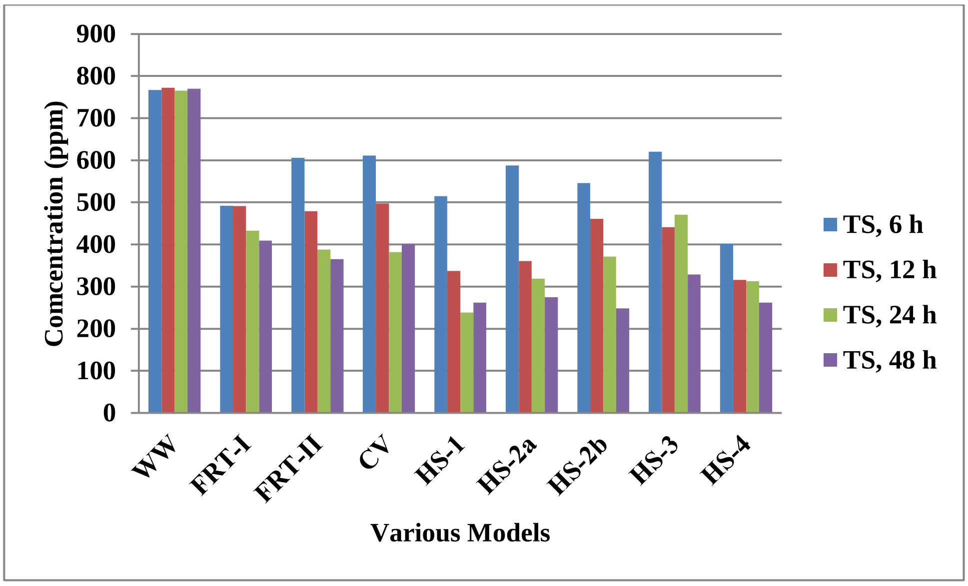

Fig. 4.12 TS reduction by various models at different HRTs

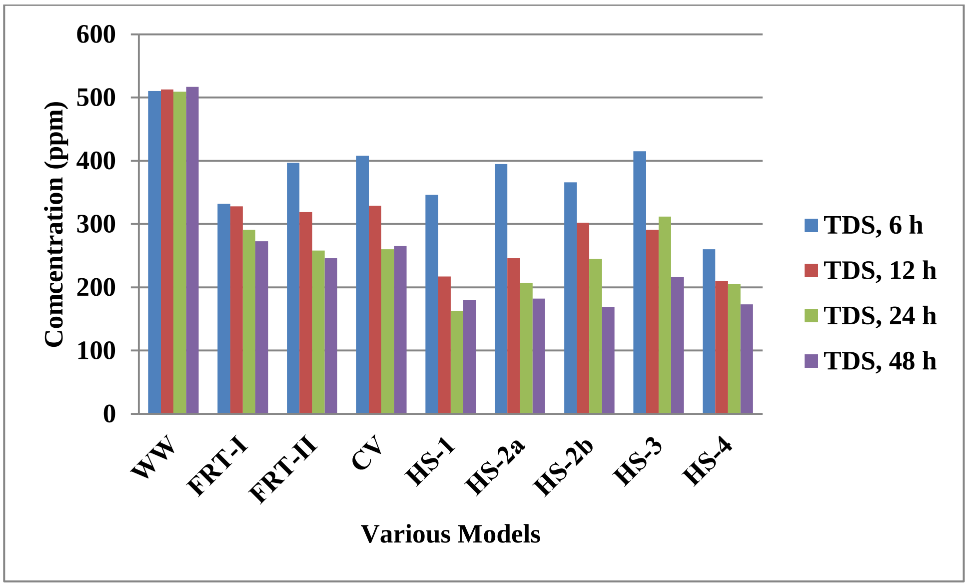

Fig. 4.13 TDS reduction by various models at different HRTs

TS = total solids, h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), TDS = total dissolved solids

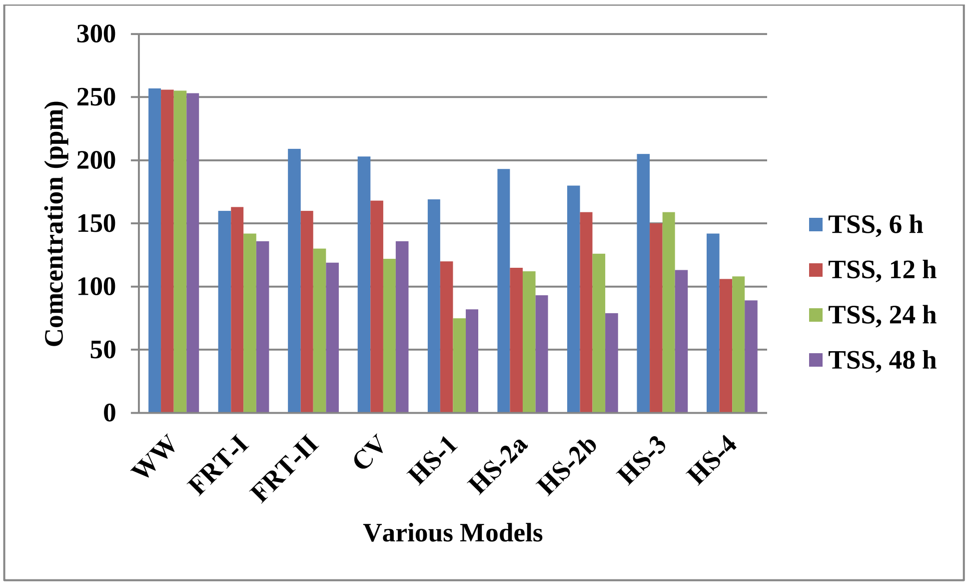

Fig. 4.14 TSS reduction by various models at different HRTs

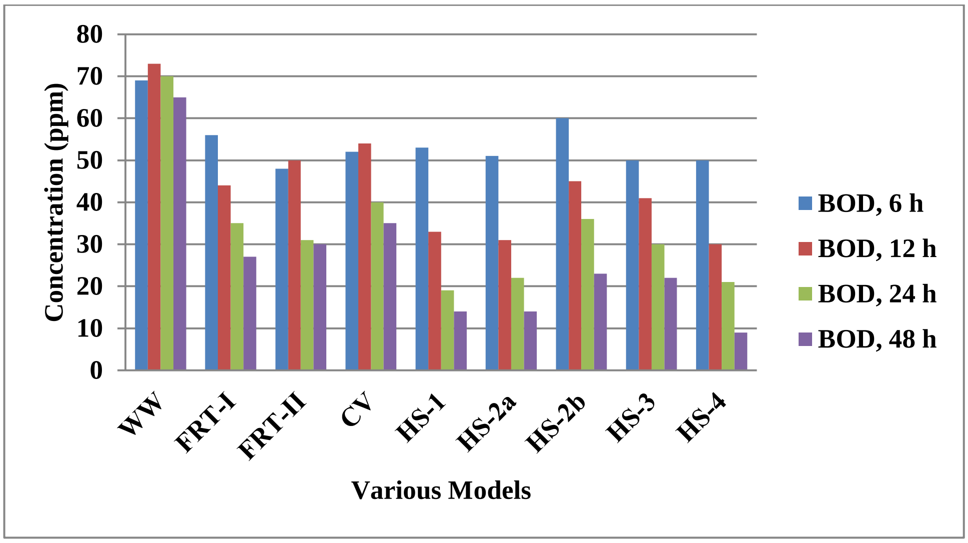

Fig. 4.15 BOD reduction by various models at different HRTs

TSS = total suspended solids, h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), BOD = biological oxygen demand

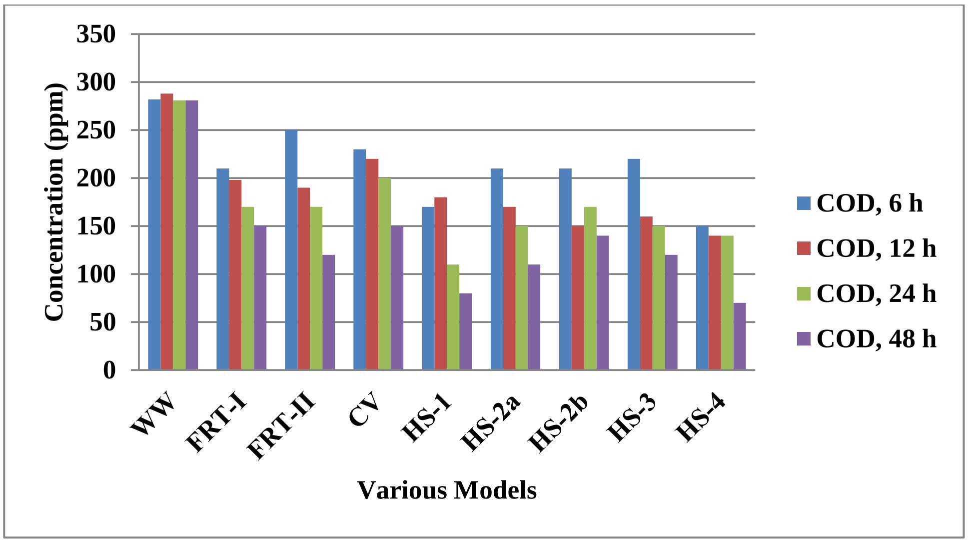

Fig. 4.16 COD reduction by various models at different HRTs

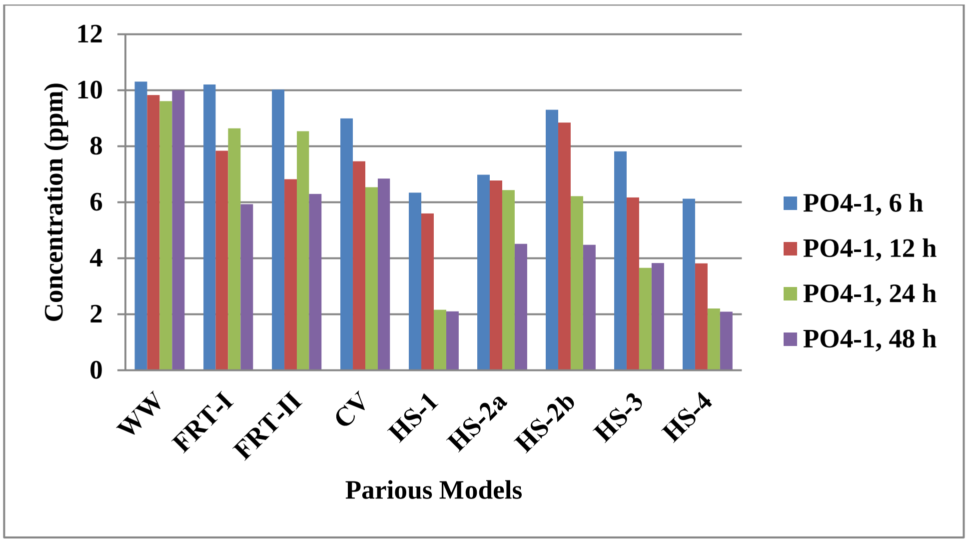

Fig. 4.17 PO_4^- reduction by various models at different HRTs

COD = chemical oxygen demand, h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), PO_4^- = phosphate

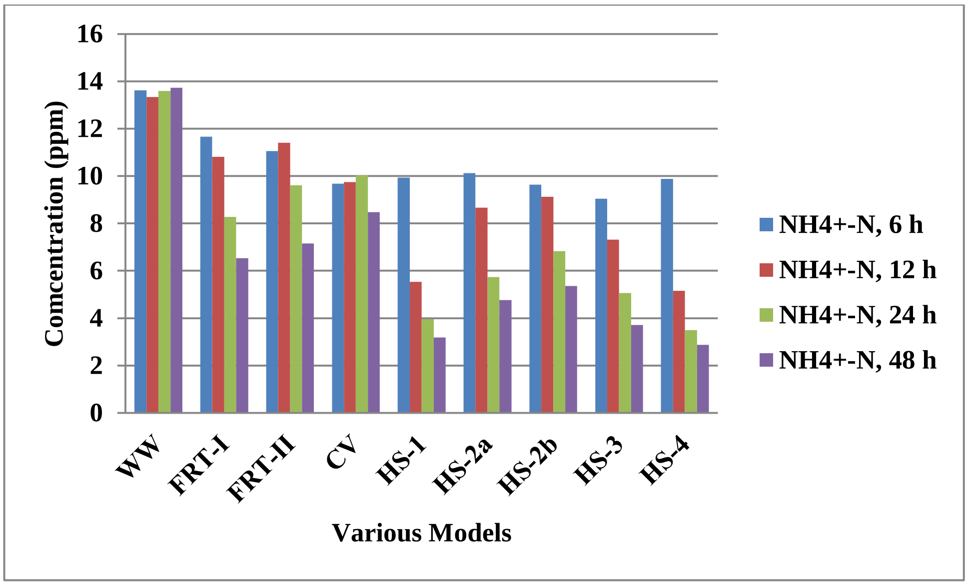

Fig. 4.18 NH_4^+-N reduction by various models at different HRTs

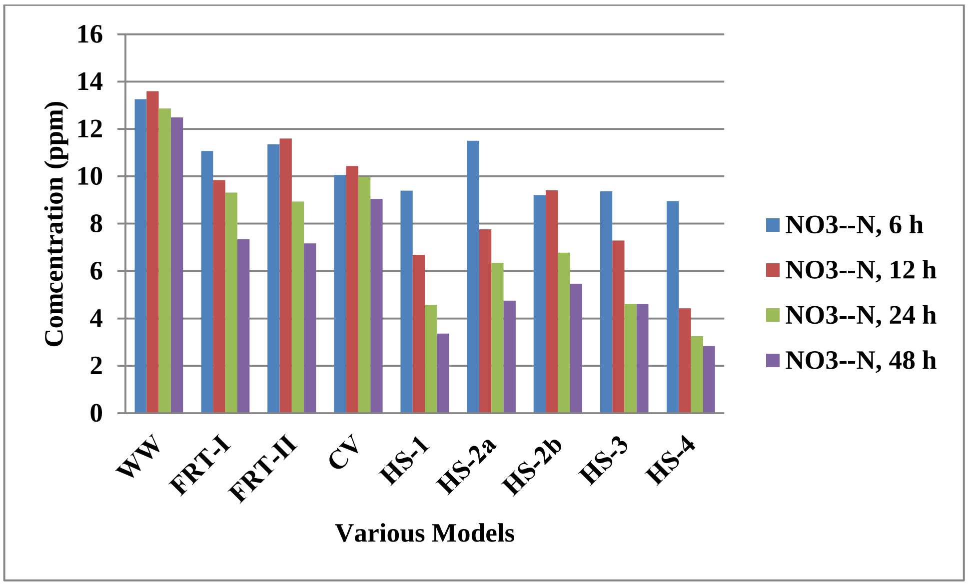

Fig. 4.19 NO_3^--N reduction by various models at different HRTs

NH_4^+-N = ammonical nitrogen, h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP), NO_3^--N = nitrate nitrogen

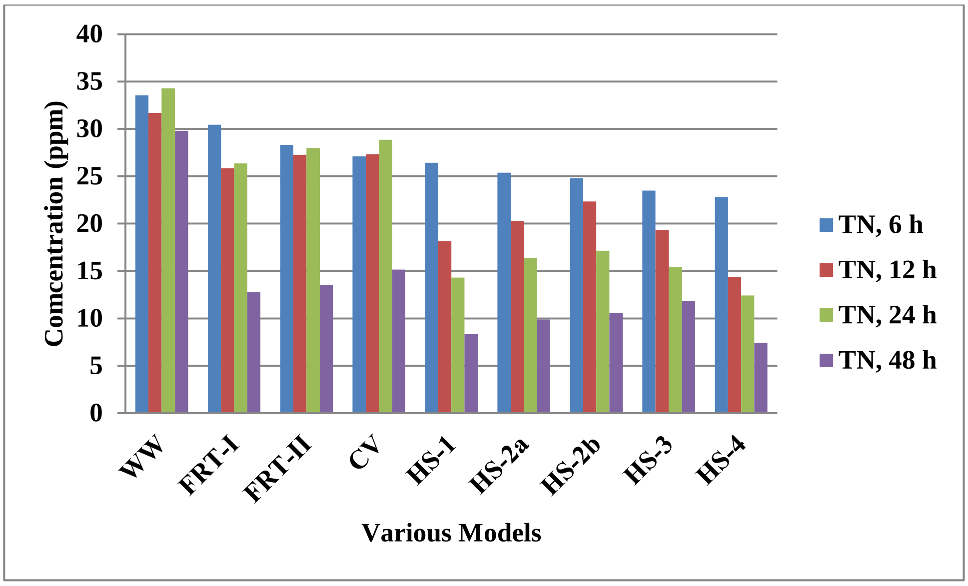

Fig. 4.20 TN reduction by various models at different HRTs

TN = total nitrogen, h = hour, HRT = hydraulic retention time, FRT-I = floating raft tank - I, FRT-II = floating raft tank - II, CW = constructed wetland, OP = oxidation pond, HS-1 = hybrid system - 1 (FRT-I + FRT-II), HS-2a = hybrid system - 2a (FRT-I + OP), HS-2b = hybrid system – 2b (FRT-II + OP), HS-3 = hybrid system - 3 (CW + FRT-II), HS-4 = hybrid system - 4 (CW + FRT-II + OP)

Rai *et al*. (2015) also used constructed wetland (horizontal subsurface type) for treatment of urban wastewater to conserve river Ganga at Haridwar, India. This horizontal sub surface type of constructed wetland was planted with *Phragmites australis*, *Typha latifolia* and *Colocasia esculenta* and removed lead (Pb) by 86 %, copper (Co) by 84.01 %, zinc (Zn) by 83.48 %, arsenic (As) by 82.23 %, chromium (Cr) by 81.63 %, cobalt (Co) by 76.86 %, nickel (Ni) by 68.14 % and manganese (Mn) by 62.22 % during summer, while in winter, the reduction for these pollutants were in order of Pb (78.59 %) > Cu (72.50 %) > Zn (68.40 %) > Co (65.12 %) > Cr (64.50 %) > As (63.18 %) > Mn (53.34 %) and Ni (51.39 %), respectively at 36 h of treatment time.

4.4 Plant growth performance

Physiological and biological growth of selected plant was also observed from time to time to assess the production of biomass and their harvesting was done at appropriate time for maximum removal of various pollutants from the domestic wastewater at minimum HRT time.

4.4.1 *Canna indica* L.

At the time of transplantation of Canna on the floating raft, there was on an average 7 numbers (5-9) of roots and average length of root was 5 cm (3-7) while after 60-70 days of transplantation the average number of roots were reached to 180 (90-270) and average length of root was reached to 20 cm (15-25). At this stage the average plant height of Canna was 5 (4-6) feet and average developed rhizomes were 9 (7-11) as depicted in **Fig. 4.21**.

On the basis of overall water analysis it can be concluded that Canna having more pollutants removal efficiency as compared to Pistia, Water lily and American aloe species. Probably it was happened due to more root hair zone, developed microbial layer on the root surface, thicker leaves and high biomass production of Canna, however the long time seasonal detailed study needs for further support to this result.

4.4.2 *Pistia stratiotes* L.

The growth of Pistia plant was also upto the mark however it was also observed that Pistia was unable to coupup with extreme summer. In the extreme summer, most of the Pistia plants were died due to damaging in the gourd cells of the stomata.

4.4.3 *Nymphaea* sp.

The growth of Water lily was very fast and healthy once it was transplanted on the floating raft because the wastewater worked as nutrient medium. The nutrients such as nitrogen, phosphorus, potassium, sodium etc. present in the wastewater, lead to boost up the biological growth of plant. At the time of transplantation there was on an average 10 numbers (6-14) of roots and average length of root was 1.5 feet (1-3), while after 60-70 days of transplantation the average number of roots were reached to 32 (28-36) and average length of root was reached to 4.5 feet (3-6) as depicted in **Fig. 4.22**.

Fig 4.21 Biological performance of *Canna indica* L.

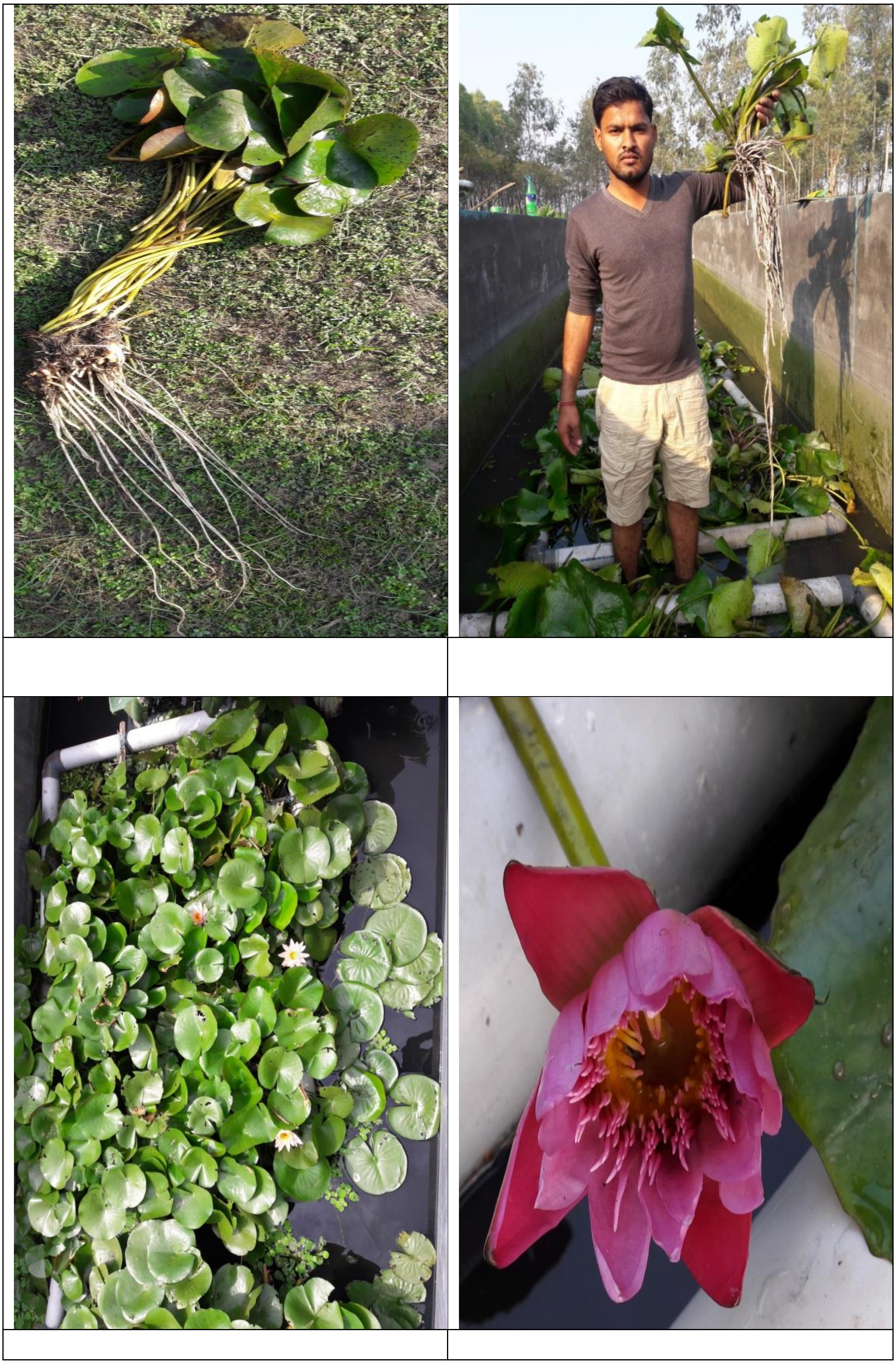

Fig 4.22 Biological performance of *Nymphaea* sp.

4.4.4 *Agave Americana*

The biological growth of American aloe was average and it was least efficient in the phytoremediation of wastewater as compared to Canna > Water lily and Pistia plant.

4.5 Experiment on heavy metals

To assess the heavy metals scavenging potential of Canna and Pistia, synthetic solutions of cadmium, chromium and lead were prepared in different concentrations such as 5, 10, 25 50 and 100 ppm, later these solutions were treated with Canna and Pistia for 30 days of retention time. In this experiment Canna was observed more efficient as compared to Pistia for removal of cadmium, chromium and lead as detailed below.

4.5.1 Cadmium (Cd)

Dry biomass production in case of control (without cadmium) for root, shoot and whole plant was 43.79, 262.41 and 306.20 mg/plant, respectively by Canna and 7.31, 43.78 and 51.10 mg/plant, respectively by Pistia as presented in **Table 4.8** and **Fig. 4.23**. The trend of biomass production (mg/plant) was decreased as the concentration of cadmium was increased from 5 to 100 ppm. The least production of biomass was observed in case of 100 ppm cadmium treatment (17.63, 99.86 and 117.49 mg/plant, respectively in root, shoot and whole plant of Canna; 2.18, 16.60 and 19.42 mg/plant, respectively in root, shoot and whole plant of Pistia) followed by 50 ppm cadmium treatment (21.44, 112.54 and 133.98 mg/plant, respectively in root, shoot and whole plant of Canna; 3.53, 18.68 and 22.21 mg/plant, respectively in root, shoot and whole plant of Pistia) and 25 ppm cadmium treatment (24.76, 129.97 and 154.73 mg/plant, respectively in root, shoot and whole plant of Canna; 4.18, 21.61 and 25.80 mg/plant, respectively in root, shoot and whole plant of Pistia).

Das *et al*. (2014) reported that there was 48.08 %, 60.36 %, 65.19 % and 70 % decline in root biomass of Pistia which was exposed to 5, 10, 15 and 20 ppm Cd concentration, respectively. Similarly, shoot biomass was declined by 30.12 %, 54.8 %, 56 % and 67.7 % respectively.

Table 4.8 Dry biomass production (mg/plant) by Canna and Pistia after 30 days in different concentration of Cd

Treatments (ppm)	Cd (Cadmium)					
	Canna			Pistia		
	Root	Shoot	WP	Root	Shoot	WP
5	32.85±4.40	140.02±9.68	172.87 ± 10.15	5.47±1.22	23.35±2.49	28.82±2.48
10	27.96±5.01	136.49±8.09	164.45 ± 9.97	4.68±0.57	22.69±2.44	27.38±3.05
25	24.76±3.84	129.97±8.70	154.73 ± 9.30	4.18±0.65	21.61±2.09	25.80±2.56
50	21.44±3.41	112.54±6.83	133.98 ± 8.83	3.53±1.71	18.68±1.10	22.21±0.63
100	17.63±3.27	99.86±8.92	117.49 ± 11.88	2.18±2.19	16.60±1.90	19.42±1.30
Control	43.79±7.75	262.41±12.46	306.20 ± 14.22	7.31±4.37	43.78±4.03	51.10±3.71
C.D.	6.85	15.67	18.68	N/A	4.51	4.72
C.V.	4.9	6.46	6.48	4.33	10.25	9.02

Cd = Cadmium, WP = whole plant, CD = critical difference, CV = coefficient of variation, N/A = not applicable

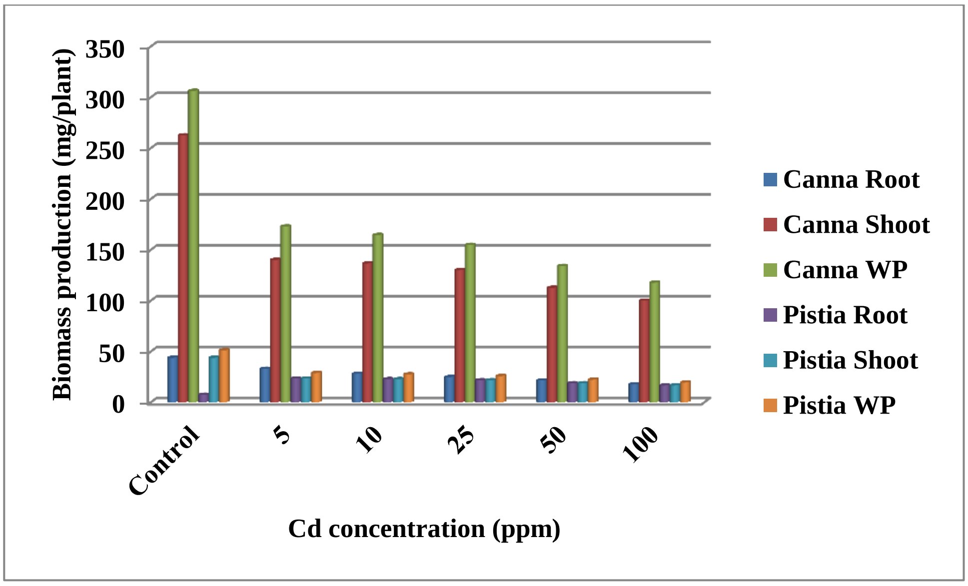

Fig. 4.23 Dry biomass production (mg/plant) by Canna and Pistia after 30 days in different concentration of Cd

Maximum uptake of cadmium by Canna's root (58.69 ppm) and shoot (10.13 ppm) was observed in case of 100 ppm Cd treatment followed by 50 ppm Cd treatment; similar trend was also observed in case of Pistia. Further in case of Canna maximum bioconcentration factor (0.169) was observed in 25 ppm Cd treatment, maximum root concentration factor (0.689) was observed in 50 ppm Cd treatment and maximum translocation factor (0.268) was observed in 25 ppm Cd treatment. While in case of Pistia, maximum BCF (0.098) and TF (0.221) were observed in 25 ppm Cd treatment, while maximum RCF (0.522) was observed in 10 ppm Cd treatment (see **Table 4.11, Fig. 4.26 and Fig. 4.27**).

This difference between root and shoot concentrations of various heavy metals indicates an important restriction of the internal transport of Cd and other metals from root towards stems and leaves, resulting in higher root concentrations rather than translocation of metals to leaves. The greatest amount of Cd accumulated by a wetland plant species was 36 g/kg, by *Eichorrnia crassipes* **(Muramoto and Oki 1983)**.

Cd concentration in the shoot and root of the Pistia was presented by **Das *et al*. (2014)** and the highest Cd concentration was observed in the root of Pistia (11.68 mg Cd g-1 dry weight) which was 2.43 times more than the concentration in shoot at 10 ppm dose of Cd. But in 15 ppm exposure dose, the root concentration of Cd was lower than that observed in 10 ppm while shoot accumulation was increased. Shoot Cd concentration was never more than that of the root concentration at any doses; similar trend was also observed in the present experiment for Cd, Cr and Pb concentration in the root and shoot concentration of the Canna and Pistia plant. At 20 ppm, translocation to shoot was reduced to 3.0 mg Cd g-1 but roots also showed lower accumulation. Cadmium extraction by total plants increased with increasing Cd dose up to 10 ppm but progressively declined at subsequent higher doses after 21 days of growth **(Das *et al*. 2014)**.

A large value of BCF implies a better phytoaccumulation and phytoextraction capability of plants **(Madera-Parra *et al*., 2013).** High BCF values for wetland plants were also reported by **Ye-Tao *et al*. (2009)** and **Soda *et al*. (2012)**.

Wang *et al*. (2002) conducted a pot experiment to test five wetland plant species, i.e., sharp dock, duckweed, water hyacinth, water dropwort and calamus for their possible use in remedying the polluted water. The results show that sharp dock was a good accumulator of N and P. Water hyacinth and duckweed strongly accumulated Cd with a concentration of 462 and 14200 mg/kg, respectively. Water dropwort achieved the highest concentration of Hg, whereas the calamus accumulated Pb (512 m/kg) substantially in its roots. **Ingole and Bhole (2003)** conducted hydroponic studies to investigate the uptake of As, Cr, Hg, Ni, Pb and Zn by water hyacinth from the aqueous solution at the concentrations ranging from 5 to 50 ppm, and observed that in aqueous solutions containing 5 ppm of As, Cr and Hg, the maximum uptake was 26, 108 and 327 mg/kg dry weight of water hyacinth, respectively.

4.5.2 Chromium (Cr)

The trend of biomass production by both Canna and Pistia in case of different doses of chromium was control > 100 ppm > 50 ppm > 25 ppm > 10 ppm > and 5 ppm, because with the increased concentration of chromium, plant showed phytotoxisity symptoms, therefore the production of biomass was inversely proportional to the concentration of chromium. The biomass production (mg/plant) by both Canna’s and Pistia’s root, shoot and whole plant was significantly more in case of control as compared to 100 ppm treatment. Rest data are presented in **Table 4.9** and depicted in **Fig. 4.24**.

Table 4.9 Dry biomass production (mg/plant) by Canna and Pistia after 30 days in different concentration of Cr

Treatments (ppm)	Cr (Chromium)					
	Canna			Pistia		
	Root	**Shoot**	**WP**	**Root**	**Shoot**	**WP**
5	27.58±6.89	116.55±22.73	144.13±13.12	4.62±1.09	19.60±0.94	24.23±1.88
10	23.43±2.56	113.58±12.03	137.01±14.57	3.94±0.38	19.09±1.73	23.03±2.11
25	20.96±3.20	107.90±4.37	128.86±7.55	3.52±0.50	18.15±0.55	21.67±1.03
50	17.43±7.30	94.12±14.02	111.56±11.77	2.94±1.29	15.80±1.94	18.74±1.54
100	14.68±9.78	82.77±2.91	97.45±10.79	2.45±2.08	13.93±0.54	16.38±1.53
Control	53.74±15.27	219.83±27.72	255.54±12.89	6.06±2.74	36.92±3.88	43.98±1.43
C.D.	6.48	25.20	21.54	1.23	3.55	2.85
C.V.	9.87	11.44	8.21	2.89	9.58	6.47

Cr = Chromium, WP = whole plant, CD = critical difference, CV = coefficient of variation

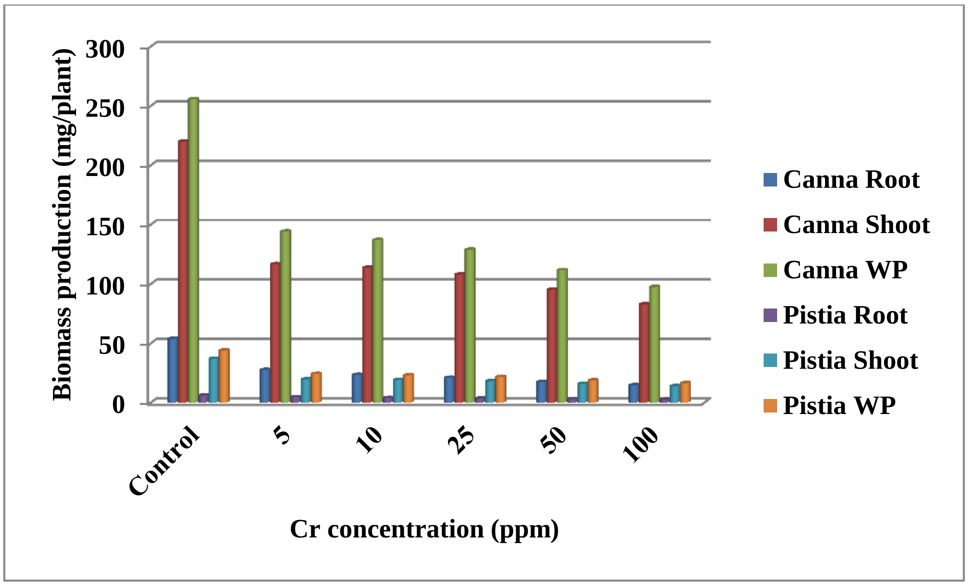

Fig. 4.24 Dry biomass production (mg/plant) by Canna and Pistia after 30 days in different concentration of Cr

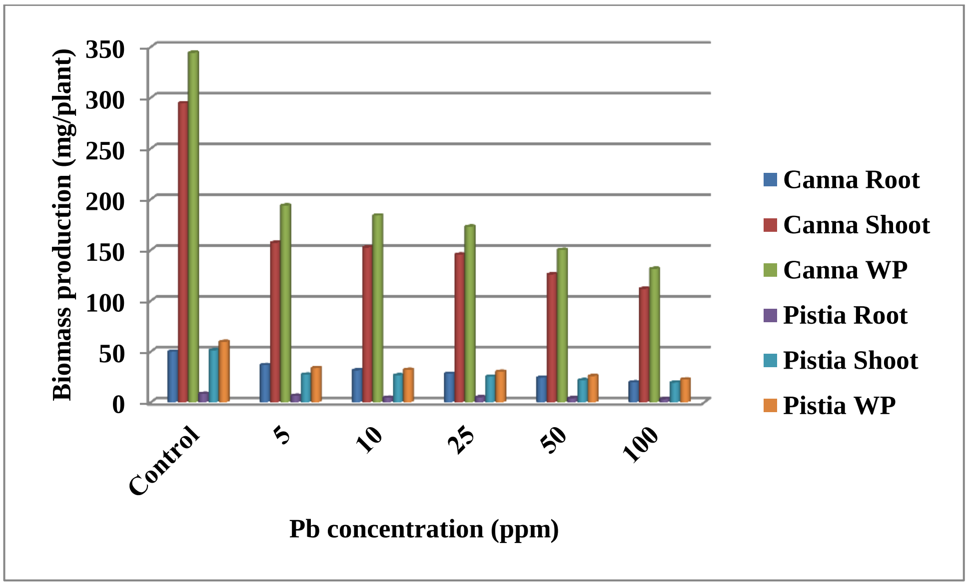

Fig. 4.25 Dry biomass production (mg/plant) by Canna and Pistia after 30 days in different concentration of Pb

Metal uptake by the plant involves transport of metals across the plasma membrane of root cells, loading in xylem tissues and translocation and subsequently detoxification and sequestration of metals at the whole plant and at cellular levels **(Lombi *et al*., 2002)**. Plants can extract Cr from the water through root system and transport it via the xylem into shoots and leaves where it accumulates **(Lombi *et al*., 2002)**.

Chromium uptake by root and shoot of both Canna and Pistia was linearly increased as the concentration of chromium was increased from 5 to 100 ppm. Both, in Canna and Pistia, the minimum uptake of Cr was observed in 5 ppm Cr treatment followed by 10 ppm Cr treatment (see **Table 4.12**). Likewise in Canna and Pistia the maximum uptake was observed in 100 ppm Cr treatment followed by 50 ppm Cr treatment and 25 ppm Cr treatment. In case of Canna the maximum BCF (0.104) and TF (0.243) were observed in 25 ppm Cr treatment, while maximum RCF (0.500) was observed in 10 ppm Cr treatment. Similarly in case of Pistia the maximum BCF (0.068) and TF (0.241) were observed in 25 ppm Cr treatment, while maximum RCF (0.328) was observed in 10 ppm Cr treatment (See **Fig. 4.26** and **Fig. 4.27**).

The potential of duck weed was investigated by **Zayed *et al*. (1998)** for the removal of Cd, Cr, Cu, Ni, Pb and Se from nutrient-added solution and the results indicate that duck weed was a good accumulator for Cd, Se and Cu, a moderate accumulator for Cr, but a poor accumulator of Ni and Pb. Heavy metal tolerance may depend on the plant species as seen by a wide range of BCFs that were reported. Even, the uptake and accumulation of pollutants vary from plant to plant and also from species to species within a genus **(Singh *et al*., 2003)**.

The metal concentration in water/sediments is the major factor influencing the metal uptake efficiency and thus BCF which depends upon concentrations in the environment, abiotic factors, exposure time, growth form of the plant, type of absorption mechanism, affinity of trace elements for the adsorption sites and sampling period **(Mazej and Germ, 2009)**. The BCF values for trace elements were higher in summer than winter which confirms high accumulation of trace elements in summer.

4.5.3 Lead (Pb)

The trend of biomass production by both Canna and Pistia in case of treatment with different concentration of lead (Pb, ppm) was similar to the trend which was observed in case of cadmium (Cd, ppm) and chromium (Cr, ppm). Significant difference was observed in 5 ppm treatment and 100 ppm treatment in case of Canna while there was no significant difference in case of Pistia as presented in **Table 4.10** and depicted in **Fig. 4.25**. The maximum dry biomass production was observed in case of control (without Pb) for root, shoot and whole plant was 49.75, 294.42 and 344.18 mg/plant, respectively by Canna and 8.37, 51.10 and 59.48 mg/plant, respectively by Pistia as presented in **Table 4.10** and depicted in **Fig. 4.25**. The trend of biomass production (mg/plant) was decreased with the increasing concentration of cadmium from 5 to 100 ppm. The least production of biomass was observed in case of 100 ppm chromium treatment (19.67, 111.72 and 131.39 mg/plant, respectively in root, shoot and whole plant of Canna while 8.37, 51.1, 59.48 mg/plant, respectively were found in root, shoot and whole plant of Pistia).

The present study showed that, as compared to control, there was a significant decline in root and shoot biomass of both Canna and Pistia, with maximum decline in biomass production at 100 ppm doses of Cd, Cr and Pb. The decrease in biomass might be due to disturbed carbohydrate and nitrogen metabolisms and reduction in protein synthesis or low photosynthetic reactions as observed under metal stress conditions **(Barcelo *et al*., 1993)**.

Lead (Pb) uptake by root of Canna were 3.11, 7.53, 15.93, 31.96 and 67.77 ppm; by shoot of Canna were 0.82, 2.08, 6.61, 11.22 and 15.74 ppm, respectively in the treatments of 5, 10, 25, 50 and 100 ppm Pb, respectively. While uptake by root of Pistia were 2.69, 7.09, 15.32, 35.12 and 60.28 ppm; by shoot of Pistia were 0.54, 1.35, 4.31, 7.38 and 10.34 ppm, respectively in the treatments of 5, 10, 25, 50 and 100 ppm Pb, respectively as presented in **Table 4.13**. In case of Canna the maximum BCF (0.264) and TF (0.415) were observed in 25 ppm Pb treatment, while maximum RCF (0.753) was observed in 10 ppm Pb treatment. Similarly in case of Pistia the maximum BCF (0.172) and TF (0.281) were observed in 25 ppm Pb treatment, while maximum RCF (0.709) was observed in 10 ppm Pb treatment **(Fig. 4.26** and **Fig. 4.27**).

Table 4.10 Dry biomass production (mg/plant) by Canna and Pistia after 30 days in different concentration of Pb

Treatments (ppm)	Pb (Lead)					
	Canna			Pistia		
	Root	Shoot	WP	Root	Shoot	WP
5	36.64±5.97	157.04±11.17	193.68±9.27	6.43±1.98	27.23±4.70	33.65±6.32
10	31.46±1.72	152.44±6.33	183.90±8.04	5.47±1.12	26.50±5.11	31.98±6.23
25	28.07±2.35	145.45±10.55	172.89±10.64	4.90±1.19	25.17±3.97	30.08±5.07
50	24.14±12.23	125.93±8.21	150.08±13.29	4.02±1.84	21.73±2.85	25.76±1.62
100	19.67±16.04	111.72±10.27	131.39±16.03	3.14±2.35	19.34±3.26	22.48±1.07
Control	49.75±9.48	294.42±8.09	344.18±19.20	8.37±4.10	51.10±9.12	59.48±8.20
C.D.	14.7916.80	16.65	23.97	8.74	9.46	9.72
C.V.	8.98	5.63	6.79	12.86	18.44	15.94

Pb = Lead, WP = whole plant, CD = critical difference, CV = coefficient of variation

Table 4.11 Cadmium uptake (ppm) by root and shoot of Canna and Pistia after 30 days in different concentration of Cd with their BCF, RCF and TF

Treatments (ppm)	Canna					Pistia				
	Root	Shoot	BCF	RCF	TF	Root	Shoot	BCF	RCF	TF
5	3.31	0.53	0.106	0.662	0.160	2.29	0.31	0.062	0.458	0.135
10	6.70	1.33	0.133	0.670	0.199	5.22	0.77	0.077	0.522	0.148
25	15.79	4.23	0.169	0.632	0.268	11.08	2.45	0.098	0.443	0.221
50	34.46	7.23	0.145	0.689	0.210	22.12	4.20	0.084	0.442	0.190
100	58.69	10.13	0.101	0.587	0.173	34.40	5.89	0.059	0.344	0.171

BCF = Bioconcentration factor, **RCF** = Root concentration factor, **TF** = Translocation factor

Table 4.12 Chromium uptake (ppm) by root and shoot of Canna and Pistia after 30 days in different concentration of Cr with their BCF, RCF and TF

Treatments (ppm)	Canna					Pistia				
	Root	**Shoot**	**BCF**	**RCF**	**TF**	**Root**	**Shoot**	**BCF**	**RCF**	**TF**
5	2.41	0.32	0.064	0.482	0.133	1.57	0.21	0.042	0.314	0.134
10	5.00	0.82	0.082	0.500	0.164	3.28	0.54	0.054	0.328	0.165
25	10.76	2.61	0.104	0.430	0.243	7.05	1.70	0.068	0.282	0.241
50	22.97	4.43	0.089	0.459	0.193	14.96	2.88	0.058	0.299	0.193
100	35.61	6.22	0.062	0.356	0.175	23.20	4.04	0.040	0.232	0.174

BCF = Bioconcentration factor, **RCF** = Root concentration factor, **TF** = Translocation factor

Table 4.13 Lead uptake (ppm) by root and shoot of Canna and Pistia after 30 days in different concentration of Pb with their BCF, RCF and TF

.

Treatments (ppm)	Canna					Pistia				
	Root	**Shoot**	**BCF**	**RCF**	**TF**	**Root**	**Shoot**	**BCF**	**RCF**	**TF**
5	3.11	0.82	0.164	0.622	0.264	2.69	0.54	0.108	0.538	0.201
10	7.53	2.08	0.208	0.753	0.276	7.09	1.35	0.135	0.709	0.190
25	15.93	6.61	0.264	0.637	0.415	15.32	4.31	0.172	0.613	0.281
50	31.96	11.22	0.224	0.639	0.351	35.12	7.38	0.148	0.702	0.210
100	67.77	15.74	0.157	0.678	0.232	60.28	10.34	0.103	0.603	0.172

BCF = Bioconcentration factor, **RCF** = Root concentration factor, **TF** = Translocation factor

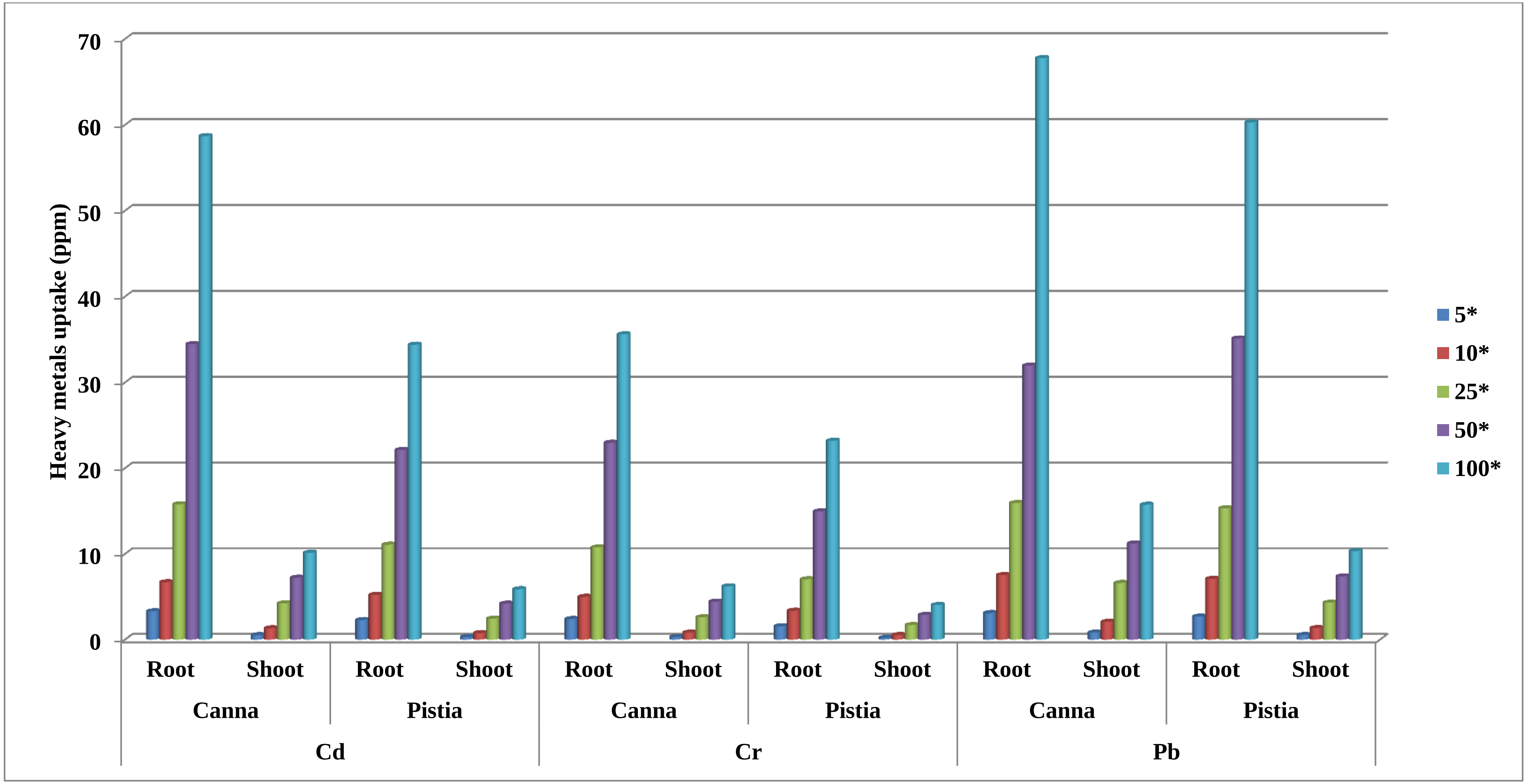

Fig. 4.26 Cadmium, chromium and lead concentration (ppm) in root and shoot of Canna and Pistia after 30 days in different concentration of Cd, Cr and Pb (* = Cd, Cr and Pb concentration in artificial solution, ppm)

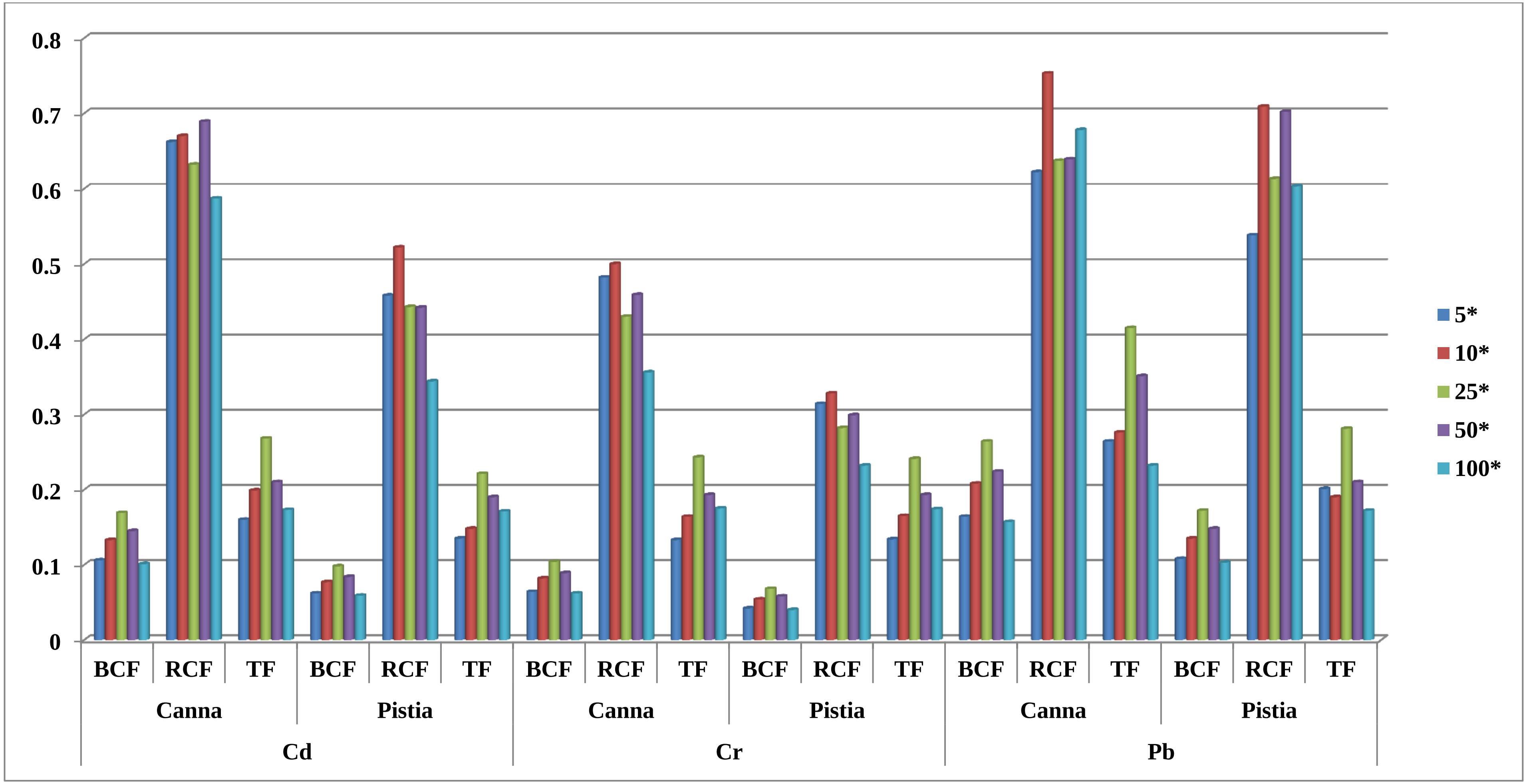

Fig. 4.27 BCF, RCF and TF of Canna and Pistia after 30 days treatment in different concentration of Cd, Cr and Pb (* = Cd, Cr and Pb concentration in artificial solution, ppm)

BCF values over 1,000 are generally considered as proof of significant phytoremediation potential plant **(Zayed *et al*., 1998)**. For an ideal hyperaccumulator plant, the translocation factor (TF) value should be higher than 1 **(Garbisu and Alkorta, 2001)**. However, in the present study, the maximum TF for Cd was 0.268 and 0.221, respectively for Canna and Pistia; 0.243 and 0.241, respectively for Cr; 0.415 and 0.281, respectively for Pb.

Rai *et al*. (2015) also used constructed wetland (horizontal subsurface type) for removal of Pb from urban wastewater to conserve river Ganga at Haridwar, India. This horizontal sub surface type of constructed wetland was planted with *Phragmites australis*, *Typha latifolia* and *Colocasia esculenta*. The BCF and TF of *Phragmites australis* (85.42 and 0.60), *Typha latifolia* (145.15 and 0.68) and *Colocasia esculenta* (74.95 and 0.616) for Pb were observed in winter and BCF and TF of *Phragmites australis* (5.15.61 and 1.25); *Typha latifolia* (948.66 and 0.82) and *Colocasia esculenta* (749 and 1.16) for Pb were observed in summer season.

Heavy metals are some of the most common constituents of wastewater. According to the World Health Organization, four of the ten most dangerous chemicals to humans are heavy metals; namely, arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg) **(WHO, 2011)**.

4.6 Field visits and technology demonstrations

Various scientific officials, professors, industrial personals and students from different institutions were visited to this experimental field for technology and knowledge demonstrations. Developed technologies and their benefits should always reach to the society and for that purpose; maximum possible field demonstrations were done (**Fig. 4.28**).

Field visit by Dr. Basant Maheshwary (Prof. at Western Sydney University, Australia), Dr. B. S. Kotlia (Prof. at Kumaun University, Nainital-Uttarakhand), Dr. H.J. Shiva Prasad, Dr. Jyothi Prasad, Dr. Deepak Kumar (Prof. at College to Technology, Pantnagar)

Field visit by Professors and Scientists from Dept. of Env. Sci. GBPUA&T and IIT Delhi

Fig 4.28 Field visits and technology demonstrations

Summary and Conclusion

Present study envisaged about the phytoremediation of domestic wastewater using floating raft based ecofriendly hybrid model at GBPUA&T, Pantnagar campus premises. Domestic wastewater used in this experiment was slightly alkaline in nature with average pH value of 7.3 and with the EC value of 624.1 µS/cm. The average concentration of TS, TSS and TDS were found to be 767.62, 527.12 and 244.5 ppm, respectively; while the value of BOD and COD of wastewater were 64.75 and 277.25 ppm, respectively. Major nutrients i.e., nitrate nitrogen, ammonical nitrogen; total nitrogen, phosphate and potassium were 11.44, 12.73, 25.73, 11.03 and 11.5 ppm, respectively. While sodium was 25.67 ppm.

Among different parameters TSS, BOD, COD, phosphate and nitrate nitrogen were found beyond their discharge permissible limits as per the EPA Rules 1986.

Both Canna and Pistia were examined first at lab level experiment to standardize the system for phytoremediation of domestic wastewater in floating rafts and constructed wetland as well as validated the system at laboratory scale before field level study. Where both plants were showed good efficiency to remove various pollutants from the wastewater, moreover in the present experiment Canna plant was more superior as compared to Pistia.

Among various hybrid models developed for wastewater treatment the hybrid system-1 (HS-1) which was combined with two floating raft tanks such as floating raft tank-I planted with Canna and floating raft tank-II planted with Water lily was found the most efficient, ecofriendly and cost effective in nature for maximum reduction of various pollutants from the wastewater as compared to other models. After 48 h HRTs the remaining concentration of pollutants such as pH, EC, K, Na, TS, TDS, TSS, BOD, COD, PO_4^{-1}, NH_4^+-N, NO_3^--N and TN were reduced to 7.1, 490, 3, 6, 262, 180, 82, 14, 80, 2.1, 3.18, 3.36 and 8.35 ppm, respectively with their percentage reduction by 5.33, 20.98, 71.43, 77.25, 66.00, 65.19, 67.65, 78.71, 71.56, 79.06, 76.84, 73.08 and 71.79 %, respectively through the HS-1. After this treatment those parameters were beyond their discharge permissible limits were reduced within their permissible limits.

The trend of biomass production by Canna and Pistia was inversely proportional as the concentration of cadmium, chromium and lead was increased from 5 to 150 ppm. When the concentration of these heavy metals was beyond the 100 ppm both the plants died due to phytotoxicity of the heavy metals. Maximum concentration of Cd, Cr and Pb such as 58.69, 35.61 and 67.77 ppm, respectively were found in root of Canna and 10.13, 6.22 and 15.74, respectively in shoot of Canna which were higher as compared to these metals concentration in the root and shoot of Pistia.

Mostly the maximum bioconcentration factor, root concentration factor and translocation for both Canna and Pistia were found in cases of 25 ppm solutions of Cd, Cr and Pd, because beyond 25 ppm concentration the guard cells of stomata were damaged while uptake of these metals.

On the basis of overall water analysis it can be concluded that Canna having more pollutants removal efficiency as compared to Water lily >, Pistia and American aloe species probably due to more root hair zone, thicker leaves and high biomass production of Canna, however the long time seasonal detailed study needs for further support to the result.

Using planted floating raft to purify polluted water is a process of ecological restoration at in-situ. Its core is utilizing aquatic plants and root’s microbes to absorb nutrients/pollutants such as nitrogen, phosphorus, Potassium, organic matter, inorganic, heavy metals and other substances present in wastewater by natural basis. Therefore floating rafts could be applied as a water pollution control method in urban as well as peri urban areas.

Depending on the structure and materials used, floating raft wetlands are particularly suitable for pollutant removal, where the number (and % coverage) of floating rafts can be easily increased in order to improve treatment performance if necessary, since it is very easy to install and cast effective as well. Floating wetlands may be perceived to enhance the aesthetic values of a wastewater treatment pond, depending on the shape, structure and vegetation used. There may also be some additional benefits in terms of provision of habitat for aquatic life.

Further it is envisaged that pollutant removal mechanisms by designed floating rafts will constitute a wastewater treatment system that could be a low cost and ecofriendly/ sustainable method for removal of pollutants and reclamation of wastewater and its further reuse after proper optimization, validation and standardization of this pilot level field study. Floating rafts have been used as a low-cost treatment to remove a wide range of contaminants from polluted waters such as municipal wastewater, effluents from industries, oil refineries waste and agricultural runoff and so on.

These days' technology involved in wastewater treatment uses innovative, efficient, and advanced methods. However, these need to be economically viable, especially in the rural part of India in order to support wastewater treatment and its reuses.

Some predominant benefits associated with FRWTS as follows:

- The developed floating raft model would be allow a complimentary effort for the *Namami Gange*, *Clean India* campaigns launched by Govt. of India, NGOs, Industries, Municipal bodies and researcher for sustainable water resource management.
- Moreover, this technique can be utilized profitably for wastewater treatment prior to discharge by competent authorities of big and small cities as well as cities towns located on banks of holy river Ganga, Yamuna and others in country.
- The outcome of domestic wastewater treatment and its polishing leading to flowers and biomass production that will generate money and can be further utilized as revolving fund to sustain the operation and maintenance of the floating raft model.
- Furthermore, from techno-commercial point of view, this study under hydroponic condition would be phenomenal for adopting and accelerating concerted effort of various concerned organizations at National and International level.
- The present study also recommend further research using different plant species to exploit the pollutant removal efficiency in domestic wastewater as

well as industrial wastewater treatment systems for sustainability in wastewater treatment as well as fresh water security in the country.

Limitation of present study

The only limitation of the present study was harvesting of the plants at various time and further utilization of harvested biomass which may be the potential area for research in the upcoming future. Biological stability of floating raft bed is the prime requirement for successful wastewater treatment. Maintenance of the floating raft bed tank and gravel constructed wetland should include harvesting of plants at various intervals of time and removal of detritus accumulation on the bottom of the floating raft tank.

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ABSTRACT

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Present study envisaged about the phytoremediation of domestic wastewater using floating raft based ecofriendly hybrid model at GBPUA&T, Pantnagar campus premises. Domestic wastewater used in this experiment was slightly alkaline in nature with average pH value of 7.3 with the EC of 624.1 µS/cm. The average concentration of TS, TSS and TDS were found to be 767.62, 527.12 and 244.5 ppm, respectively. BOD and COD of wastewater were 64.75 and 277.25 ppm, respectively. Major nutrients i.e., nitrate nitrogen, ammonical nitrogen, total nitrogen, phosphate and potassium were 11.44, 12.73, 25.73, 11.03 and 11.5 ppm, respectively. While sodium was 25.67 ppm. Among different parameters TSS, BOD, COD, phosphate and nitrate nitrogen were found beyond their discharge permissible limits as per the EPA Rules 1986.

Both Canna and Pistia were examined first at lab level experiment to standardize the system for phytoremediation of domestic wastewater in floating rafts and constructed wetland as well as validated the system at laboratory scale before field level study. Where both plants were showed good efficiency to remove various pollutants from the wastewater, moreover in the present experiment Canna plant was more superior as compared to Pistia.

Among various models developed for wastewater treatment the hybrid system-1 (HS-1) which was combined with two floating raft tanks such as floating raft tank-I planted with Canna and floating raft tank-II planted with Water lily was found the most efficient and ecofriendly in nature for maximum reduction of various pollutants from the wastewater. After 48 h HRTs the remaining concentration of pollutants such as pH, EC, K, Na, TS, TDS, TSS, BOD, COD, PO_4^{-1}, NH_4^+-N, NO_3^--N and TN were 7.1, 490, 3, 6, 262, 180, 82, 14, 80, 2.1, 3.18, 3.36 and 8.35 ppm, respectively with their percentage reduction by 5.33, 20.98, 71.43, 77.25, 66.00, 65.19, 67.65, 78.71, 71.56, 79.06, 76.84, 73.08 and 71.79 %, respectively. After this treatment those parameters were beyond their discharge permissible limits were reduced within the permissible limits.

The trend of biomass production by Canna and Pistia was inversely proportional as the concentration of cadmium, chromium and lead was increased from 5 to 150 ppm. When the concentration of these heavy metals was beyond the 100 ppm both the plants died due to phytotoxicity. Maximum concentration of Cd, Cr and Pb such as 58.69, 35.61 and 67.77 ppm, respectively were found in root of Canna and 10.13, 6.22 and 15.74, respectively in shoot of Canna which were higher as compared to these metals concentration in the root and shoot of Pistia.

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सहायक विषय	:	कृषि मौसम विज्ञान			
शोध शीर्षक	:	अपशिष्ट जल के उपचार के लिए पारिस्थितिकीय हाइब्रिड मॉडल का विकास			
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वर्तमान अध्ययन पंतनगर परिसर में फ्लोटिंग राफ्ट आधारित पारिस्थितिकीय हाइब्रिड मॉडल का उपयोग करके घरेलू अपशिष्ट जल के फाइटोरिमीडिएशन के बारे में किया गया। इस प्रयोग में इस्तेमाल किया गया घरेलू अपशिष्ट जल प्रकृति में थोड़ा क्षारीय था जिसमें 624.1 μS/cm की ईसी के साथ 7.3 का औसत पीएच मान था। टीएस, टीएसएस और टीडीएस की औसत सांद्रता क्रमशः 767.62, 527.12 और 244.5 पीपीएम थी। अपशिष्ट जल का बीओडी और सीओडी क्रमशः 64.75 और 277.25 पीपीएम था। प्रमुख पोषक तत्व अर्थात नाइट्रेट नाइट्रोजन, अमोनिकल नाइट्रोजन, कुल नाइट्रोजन, फॉस्फेट और पोटेशियम क्रमशः 11.44, 12.73, 25.73, 11.03 और 11.5 पीपीएम थे। जबकि सोडियम 25.67 पीपीएम था। ईपीए नियम 1986 के अनुसार विभिन्न मापदंडों में टीएसएस, बीओडी, सीओडी, फॉस्फेट और नाइट्रेट नाइट्रोजन उनके निर्वहन अनुमत सीमा से परे पाए गए थे।

केना और पिस्टिया की पहले प्रयोगशाला स्तर में जांच की गई थी ताकि वे फ्लोटिंग राफ्ट्स में घरेलू अपशिष्ट जल के फाइटोरिमीडिएशन के लिए सिस्टम को मानकीकृत कर सकें। आर्द्रभूमि के साथ-साथ फील्ड स्तर के अध्ययन से पहले प्रयोगशाला पैमाने पर सिस्टम को प्रमाणित किया गया। जहां दोनों पौधों ने अपशिष्ट जल से विभिन्न प्रदूषकों को हटाने के लिए अच्छी दक्षता दिखाई गई थी व केना, पिस्टिया की तुलना में अधिक बेहतर था।

अपशिष्ट जल उपचार के लिए विकसित विभिन्न मॉडलों में से हाइब्रिड सिस्टम-1 (एचएस -1) जिसे दो फ्लोटिंग राफ्ट टैंकों के साथ जोड़ा गया था (जैसे फ्लोटिंग राफ्ट टैंक-1 में केना के साथ लगाया गया था और फ्लोटिंग राफ्ट टैंक-2 को वाटर लिली के साथ लगाया गया था), ने सबसे कुशल और पारिस्थितिक रूप से अपशिष्ट जल से विभिन्न प्रदूषकों कों अधिकतम कम किया। 48 घंटे एचआरटी के बाद पीएच, ईसी, पोटैशियम, सोडियम, टीएस, टीडीएस, टीएसएस, बीओडी, सीओडी, फॉस्फेट, अमोनीकल नाइट्रोजन, नाइट्रेट नाइट्रोजन और कुल नाइट्रोजन प्रदूषकों की शेष सांद्रता 7.1, 490 (μS/cm), 3, 6, 262, 180, 82, 14, 80, 2.1, 3.18, 3.36 और 8.35 पीपीएम क्रमशः 5.33, 20.98, 71.43, 77.25, 66.00, 65.1 9, 67.65, 78.71, 71.56, 79.06, 76.84, 73.08 और क्रमशः 71.79 द्वारा उनके प्रतिशत में कमी देखी गई। इस उपचार के बाद निर्वहन सीमा से परे पैरामीटरों कों अनुमत सीमाओं के भीतर पाया गया।

केना और पिस्टिया द्वारा बायोमास उत्पादन की प्रवृत्ति विपरीत आनुपातिक थी क्योंकि कैडमियम, क्रोमियम और लीड की सांद्रता 5 से 150 पीपीएम तक बढ़ी थी। जब इन भारी धातुओं की सांद्रता 100 पीपीएम से अधिक थी तो दोनों पौधे फाइटोटोक्सिसिटी के कारण मर गए थे। क्रमशः 58.69, 35.61 और 67.77 पीपीएम Cd, Cr और Pb की अधिकतम सांद्रता क्रमशः केना की जड़ो में और 10.13, 6.22 और 15.74 केना के तनो पाई गई थी जो कि इन धातुओं की पिस्टिया की जड़ो और तनो में सांद्रता की तुलना में अधिक थी।

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Bulletin of Environmental Contamination and Toxicology
https://doi.org/10.1007/s00128-018-2416-3

Assessment of Cadmium Scavenging Potential of *Canna indica* L.

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Received: 12 May 2018 / Accepted: 9 August 2018

Abstract

The aquatic plant, *Canna indica* L. (Indian shoot) of Cannaceae family was investigated to assess cadmium scavenging potential at 5, 10, 25, 50, 100 and 150 mg Cd L^{-1} exposers. The results showed that *Canna* has considerable potential of cadmium accumulation, which was up to 58.69 and 10.13 mg Cd kg^{-1} dry weight in root and shoot of *Canna*, respectively. The effects of different cadmium levels on biomass production of plant tissues were significantly ($p=0.05$) showed negative relation due to cadmium toxicity. The root concentration factor was higher than the bioconcentration factor which indicated the lower translocation factor of *Canna*. Considering the high root concentration factor, average bioconcentration factor, rapid growth and optimum adaptive properties up to 100 mg Cd L^{-1} level, the *Canna* could be employed as an eco-friendly and efficient aquatic plant for cadmium scavenging. This study plays a potential role in remediation of cadmium contaminated wastewater.

Keywords Cadmium · *Canna indica* L. · Phytoremediation · Phytotoxicity · Root concentration factor (RCF)

Intake of heavy metals via food-chain contamination to micro and macro fauna followed by the human being has now been widely investigated across the world (Muchuweti et al. 2006; Sekabira et al. 2011). Discharge of untreated industrial effluents into vicinity water bodies, lead to the addition of various heavy metals, viz. Cu, Cr, As, Hg, Cd, Pb etc. into water bodies and further bio-magnify into the micro and macro faunas (Purushothaman and Chakrapani 2007; Rai et al. 2012; Dotaniya et al. 2016; Xiaoqiang et al. 2016). Among the heavy metals, cadmium (Cd) is extensively discharged from mining, phosphate fertilizers, batteries, metal coating, and pesticides industries (Kamran et al. 2014; Arslan et al. 2017; Mishra and Maiti 2017). Among different heavy metals drained into the environment, Cd is stated highly toxic for human beings due to its high biomagnification property (He et al. 2005) and is placed seventh in the ASTDR hazardous substances list with total points of 1320 (ASTDR 2017). The level of Cd pollution in developing countries like India has gained much concern where the cost of treatment is quite steep to afford. Cadmium is one of the major toxic trace elements in the periodic table. The accumulation of Cd is more addressed in leafy vegetables than cereal crops. Moreover the long term exposer with Cd reduces the soil fertility and crop productivity as well, even in the Japan, itai-itai disease was observed due to feeding of Cd contaminated rice.

However, different aquatic macrophytes are proven good for metals uptake, their degradation and rhizofiltration (Solanki et al. 2017a), furthermore, the rhizospheric secretion of different low molecular organic acids lead to an increase in the rhizofiltration of heavy metals (Headley et al. 2005; Tangahu et al. 2011). Since heavy metals are persistent in nature and cannot be removed through degradation by naturally occurring biological phenomenon; using macrophytes as metals scavengers to remove and detoxification of metals have been investigated and accepted globally (Li et al. 2013; Varun et al. 2017). In addition to this, macrophyte based phytoremediation technology is cost-effective, eco-friendly and more efficient (Pilon-Smits and Freeman 2006; Srivastava et al. 2015).

The plant used for phytoremediation, should have high rhizospheric zone, rapid growth, high bio-concentration and translocation factors (BCF and TF) as well as high tolerance and removal efficiency for the pollutant to be removed (Rai et al. 2015; Solanki et al. 2017b). Beside these, the harvestable part should be economically viable for metals recovery, bio-energy production etc. (Chaney et al. 1995). The *Pistia stratiots* L. (Li et al. 2013; Das et al. 2014; Rodrigues

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Published online: 16 August 2018

et al. 2017), duckweed (Wang et al. 2002), *Eichhornia crassipes* (Swainet al. 2014; Li et al. 2015; Mishra and Maiti 2017) and many other macrophytes have been successfully employed for phytoremediation of Cd; however the Cd scavenging potential of *Canna indica* L. is much less studied. It is widely known for its high growth rate, prolifer root system and adaptation in the wide range of climatic conditions (Sun et al. 2009; Cui et al. 2010; Solanki et al. 2018). Therefore, the aim of this experiment was to assess Cd scavenging potential of *Canna indica* L. without application of any chelating agent.

Materials and Methods

The *Canna* (*Canna indica* L.) also called 'Indian shoot' (Talukdar et al. 2013), was chosen as Cd scavenger for the present study. The *Canna* is getting much concern as green phytoremediation tool due to its colossal root mass, long root hair biofilms and relatively more root concentration factor (RCF). The rhizomes of this plant were collected from National Botanical Research Institute (NBRI), Lucknow, India and initially shifted to the nursery at the experimental site for its growth. Mature plants with similar height and health were shifted into 5 L plastic pots and fed with tap water for a period of 10 days for acclimatization in hydroponic condition. Test for initial Cd content in plant roots and shoots was negative. A synthetic cadmium chloride ($CdCl_2$) stock solution of 1000 mg Cd L^{-1} was prepared and sequentially diluted to 5, 10, 25, 50, 75, 100 and 150 mg Cd L^{-1} using 4 L Hoagland and Arnold solution (Hoagland and Arnold 1950), while in control only Hoagland and Arnold solution (4 L) was taken. Only once the 4 L Hoagland and Arnold solution was added in each treatment in the entire experimental period. The nutritive composition of Hoagland and Arnold solution is depicted in Table 1. There were triplicates for each treatment and each replicate had one *Canna* plant. All chemicals including $CdCl_2$ (produced by Merck, Germany) used in the present experiment were of analytical grade. Throughout the experiment, standard methods given in APHA (2012) were followed. This experiment was conducted in the greenhouse (controlled environment), Department of Environmental Science, GBPUA&T, Pantnagar, India for 30 days in the month of November 2017. All necessary data were collected and the evapotranspiration loss was compensated using double distilled water.

Table 1 Composition of Hoagland and Arnold solution (Hoagland and Arnold 1950)

Components	Concentration
KNO_3	1.02 g L^{-1}
$Ca(NO_3)_2$	0.49 g L^{-1}
$NH_4H_2PO_4$	0.23 g L^{-1}
$MgSO_4·7H_2O$	0.49 g L^{-1}
$MnCl_2·4H_2O$	1.81 mg L^{-1}
H_3BO_3	2.86 mg L^{-1}
$CuSO_4·5H_2O$	0.08 mg L^{-1}
$ZnSO_4·7H_2O$	0.22 mg L^{-1}
$H_2MoO_4·H_2O$	0.09 mg L^{-1}
$FeSO_4·7H_2O$	0.60 mg L^{-1}

Preparation of plant samples Harvested samples were rinsed thoroughly using distilled water followed by the separation of the root and shoot portion. Thereafter, the separated root and shoot samples were oven dried at 80°C until a constant weight was achieved. Harvested and dried plant samples (100 mg each) were digested using 5 ml of concentrated HNO_3 at 100°C. Throughout the digestion, the volume of samples was maintained approximately 15 ml using 0.6% HNO_3 (Rai et al. 2015); the digested samples were allowed to cool at room temperature and later the volume of sample was make up to 15 mL and filtered using Whatman No. 42 (2.5 µm pore size) filter paper. Well filtered samples were fed into the atomic absorption spectroscopy (model SENS AA, sr. no. A7040, provided by GBC Scientific Equipment Pvt. Ltd.), equipped with air-acetylene flame (D'Souza et al. 2010; Varun et al. 2015) for Cd uptake analysis.

Bio-concentration factor (BCF) BCF in this experiment was calculated using the formula given by Soda et al. (2012), which shows the metal uptake potential of the shoot.

$$BCF = \frac{Cshoot}{Csw}$$

where C_{shoot} is the Cd concentration in the shoot biomass (mg Cd kg^{-1} DW) and C_{sw} is the Cd concentration in artificial water (mg Cd L^{-1}, distilled water with known concentration of Cd used as treatment).

Root concentration factor (RCF) RCF was calculated according to the formula given by Fitz and Wenzel (2002) and Mendez and Maier (2008).

$$RCF = \frac{Croot}{Csw}$$

where C_{root} represent as the Cd concentration in the root biomass (mg Cd kg^{-1} DW).

Translocation factor (TF) TF in the present work was calculated based on the mathematical formula given by Rai et al. (2015), which represent the metal translocation (from root to shoot) efficiency of the plant.

$$TF = \frac{Cs}{Cr}$$

where C_s represent as Cd concentration in shoot biomass (mg Cd kg^{-1} DW) and C_r represent as Cd concentration in root biomass (mg Cd kg^{-1} DW).

Quality control and quality assurance (QC/QA) In this experiment, all reagents and chemicals used for plants and water digestion, analysis, were of AR grade. The standard reference method of Cd (E-Merck, Germany) was followed for calculation and quality assurance analysis. Accuracy in this work was achieved with repeated analysis (n = 3) of quality controlled samples, and the results of the repeated analysis were found within the certified values. The minimum detection limit in AAS for Cd was 1 mg L^{-1}. Quality assured was done by FMEA (failure mode effect analysis) while quality control was done by AAS and computer based software. The above QA/QC was followed based on APHA book entitled Standard methods for the examination of water and wastewater.

Statistical study Statistical analysis was done with the help of completely randomized design (CRD) with three replications. Statistical calculation of collected data was done through ANOVA (analysis of variance) test and the value of $p = 0.05$ was considered for statistical differences.

Results and Discussion

The results showed significant uptake of Cd by *Canna* at various doses; however, the *Canna* failed to grow at or beyond 150 mg Cd L^{-1}, which might be due to phytotoxicity. Data presented in Table 2 for plant biomass production against different levels of Cd doses. The analysed data showed reduction in plant biomass with the increasing level of Cd compared to control was 46.64%, 47.79%, 50.47%, 57.11% and 61.94% in 5, 10, 25, 50 and 100 mg Cd L^{-1}, respectively. Similar pattern was observed in root biomass by 24.98%, 36.14%, 43.45%, 51.03% and 59.73%, respectively. Inhibited biomass of pumpkin (Subin and Francis 2013) and durum wheat (Yourtchi and Bayat 2013) was recorded in Cd supplemented soil. Slow distribution of carbohydrate, nitrogen metabolism and reduced protein synthesis due to Cd toxicity can be attributed to declining biomass (Barcelo et al. 1993). Das et al. (2014) also reported significantly decline in root and shoot biomass of water lettuce at 20 mg Cd L^{-1} compared with control. Root tips of *Canna* were observed slightly yellow at 25 mg Cd L^{-1}, brown at 50 mg Cd L^{-1} and partially decomposed at 100 mg Cd L^{-1} after 30 days. Changes in root colour could attribute due to the negative effect of Cd on pigment accumulation as stated by previous pieces of literature (Sarvari et al. 1999; Kupper et al. 2007). Similar work was also done by Subhashini and Swamy (2014) for phytoremediation of contaminated soil with Cd and other toxic pollutants.

Cadmium accumulation/uptake (mg Cd kg^{-1} DW) by shoot and root biomass of *Canna* are depicted in Table 3. The maximum Cd concentration (58.69 mg kg^{-1}) was recorded in the root of *Canna* which was 5.79 times higher than the maximum Cd concentration (10.13 mg kg^{-1}) in the shoot at 100 mg Cd L^{-1} expose dose. Relatively lower Cd content in shoot shows resistance or saturation of Cd in aerial parts (Seregin and Ivanov 2001; Lombi et al. 2002; Xiaoqiang et al. 2016). In this experiment, Cd concentration in both shoot and root of *Canna* had linearly increased as the concentration of Cd increase; however, the harvested biomass of root and shoot after 30 days was decreased at high concentration of Cd. The Cd concentration in root was significantly ($p = 0.05$) higher than shoot concentration at all exposer doses of Cd, which is supported by previous results in case of *Eichhornia crassipes* (Elfeky et al. 2013; Romanova et al. 2016). Similar type of results were obtained in spinach (Dotaniya et al. 2017), wheat (Dotaniya et al. 2014a) and pigeon pea (Dotaniya et al. 2014b) crops under heavy metal contamination. The greatest Cd uptake of 36 g kg^{-1} was recorded in *Eichorrnia crassipes* (Muramoto and Oki 1983).

The highest BCF of 0.17 and TF of 0.23 were recorded in 25 mg Cd L^{-1} treatment; however, the highest RCF of 0.86 was observed in 10 mg Cd L^{-1} expose dose. Results on relatively low BCF than RCF makes *Canna* more suitable for Cd phytoremediation as well as for its safe disposal since the root biomass was only 14%–20% of the whole plant biomass at all doses. Varun et al. (2017) also reported lower bioabsorption coefficient (BAC) ranging from 0.04 to

Table 2 Dry matter (mg $plant^{-1}$) of *Canna*

Cd (mg L^{-1})	Root	Shoot	Whole plant
Control	43.79 ± 7.75	262.41 ± 12.46	306.20 ± 14.22
5	32.85 ± 4.40*	140.02 ± 9.68*	172.87 ± 10.15*
10	27.96 ± 5.01*	136.49 ± 8.09*	164.45 ± 9.97*
25	24.76 ± 3.84*	129.97 ± 8.70*	154.73 ± 9.30*
50	21.44 ± 3.41*	112.54 ± 6.83*	133.98 ± 8.83*
100	17.63 ± 3.27*	99.86 ± 8.92*	117.49 ± 11.88*

*Significantly different as compared to control at $p = 0.05$; values are mean ± SD, ($n = 3$)

Table 3 Cadmium concentration (mg Cd kg^{-1} DW) in root and shoot of *Canna* after 30 days

Cd (mg L^{-1})	Root	Shoot	BCF	RCF	TF
5	3.93 ± 1.05^{a}	0.53 ± 0.13^{a}	0.12	0.79	0.14
10	8.63 ± 2.25^{a}	1.38 ± 0.46^{a}	0.14	0.86	0.16
25	18.42 ± 3.55^{a}	4.22 ± 1.48^{a}	0.17	0.74	0.23
50	37.80 ± 7.11^{b}	7.28 ± 1.99^{a}	0.15	0.76	0.20
100	58.69 ± 10.08^{c}	10.13 ± 2.89^{b}	0.11	0.59	0.17

Values are mean ± SD of triplicates; values followed by the same letter in each column are not significant with each other at $p = 0.05$

DW dry weight

0.10 and higher RCF ranging from 0.33 to 0.79 in *Sesbania sesban* treated with different doses (25–300 mg Cd L^{-1}) of Cd. In this investigation, decreasing trend in BCF after 25 mg Cd L^{-1} was supported by findings of Das et al. (2014). The data on TF are depicted in Table 3 which conclude that the maximum Cd TF of *Canna* was 0.23 in the treatment of 25 mg Cd L^{-1} followed by 0.20 in 50 mg Cd L^{-1}, while the lowest TF (0.14) was in 5 mg Cd L^{-1}. TF is an indicator, which shows the metal translocation potential from root to shoot in the plant. Plants with > 1 BAC, RCF and TF are stated as potential phytoaccumulator plants (Fitz and Wenzel 2002; Mendez and Maier 2008; Sekabira et al. 2011), however, the Canna had all values < 1 (Table 3).

Growth and biomass production of *Canna* was declined up to 100 mg Cd L^{-1} and failed to grow at 150 mg Cd L^{-1} due to phytotoxicity. However, the uptake and accumulation of Cd in plant tissues were significant ($p = 0.05$) up to 100 mg Cd L^{-1}. The higher Cd concentration was observed in the root of *Canna* than shoot at all exposer doses of Cd which shows that the Cd R/S ratio > 1. Relatively low BCF rather than RCF makes *Canna* more suitable candidate for Cd phytoremediation, beside this the relatively low proportion of root biomass encouraging volume reduction to be disposed of. Considering the above findings along with its high adaptability in the wide range of climatic conditions, we can conclude that the *Canna* could be a promising plant for Cd scavenging in Cd contaminated water/soil.

In the present experiment authors observed that the *Canna* plays a crucial role in phytoremediation of cadmium contaminated water upto 100 mg Cd L^{-1}, beyond this concentration the plant died due to high phyto-toxicity. Production of plant biomass was negatively affected by higher concentration of cadmium. *Canna* observed with relatively low bio-concentration factor than root-concentration factor which makes *Canna* more suitable for Cd phytoremediation as well as safe disposal since the root biomass was only 14%–20% of the whole plant biomass at all levels of cadmium concentration.

Acknowledgements We gratefully acknowledge Prof. Erin Bennett (Editor-BECT) as well as three anonymous reviewers for their considerable and positive feedback to this work. This investigation was, in part, supported by the Grant (No. 7056) from Indian Institute of Technology, New Delhi (IITD). Authors also thanks to G. B. Pant University of Agriculture & Technology, Pantnagar, India for all the facilities to conduct this experiment.

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Environment and Ecology 36 (1A) : 316—320, January—March 2018
Website: environmentandecology.com ISSN 0970-0420

Relative Comparison for Phytoremediation Potential of Canna and Pistia for Wastewater Recycling

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Received 19 October 2017; Accepted 21 November 2017; Published on 14 December 2017

Abstract At present the water crises is one of the higgest threat to the entire Global ecosystem. Due to rapid growth of industrialization and urbanization, available water resources are decreasing and simultaneously wastewater generation is boosting up. Hence, it is necessary to develop most efficient low-cost-eco-friendly-plant based technology for wastewater recycling. Present experiment focused on phytoremediation of wastewater using Canna and Pistia, in which parameters viz. EC, pH, BOD, COD, TS, TDS, TSS, TN, TP, TK and Na were analyzed. The result shows that, most of the pollutants were removed by 20-50% in 5-15 days HRTs and Canna was observed more efficient for phytoremediation of above said parameters as compared to Pistia.

Keywords Phytoremediation, Canna, Pistia, Wastewater, Hydraulic Retention Time (HRTs).

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Introduction

Recently in the modern era of rapid urbanization, industrialization and population exploitation, it is more observing that the wastewater generation is growing in unmanageable quantity and simultaneously degrading the quality of fresh water. The Central Pollution Control Board [1], realized the big gap between sewage generation and treatment capacity for urban India in 2015 and reported that only a small fraction of about 23277 MLD (37.54% of total wastewater) out of 62000 MLD (million liters per day) is only treated through 816STPs across the country. Hence, there is urgent need to reduce this gap between generated and treated quantity of wastewater by using low-cost-ecofriendly method of wastewater treatment and recycling.

Phytoremediation is a plant-based technology [2], viz. phytoextraction, rhizofiltration, rhizodegradation, phytovolatilization, phytostabilization, which is relatively inexpensive since they are performed *in-situ* and are natural-driven [3]. Since low-tech, low-cost and eco-friendly in nature, phytoremediation is the most emerging clean-up method for contaminated wastewater. The selection and indigenous availability of suitable plant species according to types and concentration of the pollutants to be removed is very crucial [4]. The eco-friendly management of wastewater by the process called phytoremediation; in which wastewater is used as irrigation source, and up to some extent it is also called as fertigation [5] as it contains several essential nutrients as well as organic matter which are required for healthy plant growth [6, 7]. Most part of available freshwater, approximately

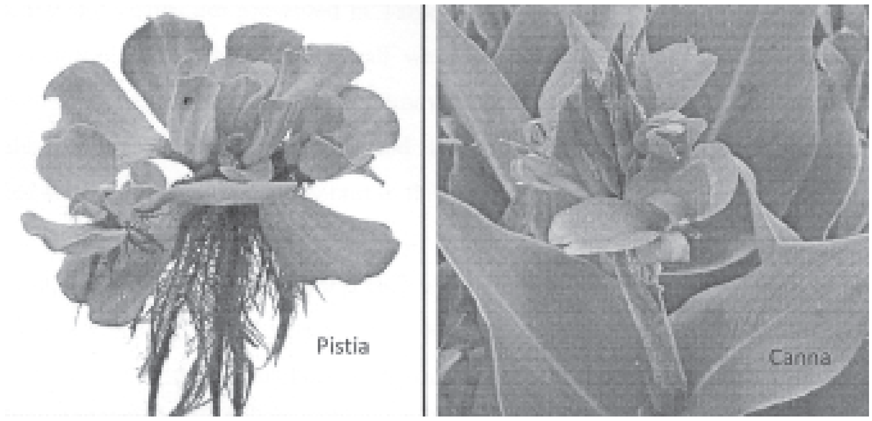

Fig. 1. Selected plant species Pistia and Canna.

79% is used in irrigation, hence for sustainable use of water resources and to reduce extreme water scarcity in future, it is very necessary to reuse the domestic and industrial wastewater for irrigation or fertigation purpose after certain treatment [8].

This experiment mainly focused on phytoremediation efficiency of Canna and Pistia for domestic wastewater. Furthermore, the study also shows that, wastewater can be safely used as irrigation for non-edible crops like flower crops.

(Authors thank to University Grant Commission (UGC) and G.B Pant University of Agriculture and Technology (GBPUA&T), Pantnagar for providing an academic platform to do this work. This experiment is a part of project entitled "Integrated Technology System for Phytoremediation of Domestic. Wastewater with Floating Rafts (Floating Wetland) : R&D and Pilot Testing" at Pantnagar University funded by IIT-Delhi).

Materials and Methods

Sampling site

Wastewater samples were collected from domestic wastewater discharge drain of University Campus-nearby Mahakaleshwar Temple at GBPUA&T, Pantnagar.

Water quality analysis

Domestic wastewater samples were collected from study site and tap water were analyzed for physico-chemical and biological parameters such as pH, Electrical Conductivity (EC), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Solids (TS), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP), Total Potassium (TK) and Sodium (Na). For sample collection, preservation and analysis, general guidelines given in Standard Methods for the Examination of Water and Wastewater [9], was followed. The percentage reduction was calculated by observing the average influents and effluents concentration of three samples collected on consecutive days for same HRT time.

Plant species

Aquatic and some other plants have phytoremediation potential for removal of water pollutants and these plants make the repid accumulation of pollutants into their differnt body parts and biomass. Therefore, two plants species namely, Pistia *(Pistia stratiotes)* and Canna *(Canna indica)* were selected for this lab experiment (Fig. 1). Initially the experiment was carried out in lab condition for acclimatization and standardization.

Table 1. Comparison of pollutants concentration to assess the phytoremediation efficiency of Pistia and Canna at 5, 10 and 15 days HRT's.

Parameters	Initial concentration		Pollutants concentration after 5 days				Pollutants concentration after 10 days				Pollutants concentration after 15 days			
			Canna		Pistia		Canna		Pistia		Canna		Pistia	
	TW	WW	TW	WW	TW	WW	TW	WW	TW	WW	TW	WW	TW	WW
pH	7.70	8.86	7.51	8.10	7.62	8.37	7.4	7.7	7.5	7.9	7.2	7.5	7.1	7.6
EC (µs cm^{-1})	251	552	213	466	209	472	204	448	200	457	192	412	196	416
COD (mg L^{-1})	6.38	380	4.94	292	5.01	302	3.49	276	3.94	284	2.74	213	2.97	208
BOD (mg L^{-1})	3.95	50.4	3.12	39.7	3.20	40.9	2.89	34.6	2.96	36.5	2.01	28.7	2.23	32.6
TS (mg L^{-1})	281	425	220	340	225	353	197	322	211	315	172	284	182	265
TDS (mg L^{-1})	161	289	117	213	121	224	98	199	110	212	79	170	92	187
TSS (mg L^{-1})	120	145	103	127	104	129	99	123	101	103	93	114	90	78
TN (mg L^{-1})	1.71	36.5	1.42	29.3	1.53	31.6	1.21	22.1	1.32	24.8	0.92	16.5	1.12	18.7
TP (mg L^{-1})	1.37	7.42	1.25	6.23	1.32	6.74	0.93	5.92	1.01	6.19	0.67	4.31	0.79	4.39
TK (mg L^{-1})	0.95	2.30	0.87	1.93	0.89	2.01	0.62	1.62	0.53	1.73	0.41	0.98	0.47	1.29
Na (mg L^{-1})	4.68	8.84	3.94	7.43	4.16	7.24	2.21	6.37	2.95	6.85	1.78	4.35	1.01	3.12

Lab experiments

A lab experiment was conducted in the month of August and September, 2016 in ambient atmosphere at GBPUA&T Pantnagar. The objective of this study was to standardize the system for phytoremediation of domestic wastewater in floating rafts and constructed wetland and validates the system at laboratory scale before field level study.

Treatments detail : TW–100% Tap water
WW– 100% Waste water

A lab experiment conducted to assess the phytoremediation efficiency of Pistia and Canna separately in 10 liter volume plastic pots using wastewater and tap water as mention above.

Results and Discussion

Water samples were frequently collected and analyzed for plant pollutants removal efficiency and results are presented inTable 1. Each reading or data represent the mean of three samples. On the basis of overall water analysis it can be conclude that, Canna was observed to be having more pollutants removal efficiency as compared to Pistia plant species, probably due to more root hair zone and thicker leaves of Canna, however the long time detailed study needs for further support to the result.

The initial values/concentration (IC) of pH for tap water (TW) and wastewater (WW) were 7.70 and 8.86 (Table 1), respectively, which was reaching towards neutral pH (7.00) as both (Canna and Pistia) plants become aging, this trend of pH was similarly observed up to 15 days HRTs (hydraulic retention time). The initial Electrical Conductivity (EC) of wastewater was 552 µs cm^{-1}, which was reduced by 15.5% and 14.5% at 5 days HRTs by Canna and Pistia, respectively. At 10 and 15 days HRTs the Canna was observed more superior as compared to Pistia (Fig. 2).

The chemical oxygen demand (COD), removed by Canna was 23.1% in wastewater and 22.5% in tap water at 5 days HRTs, similarly decreased in COD concentration was also observed at 10 and 15 days HRTs. The trend of COD removal by Pistia was similar to the Canna's trend, but the removal efficiency was lower than Canna. Canna and calamus floating beds/ plant removal rates for COD were 42.3% and 36.3%, respectively [10]. Sun et al. [11] also showed that 39.9% COD reduction from 38.1 to 22.9 mg L^{-1} in 5 days through Canna grown floating system in polluted water.

Biological oxygen demand (BOD) was initially 3.95 and 50.4 mg L^{-1}, for tap water and wastewater. The removal rate of BOD for Canna was accordingly 21.2%, 31.3% and 43.0% at 5, 10 and 15 days HRTs. Navarro et al. [12] reported maximum 70% BOD re-

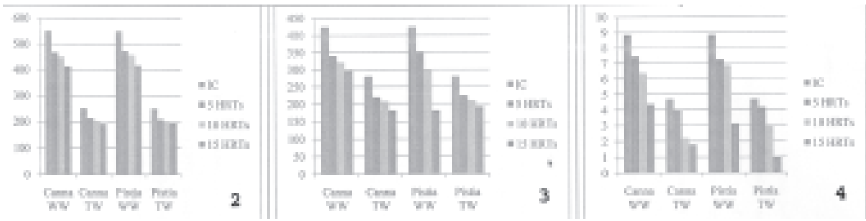

Fig. 2. Electrical Conductivity (EC). **Fig. 3.** Total solids (mg L^{-1}) removal trend. **Fig. 4**. Sodium (Na) concentration (mg L^{-1}).

duction from 325 to 98 mg L^{-1} in one day HRT for treatment of lemon industry wastewater by *Eishhornia crassipes* (Water hyacinth).

Initially total solids (TS) were 281 and 425 mg L^{-1} in tap water and wastewater, respectively. Canna was observed to remove the TS between 20 and 30% in case of wastewater, where 20% TS removed at 5 days HRTs and 30% removal rate was observed at 15 days HRTs (Fig. 3). Maximum 76% total solids reduction from 405 to 95 mg L^{-1} in one day HRT was observed by Navarro et al. [12] for treatment of lemon industry wastewater using *Eishhornia crassipes.* Similar decreasing trend was also observed for total dissolved solids (TDS) and total suspended solids (TSS) at all given HRTs (5, 10 and 15 days) and the Canna had shown the more efficient to remove these solids as compared to Pistia.

Total nitrogen (TN) in the tap water and wastewater were 1.71 and 36.5 mg L^{-1} (Table 1). The maximum reduction rate of 54.7% was observed by Canna at 15 days HRTs followed by 39.4% at 10 days HRTs. The maximum removal rate for Pistia was 48.7% in case of wastewater at 15 days HRTs. Total phosphorus and total potassium removal trend was similar to the trend of total nitrogen reduction, the maximum removal was done by Canna at all given HRTs as compared to Pistia. Aquatic plants have a good efficiency to remove nitrogen and phosphorus elements from wastewater [13, 14]. Cress has observed strong capacity to remove TN and TP, which was 76.86% and 90.45%, respectively at 20 days treatment [15].

The initial sodium (Na) of 4.68 and 8.84 mg L^{-1} were found in the tap water and wastewater, respectively (Fig. 4). Canna's removal rate for Na was 15.9% in wastewater at 5 days HRT, while it was 18.0% by Pistia. Similarly at 15 days HRT the Pisita's removal rate (64.7%) was higher than Canna's removal rate (50.7%). However, at 10 days HRT Canna was more efficient to remove the Na as compared to Pistia.

The result of this experiment was relatively assess to select plant species out of Canna and Pistia, as more efficient phytoremediation plant for above selected parameters and more efficient one, that was Canna, subjected to further extension of this method at field level for phytoremediation of domestic wastewater discharge through residential colony at (Mahakaleshwar Temple, Pantnagar) G.B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand.

Cunclusion

Increased concern about pollution free environment and huge generation of wastewater encourages enough to treat the wastewater and its reuse for non-potable applications after certain treatment using phytoremediation process as plant based green technology. On the basis of laboratory analysis of all above mentioned parameters, the relative comparison for phytoremediation potential between Canna and Pistia was done and concluded that, the Canna was found more potential for pollutants removal at all selected HRTs as compared to Pistia, and the Canna was again selected and presently under process for field level experiment at GBPUA&T, Pantnagar.

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Journal of Applied and Natural Science 9 (4): 1931 -1942 (2017)

Effectiveness of domestic wastewater treatment using floating rafts a promising phyto-remedial approach: A review

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Received: December 2, 2016; Revised received: April 18, 2017; Accepted: September 10, 2017

Abstract: Treatment of wastewater willleads to the problems again,if we will not use new more efficient alternative technologies/methods to avoid drawback of old technologies. Loss of water can be reduce throughapplication of easy, inexpensive and eco-friendly technologies for wastewater treatment. Using Floating rafts to purify polluted wastewater is a process/method of ecological restoration at in-situ, as well as a complicated physical (attachment of pollutants to the root surface), chemical (degradation of matels into less toxic form) and biological process (microbial processes). Its core is utilizing aquatic plants such as Canna and Water lily and root attached microbes such as bacteria, fungi and algea to absorb pollutants such as nitrogen and phosphorus, degrade organic matter and accumulates heavy metals in their biomass. Phyto-remediation of polluted wastewater using the Floating rafts technique is an Eco-friendly method of wastewater treatment, which is economically effective to construct, requires little maintenance and increase the biodiversity as different types of plants are used. Floating rafts technique has been applied to some water pollution control projects at domestic and abroad. However, there are some factors such as plants, temperature, seasons, hydraulic retention time, coverage and initial concentration of pollutants etc. influenced to the pollutants removal efficiency of Floating rafts. In the future, the development orientation has been subjected to plant and its combinations, the transformation of Floating rafts structure and the utilization of aquatic plants, and probed the technology of Floating rafts building and management, to implement the win-win of landscape benefit and ecological function.

Keywords: Attached microbial growth, Domestic wastewater, Floating rafts, Hydraulic retention time, Phyto-remediation

INTRODUCTION

Wastewater management and its treatment is very tedious process for removal of physico-chemical pollutants as well as for those techniques whichhaving lesspotentialfor removal of complex pollutants and nutrients. Hence, Floating rafts technology which is totally plants based (natural plant-based-eco-friendly) pollutants removal technique by the process called phytoremediation, maybe add into existing technologies and its application may leads to more pollutants reduction, not only because of its less installation cost, higher phytoremediation efficiency, no further production of any toxic pollutants, but also because, it can leads to further addition in ecological biodiversity as plants are used (Renand Deng, 2007). Floating rafts technique is also known as Ecological Floating Island/Artificial Floating Island, because it utilizes the technical principle of soilless culture (which is known as hydroponics) on the artificial floating platformmade up of bamboo/ PVC and plastic mess to batter supports plant growth (Ren and Deng, 2007).

Using these method for wastewater treatment, not only absorbs excess nutrients' such as N and P, to reduce eutrophic level of wastewater, but also leads to further economic benefit as the plants give returns, *viz*. flowers, nutrients and organic matter back to the soil in the form of nutrients reach litter and so on (Hu *et al*., 2010). In past few years, Floating rafts technology is getting mere concerned due to its higher pollutants removal rates and environmentally friendly in nature. "In the future, the development orientation will be prospected from plant and its combinations, the transformation of Floating rafts structure as well as the utilization of aquatic resources and probed the technology of Floating rafts building and management" (Faping and Xiaoyi, 2013).

Rapid growth in industrialisation and urbanisation are main causes to the more generation of municipal/ industrial wastewater, *i.e.*, sewage, which are leads to biological and physiological degradation andserious threats to the ecosystem. Hence, it is necessary to recycle or treatment of the wastewater before it discharges into the vicinity river/environment (Mulling *et al*., 2014). A large number of technologies, such as sewage treatment plants (STPs), oxidation ponds or activated sludge processes, have been applied for domestic wastewater treatment but most of these practices are

ISSN : 0974-9411 (Print), 2231-5209 (Online)

"expensive and time consuming to erect and run" (Shen *et al*., 2013). Therefore, it is strong need today to develop such technology which would be more efficient if pollution reduction as well as eco-friendly and sustainable in nature

In recent years, the application of Floating rafts/ Floating wetlands (with rooted and free-floating aquatic plants) and facultative ponds treating domestic/ industrial wastewater have gained considerable attention because they offer an environmentally sound approach (Chang *et al*., 2012; Pan *et al*., 2012; Avila *et al*., 2013; Mburu*et al*., 2013). The mechanisms of pollutants removal in Floating rafts/wetlands involve an "interaction between the bacterial metabolism, plant uptake and accumulation of pollutants in their biomass" (Osem*et al*., 2007). "The impurities are removed in facultative ponds entirely by natural processes involving both algae and bacteria" (Abdel *et al*., 2012). In that order, vegetation is considered as a dominant feature of Floating rafts and acts as an important biotic factor in the overall treatment process (Dhote*et al*., 2009). Some of the plant's species, *viz*. canna, pistia and water hyacinth appears to having excellent property for pollutants removal owing to their rapid growth rate and extensive root system (Kumari and Tripathi, 2014; Olukanni and Kokumo, 2014). The plants lagoons/ponds functions as a "horizontal trickling filter", where the submerged roots provide physical support for the "bio-film bacterial to growth" (Dhote*et al*., 2009). However, despite the efforts made worldwide, the construction of aquatic systems, particularly the water hyacinth treatment process, has not gained much popularity due to the requirement of a large land area and considerable capital investment (Chang *et al*., 2012).

Based on the oxygen transfer through the floating plants, water column can be divided into three zons, *viz*. aerobic, facultative and anaerobic. An excess pond depth (typically ~50-100 cm) reduces the oxygen transfer efficiency through the "roots and sustains high anaerobic microbial growth" (Truijenand Van, 2013; Sooknah, 2010). The oxygen concentration is likely todecrease in the direction towards bottom and it is to be high in the upper part of the lagoon/pond, approaching almost zero below a 200 mm depth, which can leads to rise the anaerobic zone; resulting a slower biodegradation process and cause the emission of foul odours. To overcome this drawback, a shallow pond-Floating rafts system was reported and as the Floating rafts are free floating on water body by natural air circulation, hence it will add additional oxygen to the water body (Valipour*et al*., 2010; Valipour*et al*., 2015).

The shallow pond-Floating rafts is an alternative to the conventional treatment process because it has a low water depth (140-150 mm) based on the fully matured plant root submerged (80-130 mm) to "avoid the anaerobic zone" (Valipour*et al*., 2009). Shallow pond floating raft technique ensures the optimal interactions between the wastewater effluent and microbial biomass in the phyto-remediation treatment practice. The shallow pond technique is an attempt to minimize these constraints due to the better oxygen diffusion efficiency through the roots and the accumulation of a larger aerobic bacterial population. This is a new biological-plant-basedeco-friendly technique that can be applied to the efficient and reliable elimination of pollutants at a lower hydraulic retention time (HRT) through providing of extra oxygen, as the raft are free floating in nature dute to natural air circulation (Valipour*et al*., 2010; Valipour*et al*., 2015). However, further improvements in the shallow pond practice as an effective plant-based-remediation tool for purifying municipal/industrial wastewater effluents, could be the objective for future research.

Application of phyto-remediation with attached growth -based (Plant roots and submerged plant parts provide a living surface area for development of biofilms, which contains communities of attached-growth micro -organisms responsible for a number of important treatment processes such as degradation of complex organic and inorganic molecules/pollutants in simple form) engineered procedure (using *Phragmites*sp.) has been reported as a new relevant technology in Floating rafts treating domestic sewage (Valipour*et al*., 2009; Valipour*et al*., 2011). The concept of operation is void of the soil strata used in the root zone systems, and in lieu a support matrix (assembled by the number of vertical and horizontal bamboo/PVC pipes) is provided to enrich the microbial population in the form of biofilm within wetland unit. This approach overcomes the limitations of choking, clogging, slow mass transfer, poor root penetration into the multilayer water column, high area requirement and capital investment owned by water bed constructed wetlands. A further study conducted by Wang and Wang, also revealed the efficiency of this method by using *Thaliadealbata, Acoruscalamus, Zizanialatifolia*and*Iris sibirica*for river water treatment (Wang *et al*., 2012a; Wang *et al*., 2012b). Marchand*et al.* (2014) found effectively applied this technology for the removal of copper (Cu) ion from synthetic Cu-contaminated wastewaters using *Phragmitesaustralis, Juncus articulates* and *Phalarisarundinacea*. In addition, the vegetated system using *Typha*sp. reported to be a promising solution in domestic wastewater treatment seriously stressed with total dissolved solids (TDS) and Cu metal salts (Valipoue*et al*., 2014). The integrated anaerobic baffled reactor and phyto-remediation process with attached growth (using *Phragmites*sp. and *Typha*sp.), likewise, has been recommended as a novel approach for promoting a sustainable decentralization (Jamshidi, 2014). As a result, it is recommended by Jamshidi, 2014, that using Floating rafts systems upgraded with the phenomena of engineered attached growth matrix could be considered as a novel scientific advancement in domestic/industrial wastewater treatment.

Therefore, the present study aimed to enhance and examine the efficiency of the shallow pond-Floating rafts system by adding a new feature to a treatment unit. In this approach, an attempt was made to incorporate the advantages of a shallow pond and attached growth microbial techniques by introducing Floating rafts (mesh type structure), which is a support matrix to augment the indigenous microbial population. Although the performance of the water canna treatment systems has been studied elsewhere before; until now, this innovation to our knowledge has not been previously documented. This new system identified to overcome the limitations associated with the traditional methods and facultative pond technologies, and permits treatment of effluents in the most cost effective method and Eco-friendly manners. Moreover, the role of plants, microbial biofilms and evapo-transpiration in this phyto-remediation system was also important.

MATERIALS AND METHODS

The domestic/industrial wastewater or eutrophic water from River, before discharging to vicinity Rivers', can be stopped through constructing check dam in drain and can be diverted to the Floating rafts bed tank for its pollutants remediation as layout shown in Fig. 1.

The flowing volume of wastewater can be measure by V -Notch. The Floating rafts bed tank having size of approximate 20m long, 2m width and 1m depth or an appropriate size shallow rectangular tank/basin with a high length to width ration will be designed and constructed with bricks and cemented concrete lining to protect any leaching towards underground. The design will take care to reduce the potential for short circuiting and to simple harvesting operations. The domestic wastewater will be directly diverted to Floating rafts bed tank at different hydraulic retention time (HRT) such as 1, 2 ,5 ,10 and 15 days for remediation of wastewater pollutants through plant roots (rhizosphere) system (Canna and Water lily). The Floating rafts will be made-up with bamboo/PVC pipe and proper netting will be done for support of plants and to form bio-film to support the maximum attached microbial population. The desired number of Floating rafts will be made with suitable size of approximate 1.4m x 2.1m (2/3) in rectangular shape for the Floating rafts bed tank.

A comparative study may be carried out at different HRT for optimization of pollutants removal efficiency/ reclamation of wastewater and preparing the engineering design of large scale system for remediation/ restoration of domestic and other industrial wastewater. Biological stability of Floating rafts bed is the prime requirement for successful wastewater treatment. The plants belonging to Typha species, Reeds (Phagmites), Canna and other aquatic plants may be selected for uptake of pollutants by their roots considering existing climatic condition. Maintenance of the Floating rafts bed tank may include harvesting of plants at various interval of time and removal of detritus accumulation.

Phyto-remediation: Phyto-remediation of industrial/ domestic polluted water is generally believed to occur through one or more of the following mechanisms or processes: phyto-extraction, phyto-stabilization, phyto-degradation, phyto-volatilization, rhizo-filtration and rhizo-degradation (Oh *et al*., 2013a; Li *et al*., 2009), as shown in Fig. 2 and Table 1. Phyto-remediation is applicable to a broad range of contaminants/pollutants, including heavy metals and radionuclides, as well as organic compounds like chlorinated solvents, polycyclic aromatic hydrocarbons (PAHs), pesticides/ insecticides, explosives, and surfactants (Oh *et al*., 2013a) (Li *et al*., 2009).

Phyto-remediation processes rely on the ability of plants to uptake and/or metabolize pollutants to less toxic substances (Wang *et al*., 2003). The uptake, accumulation and degradation of contaminants vary from plant to plant. The plants used in phyto-remediation are generally selected on the basis of their growth rate of biomass, ability to tolerate and accumulate contaminants, the depth of their root zone and their potential to transpire wastewater (Oh *et al*., 2013b). The plants used in phyto-remediation should not only accumulate, degrade or volatilize the contaminants, but should also grow quickly in a wild range of different conditions/ environments. As an emerging hopeful technology, phyto-remediation for using in management and remediation of contaminated water has its advantages. The most positive characteristics are that phyto-remediation is a natural and *in-situ* remediation system driven by solar energy and green plants. It is faster than natural attenuation and can conserve the water resources. It is inexpensive, and does not induce the secondary contamination. Successful phyto-remediation can reduce movement of pollutants towards groundwater and sustains the water quality. Water followed phyto-remediation are still or more suitable for its original application particularly for agricultural application, thus preventing the loss of water resources (Oh *et al*., 2013a; Wang *et al*., 2003). Because most of the energy for phyto-remediation is supplied by the Sun and phyto-remediation does not need to remove the water out of the place, the costs are very low in comparison to other physical or chemical methods of wastewater treatment.

However, as a plant-based remediation, phyto-remediation has low remediation rate and generally need a longer period in comparing with other physic-chemical methods. This short coming limits, its application particularly in the developed urban areas, where land is extremely expensive. The remediation rate of phyto-remediation is different with case by case, as the plant growth was influenced easily by the climate, water conditions and management practices. Phyto-remediation has limited depth (Li *et al*., 2009). The use of phyto-remediation is limited by the climate, water type, geological conditions of site to be cleaned and the accessibility for agricultural equipment. Following critical consideration of these characteristics, phyto-remediation can be more suitable for treatment the much larger scale contaminated water or for treatment of polluted rivers.

Research on floating rafts mechanism in polluted water restoration: Use of floating rafts for treatment of pollutedwastewater is a complicated physical, chemical and biological process. In the floating rafts technique,generally aquatic plants' developed roots are utilize to contact wastewater, forming a concentrated natural filtering layer of roots (rhizosphere), as well as absorbing, adsorption, transforming and degrading (rhizodegradation) the water pollutants. Plant's roots can also release large amount of enzyme and organic acid to enhance the decomposition and degradation of the macromolecular or toxic pollutants/substances in wastewater and improve the bioavailability of nitrogen and phosphorus to the plant roots. Plant's roots also provide microorganism with oxygen source and attachment place (root surface) and enhance their metabolism to cut down water pollutants content. Through shifting the plants out (old stem can removed) and separating them from floating platform, we will achivethe purpose of purifying water quality.

Absorption of nitrogen and phosphorus: Aquatic plants such as Canna, Water lily etc. have an enormous potential on removing of nitrogen and phosphorus elements in eutrophic water (Wang *et al*., 2012; Xu, 2010). Aquatic plants make the rapid accumulation of biomass (bimegnigication) come true in the way of more vegetative reproduction and removal of more pollutants from wastewater. As indispensable nutrient, elements in plants growing process, the inorganic form of N and P in water could be absorbed directly by aquatic plants through their roots' absorption (rhizoaccumulation), and then plant protein or organic component were synthesized to facilitate plant's growth and development. Therefore, plants had a strong capacity of fixing N and P as well as other nutrients/pollutants (Xuand Lu, 2011). When aquatic plants were shifted out of water of floating platform where they established, the nitrogen and phosphorus absorbed by different parts of plant such as stem, leaves and root were brought out of water too. In the research conducted on Floating rafts purification in intensive aquaculture pond, water spinach floating beds were observed highest direct absorption rates of Total Nitrogen (TN) and Total Phosphorus (TP) on the 100 days as 52.35 and 5.39 kg hm^{-2} a^{-1}respectively (Chen *et al*., 2010).

Canna was a very good kind of sewage treatment plant, and its highest removal rates of nitrogen and phosphorus were 130 and 23 kg hm^{-2} a^{-1}respectively (Li *et al*., 2014). If the Floating rafts were made up of canna and other aquatic plants, its removal rates of N and P would be much better and the removal rates can-reached 314.6 and 156 kg hm^{-2} a^{-1}respectively (Zhen *et al*., 2013). Cress also has observed a strong capacity of purifying eutrophic water, and its removal rates of TN and TP reached 76.86% and 90.45% at 20 days treatment period (Hu *et al*., 2010). There was a positive correlation between Floating rafts removal rates of nitrogen and phosphorus in water and plant's growth speed, concentration of nitrogen and phosphorus in water (more the concentration of pollutants in wastewater, there was more growth of plants and removal rate of pollutants) (Jayaweera *et al*., 2008; Fox *et al*., 2008). In the research conducted by Lu and friends in 2000 on the water purification mechanism of aquatic plants, it is observed that plants themselves absorb N and P in water, root's microbes' activity is an important way/component of removing N and P in water, mainly because microbe's activity can accelerate the decomposition rate of N and P around roots, enhance other element's activity and improve the bioavailability of N and P to the roots (Lu *et al*., 2000). Therefore, the exertion of Floating rafts technology's purification function not only depends on plant's absorption of N and P, but a bigger factor is that, Floating rafts constructs/develop a micro ecosystem/ environment which is in favour of microbe's inhabitation so that N and P can be removed effectively in shorter of period/HRTs.

Degradation of organic matters (OMs): Floating rafts not only can remove nitrogen and phosphorus elements effectively, but it is also effective in removing organic matters (Luo *et al*., 2011; Bu *et al*., 2010). Canna and Calamus floating bed's removal rates of COD and Mn were 42.3% and 36.3% respectively in 5 days (Bu *et al*., 2010). However, the main ways of removing organic matters by Floating rafts were the degradation of roots secretion as well as absorption and utilization of microbes. Aquatic plants constantly secreted a great deal of macromolecular organics to the environment in the process of growth, such as enzyme, saccharide, organic acid etc. (Liu *et al*., 2009). Those secretions not only decomposed organic matters effectively, but it also provided root's microbes with many nutrient substances. Moreover, the oxygen produced by floating plant's photosynthesis was released to water through plant's roots (Cheng *et al*., 2003), then many anoxic and aerobic areas were formed around its rhizosphere to intensify both aerobic microbe's and anaerobic microbe's growth and reproduction, to promote microbe's constant absorption and utilization of organic pollutants in water and to raise its degradation efficiency of organic matters, thus achieving the propose of removing organic matters. For example, samphire's removal of humic like proteinoid, DOC and other organic matters were implemented by its rhizosphere's activity (Huang *et al*., 2013).

Enrichment of heavy metals (HMs): Aquatic plants are usually planted in Floating raft's upper layer, and many aquatic plants are capable of absorbing, metabolizing, enriching heavy metals, besides the content of heavy metals within the plants themselves was related to the outside world's pollution level, so Floating rafts was regarded as an important way of controlling heavy metals pollution in water. *Hydrillavarticillata* and *Myriophyllumspicatum* were together exposed in the different concentration such as 5, 50, 100 and 1000 ppm of Cu^{2+} of water after two weeks (Yan *et al*., 2006), their absorption behaviours coincide with Langmuir model (absorption increases with increase in concentration level of pollutants) (Davis *et al*., 2003) and a strong enrichment capacity is manifested. Water hyacinth was a kind of plants that accumulates Ni, Pb, Zn, Cd and Cu effectively, because in the wild environment water hyacinth's root's accumulations of Cu, Ni and Zn are 2 to 17 times that of part above ground and their maximum bio-concentration Factor (BCF) are 1344.6, 1250.0 and 22758.6 respectively (Hammad, 2011).

The enrichments of Pb and Cd for lotus within roots of every organ were positively correlated (+ 0.012 and + 0.019, respectively) with their concentrations (147 and 59 ppm, respectively) and an effective enrichment was demonstrated under combined stress of Pb and Cd. Among all the organs, lotus leaves and swollen stems enriched the most for Pb 46 and 53 ppm and for Cd 19 and 24 ppm, respectively, but the enrichment of Pb (Lead) and Cd (Cadmium) within lotus roots may cause certain toxic reactions (Xiong*et al*., 2012). *Typhalatifolia* has a strong capacity of absorbing and enriching Pb, Zn, Cd,Cu and they were mainly enriched at the root of plant (Yang *et al*., 2002). Jiang and Wang (2008) showed that after 21 days for reed to deal with 2 mmol L^{-1} Zn^{2+} of sewage and after the reed is dried; its root's, stem's and leave's enrichments of Zn^{2+}were 14.34, 0.95 and 1.45 mg g^{-1} respectively. If canna is used to deal with copper-containing wastewater, its removal rate of 2 mg L^{-1} of copper-containing wastewater can reach 74%, and its root's, stem's and leave's maximum absorption quantities of copper are 1859.04, 186.20 and 127.53 mg kg^{-1} respectively in 10 days of experimentation (Yu *et al*., 2012).

Floating rafts technique application: It was 20th century, when first time use of Floating rafts technique was started and at that time it was used for bird's natural habitat and fish's spawning place for their natural restoration. In the 1980s, German scholars had decided todesign the new modern eco-friendly Floating rafts technique and used it for purify polluted water (Nakamura and Shimatani, 1997). Because of Floating rafts not only can restore polluted water (conversion to polluted wastewater into useful form), but it also provides several benefits, such as less initial investments, simple operations and no production of secondary pollutants. The technique of Floating rafts for wastewater treatment was promoted and applied rapidly in Japan, Europe and America and other developed countries such as Canada, Denmark, Belgium etc. China brought Floating rafts technology in the 1990s, which is now applied to treatment of polluted urban rivers, lakes as well as reservoirs and it has a very good favourable effect on purification wastewater and development of ecological landscape. Guangzhou city used Floating rafts technique as a major natural ecological restoration measure to govern the Yufeng Chung, the south Pai Chung and Guan Chung around the Asian Games Town, as a result that water transparency was increased, water eutrophication was controlled effectively under certain level and a favourable effect of natural landscape and ecology was successfully achieved (He *et al*., 2010; Hung *et al*., 2010).

The Floating raft technique had been used for several river purification projects such as the water quality improvement project of Bailian Jing River's EXPO garden section, Shanghai was one of them, a Floating rafts made up of sliver carp and bighead carp, hyriopsiscumingii and plants was constructed in section. After Nine months operation, a comprehensive water quality study was done to assess the purification efficiency of Floating raft and it was observed that the river water was transformed from Grade V and worse than Grade V to Grade IIandIII, respectively. It was also found that the water quality of all the floating bed sections such as*calamus*, *blood grass* and *Acorusgramineus* cv. varies gates reached the Grade of III standard, so that the river channel's water quality was improved effectively. In another water purification project of Dianshan Lake's water source, a research was conducted for one year in the water area with area of 18,000 square meters by utilizing Floating rafts technologyIt's shown that Floating rafts purified eutrophic water effectively, because DO content of pilot site at Suzhou, Jiangsu Province was increased 2.06 and 0.38 mg L^{-1}respectively as compared to that of Qiandun Riverside's inflow and that of pilot site's inflow, besides, its transparency was increased 8.1 cm and 7.4 cm respectively. The floating bed experimental project's maximum removal amount of TN, TP and COD in Qiandun Riverside's inflow was 14.9, 0.90 and 58.3 g m^{-2} d^{-1}; its maximum removal amount in floating bed site's inflow was 5.27, 0.36 and 25.13 g m^{-2} d^{-1} (Sun *et al*., 2010; Gao *et al*., 2011). Floating rafts technology also has an effect on controlling urban river's water quality. The research on the experiment of Xinjiao Riverside River and Huifeng River's black and smelly section showed that Floating rafts obviously removed COD by 59%, TN by 86% and TP by 75%; after controlling, the outflow's concentration and transparency were increased; river's biodiversity was significantly boosted, (as the concentration of pollutants decreases the micro and macro biota of river significantly increased); water eutrophication was obviously improved (Chen *et al*., 2011).

Factors of floating raft's purifying efficiency Plant: The Biological and physical properties of each plant species have vital role with regard to the removal of different types of pollutants andtheir purifying effect on water pollutants owing to different Floating rafts plant specie's different physiological properties (Mao and Zhou, 2011), therefore, selection of plant species for wastewater treatment is very important and it one of the key factors that affects water purification efficiency of floating raft technique. In the research it was observed that yellow flag floating bed's removal rates of TN and TP was 2.82 and 5.31 times higher than Canna's removal rates, besides it, yellow flag was proposed as the major plants of urban water Floating rafts because of its freeze resistant capacity was much stronger than other plants such as Canna (Wu *et al*., 2010). There was an obvious discrepancy among canna's, thaliadealbata's and willow herb's removal rates of TN (79, 84 and 68%, respectively) and TP (85, 78 and 74%, respectively) and both canna's and dealbata's removal rates of TN and TP were higher than that of willow herb (Jiang *et al*., 2011).

Research on applying four plant floating bed species such as canna, cyperusaltrnlifolius, pontederiacordata and calamus to improve the eutrophic water in tributary area of The Three Gorges Reservoir showed that canna's maximum removal rate of TP (87%) was higher than that of cyperusaltrnlifolius (76%), pontederiacordata (73%) and calamus (67%) (Mishra *et al*., 2008). It was usually observed that the purifying effect of the floating bed plants with developed roots was better than that of the floating bed plants with undeveloped roots, because the developed root system have larger rhizospher zone and also have longer root hair to absorb more and more pollutants; the purifying effect of the floating bed plants with high growth rate was better as they absorb quickly and more nutrients/ pollutants and organic matter from wastewater (Ge *et al*., 2000). That's mainly because plants with developed roots and with high growth rate could obtain more component/pollutants, thus plant's purifying effect of water pollutants/contaminants was more facilitated.

Temperature: Among, factors affecting the efficiency of floating raft treatment, temperature aremost important which play a vital role in plant's growth and reproduction. Temperature is positively correlated with plant's purifying capacity, when the temperature is high, floating bed plant's growth and their metabolism is vigorous and plant's purifying effect of water pollutants is obviously improved and as the plant become more healthy, they accumulates more pollutants in their tissues. It was observed that, when the water temperature was increased from 2°C to 29°C, canna's re-

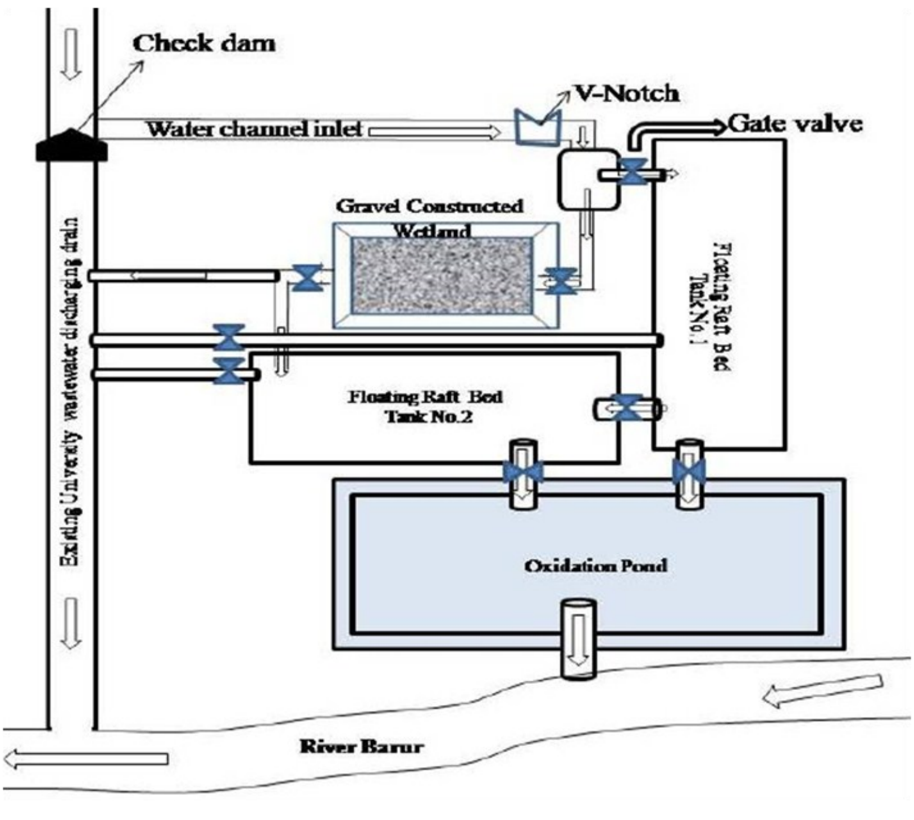

Fig. 1. *Proposed layout of Floating rafts tank (proposed for future research).*

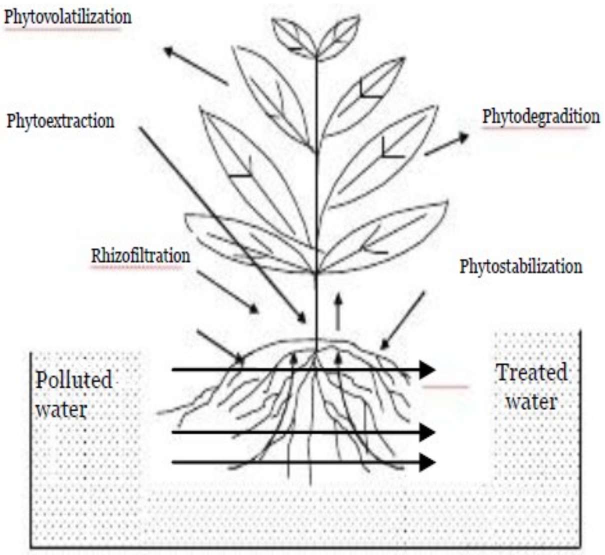

Fig. 2. *Phyto-remediation of industrial/domesticpolluted water(Ferreiroet al., 2014).*

moval rates of TN (Total Nitrogen) and TP (Total Phosphorus) were distinctly increased by 57% and 63%, respectively as compare to at 2°C. When the temperature was raised beyond 10°C, canna removal rate of TP and TN inform wastewater obviously increases; and when the temperature was lower than 10° C, canna's growth rate was at a standstill (Zhen *et al*., 2008; Luo *et al*., 2010). In another researchit was observed that cress floating bed's and water cress floating bed's removal rates of TN and TP from eutrophic water at22°C were clearly higher than that of at 10°C and 35°C (Hu *et al*., 2010); *Eichhorniacrassipes* floating bed's removal rates of TN and TP from eutrophic water at 25°C washigher than that of 15°C and 35°C temperature.

It was also observed that, plant's removal rates of TN and TP were not proportional to the temperature, but the temperature wasvery important factor that affect to the floating bed plant's biomass and more the plant biomass, more will be accumulation of pollutants (Liu *et al*., 2013). As discussed in above paragraph, plant's growth rate was different at different temperaturesand the growth of plants were very good at the optimum temperature condition and its purifying effect for polluted water was obvious mare as compare to very high or low temperature conditions where plant's growth was restrained, thereby,plant's purifying effect of polluted wastewater was influenced greatly by temperature.

Seasonal variation also well affects the plant's purifying effect. Floating raft's removal rates of TN and TP in summer (78 and 65%, respectively) and autumn (82 and 74%, respectively) were significantly higher than in winter (62 and 58%, respectively) and spring (75 and 63% respectively), and the reason behind the performance was that, floating bed plant's pollutants removal efficiency was proportional their own growth condition and metabolism which wasobviously higher in summer and autumn seasons (Zhang *et al*., 2010). Summer and autumn seasons are temperature bias floating bed plant's vigorous periods of growth, hence, the plants performed a high purifying rate as compare to winter and spring (Sun *et al*., 2008). However, there're research which was conducted at Department of Biology, Sinop Art and Science Faculty Sinop University SinopTurkeyindicating that canna floating bed's removal effect of nitrogen in spring was better than in autumn (Sivaci*et al*., 2008), because spring and summer were canna's growth periods, and it primarily stops growing and began to fall off after the 15th of July (Ge *et al*., 2000).

Table 1. Phyto-remediation processes for restoration of contaminated water (Ferreiro*et al*., 2014).

Phyto-remediation Processes	Description
Phyto-extraction	Plants absorb contaminants and store in above-ground shoots and the harvestable parts of roots.
Phyto-stabilization	Roots and their exudates immobilize contaminants through adsorption, accumulation, precipitation within the root zone, and thus prevent the spreading of contaminants.
Phyto-degradation	Plant enzymatic breakdown of organic contaminants, both internally and through secreted enzymes.
Rhizo-degradation (phyto-stimulation)	Plant roots stimulate water microbial communities in plant root zones to break down contaminants.
Phyto-volatilization	Contaminants taken up by the roots through the plants to the leaves and are volatized through stomata where gas exchange occurs.

Processing time/hydraulic retention time (HRT): Floating rafts plant's pollutants removal efficiency are proportionally related to processing time or hydraulic retention time such as more the pollution level of wastewater, more processing time will required. For example, yellow flag, canna and siberian iris floating bed's purifying capacity for nitrogen and phosphorus in polluted water increased with the growth of time of plants (Chen *et al*., 2011). Lycopus, wood betony, rumex japonicas and garden sorrel floating bed's purifying effects of N and P in sewage increased with the growth of time, moreover, in the initial 30 days plant's removal efficiency were obvious, while after 30 days plants removal rates of contaminants ware declined (Xu, 2010). With the growth in the processing time (such as 24, 48, 72 and 96 hours), watermifoil'sand water caltrop's enrichments of Cd^{2+} increased proportionally. (Zhen *et al*., 2008). Study conducted by Luo and friends have found that with the growth of processingtime, the removal rate of water pollutants had the tendency to firstly increase and then decrease (Luo *et al*., 2010). Ajayi and Ogunbayo used water hyacinth in 2012 to purify sewage and found that the content of BOD, Fe and Cu in water firstly increases and two weeks later gradually decreases.

Coverage: Pollutants purifying efficiency of plant's used in the Floating rafts technique is proportionally directly related to floating bed's/coverage area by plants: such as the coverage increases, the purifying efficiency of plant's will be improved simultaneously. For example, as compared to 10% coverage and 15% coverage area with water spinach floating beds, there was more removal of nitrogen and phosphorus with 20% coverage of spinach floating bed and its economic value was higher (Xu, 2010; Hu *et al*., 2010). Floating bed planted with *Cyperusalternifolius* observed the removal rates of N and P from eutrophic water also had the tendency to increase with the increasing growth of coverage area (39% > 26% > 13%) (Liu, 2013). Among different coverage area (50, 60, 70 and 80%) of water hyacinth's it was observed that, purifying effects of plant's for TN (total nitrogen) and TP (total phosphorus) in water raised with the increase of water hyacinth's coverage area, in addition, when plant's coverage area was more than 80% in flowing water, the removal rates of pollutants were higher; while when its coverage area was <50%, the purifying effects were better (Wang *et al*., 2012).

Initial concentration of wastewater: Initial pollution level of wastewater pollutants/contaminants is one of the most important factors that affect the Floating rafts purifying efficiency. Sometime within the threshold limits of pollutant also may leads death to the plants;it was also observed that, greater water pollutant's concentration in wastewater, there was stronger absorbing ability of plants for pollutants (Zhang *et al*., 2010). In the another research it was also found that, with increases the concentration of nitrogen in wastewater from 0 to 200 mg L^{-1} (0, 40, 80, 100, 150 and 200 mg L^{-1}N), the removal rates of nitrogen by water hyacinth was also increased correspondingby the amounts of 0.47, 5.69, 9.31, 11.86, 16.97, 22.13 mg L^{-1} (Zhang *et al*., 2010). The research on water hyacinth's also found that, the enrichments of 0 to 4 mg $L^{-1}$of Cd and Zn in wastewater showed the increment of absorbed concentration of Cd and Zn in plant parts such as roots and buds (Sivaci *et al*., 2008).

Prospects

Plants selection: The selection of plant species for Floating rafts is one of the most important aspects of Floating rafts research. Selection of plant should be according to climatic condition of that particular area where this technique is to be installed. When plant are selected for polluted wastewater restoration, usually one should prefer aquatic plants with the more biomass production, more pollutants strong capacity, well stain resistance and high removal rate of pollutants/ contaminants as floating bed plants, and some other factors also should be concedersuch as regional weather characters, freeze resistance capacity and seasons. It was commonly observed that, most aquatic plants have a low freeze resistance capacity and are more vulnerable to the chilling injury;hence the plant's ability of removing pollutants obviously decreases in low-temperature in season of winter. In the future, the research on selection of aquatic plants those are more capable to successfully grow in low-temperature or freezing environmental condition and have a strong capacity of absorbing multiple pollutants from the wastewater should be strengthened. There are number of technique such as using plant tissue culture, to select plants not only cut down the cost of installation and it was not limited by seasons condition, but it also enhanced plant's restoration capacity, so it would be a research hotspot in the upcoming future (Ajayi and Ogunbayo, 2012).

Application of the Floating rafts along with combination of different plants species to restoration of polluted waste water in the aquatic environment is leads to a research direction for the future generation. At present it was observed that, most research have been focused on the single plant's purifying capacity for polluted water, but it was also observed that it is difficult for a single plant to overcome all the factors that affect purifying effect of that particular plant, hence plant's ability to purifying is limited up to some level. However, use of complex form of Floating rafts which are prepared by multiple phytoremedial plant scan overcome the various disadvantage of a single plant such as unstable purifying effect in different seasonal variations. (Xu and Lu, 2011; Chao *et al*., 2011), combination of different plants together can also enhanced the advantage of various aquatic plant's characteristics such as growth difference in time and space and achieve Floating rafts continuous and stable operation through optimal configuration. Nevertheless, the best combination of phytoremedial aquatic plant for maximum removal of pollutant, are still requires strengthened research in the field level experiments.

Improvement of floating rafts: Traditional Floating platform in the technique of Floating rafts is mainly made using floating bed body such as bamboo, floating bed matrix such as plastic mat and floating bed aquatic plants, which are capable to cuts down nutrients viz., nitrogen, phosphorus, heavy metals, organic load (BOD, COD, TOC) , but effect of this technique for wastewater restoration is undesirable and hence it is necessary to modify this technique for more pollutants removal capacity. Structural modification of floating raft along with hyper accumulator plant species could be one of the ways for future research to enhance floating bed's pollutants removal strength (Liu *et al*., 2011).

Now a days this technique is combination of floating bed system, contact oxidation system, aerating system, aquatic phytoremedialplants, microbes, paddings and biological/natural oxidation purification tanks, which all together leads to full advantage of floating bed's cubical space, lengthens food chains in floating bed system and strengthens floating bed's enrichment specialty of microbes, immobilised enzymes, thus enhancing purifying effect (Wang and Cheng, 2010).

In some researchit was shown that a new frame-type floating bed which was made up of aquatic plants, paddings and microbes also by using the principle of biological symbiosis mechanism, and its purification strength was obviously better as compared to traditional floating bed method (Fox *et al*., 2008). Li had alsodevelopeda combined cubical floating bed ecological system and its main body was made up of aquatic plants, aquatic animals and microbes and this combination was proved better removal rate of contaminants/ pollutants(Zhao *et al*., 2011). Development of complex form of Floating rafts structure makes plants, paddings and microbes function together as the primary objective in pollutants removal strength instead of only plants, but how each components are organised together and can leads to improve purifying capacity more effectively and this can be again remains as to be further studied of interest upcoming in the future (Lu *et al*., 2004).

Resource utilization of aquatic plants: Aquatic plants are supposed to be growing rapidly and they also have capacity to gain large biomass in less time. Nutrients such as Nitrogenand Phosphorus etc.which wereabsorbed by plants can be transformed into proteins, amino acids and other nutrient materials and have certain economic value also (Zhou *et al*., 2006). As the aquatic plants have certain age limit and hence they require pruning on time otherwise plants will decay in wastewater, and as a result of that, this not only leads to production of secondary pollution but also leads to wastes of valuable resources (Chen *et al*., 2010). At present, aquatic plants are used in the form of phyto-extraction, exploitation for medical purpose, forage production for animals (Fan *et al*., 2011) and edible vegetables for human being etc., (Li *et al*., 2008). However, the performance of aquatic plant for excess removal of pollutants from wastewater is yet one of the important limiting factors of their ecological restoration in the aquatic environment/condition, and new methods and modification in this technique according to level of pollutants to enhance the performance of floating raft will be a future research direction.

Engineering application: Since long ago, Floating rafts technique is used as an aquatic plants based treatment method for wastewater and eutrophic water. There are many engineering techniques at bothdomestic and international level having gotten good purifying effect, but they also simultaneously having many problems also such as high installation cost, production of secondary pollutants, management of generated sewage sludge etc. However, Floating raft is plant based method of purification, its purifying capacity also depends upon certain climatic factors such as humidity, temperature, wind velocity, mean sea level etc.Nevertheless, once the growth of plant reached to the saturation stage, removal of these plants again will be time consuming and require labour cost (Guoand Zhang, 2010)

Plants used in the Floating rafts require daily care as they are vulnerable to the certain pest and disease with reference to the environmental condition and if the management of plants fail to form systematic specification; Floating rafts working life become short, usually < 6 years (Guoand Zhang, 2010); still there are no technology and management standards to reference in engineering application of floating raft technique. However, Floating rafts technique has excellent merits and above problems/demerits are hindering Floating rafts technology's application and promotion. Therefore, the use of Floating raft technique in combination with technology at broad and field level needs further systematically research.

Conclusion

It has been observed that phyto-remediation of wastewater using the Floating rafts technique is a predominant method which is cost effective to construct as compare to other traditional methods, requires little ornegligible maintenance and increase the biodiversity as the aquatic plants are used. However, different plant species such as Canna, Water lily, Pistia etc, having different pollutants (like TSS, TDS, BOD, COD, EC, hardness, heavy metals, nitrogen phosphorus, etc) removal rate under different conditions. Removal of pollutants also depends upon plant growth stage and hydraulic retention time and initial concentration of pollutants. Many researchers had been concluded; the combination of different plant species had more pollutants removal rates as compare to using single plant species.

ACKNOWLEDGEMENTS

This review study was supported by Indian Institute of Technology (IIT), New Delhi (India) under project entitled "Integrated Technology System for Phyto-remediation of Domestic Wastewater with Floating Rafts (Floating Wetland): R&D and Pilot Testing". The authors are very grateful to the researchers for their results have been used in this review.

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JOURNAL OF PURE AND APPLIED MICROBIOLOGY, June 2017. Vol. **11**(2), p. 1113-1116

Floating Raft Wastewater Treatment System: A Review

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http://dx.doi.org/10.22207/JPAM.11.2.55

(Received: 03 March 2017; accepted: 04 May 2017)

Recently more imbalances are observed in availability and quality of natural resources such as water, which is most precious as well as playing a vital role in the governance of entire natural as well as manmade ecosystem. Hence, the presence of water in good quality is extremely necessary for overall sustainable and eco-friendly development. The floating raft wastewater treatment system is most emerging sustainable and plant-based-eco-friendly method for wastewater treatment since it is totally plant based and there is no more initial requirement of inputs as well as there is no production of harmful by-products into the environment.

Keywords: Floating raft, Phytoremediation, Biofilms, Wastewater.

Floating raft wastewater treatment system (FRWTS) is a manmade ecosystem that mimics natural floating system/habitat. At the beginning of the 20th century, this system was used for birds' habitat and fish's spawning place as natural habitat. In the 1980s, German scholars designed the modern ecological floating bed and used it to purify polluted water for the first time (Nakamura and Shimatani 1997). Floating rafts is a new concept and promising wastewater remediation technology for improving surface water quality in wastewater body where we grow vegetation/plants on artificial floating platforms. This technology basically is an application of hydroponics using artificial floating platforms, where plants grew up and utilize nutrients and organic matter present in the wastewaters and the overall process will lead to treatment/phytoremediation of wastewater in eco-friendly manner. (Sun *et al*., 2009).

Water is our most precious and basically required natural resource, which is a key component for sustainable governance of all ecosystems and further responsible for the great abundance and diversity of life on the earth. However, drastically increasing pollution load in water and simultaneously decreasing in fresh water resources are two most emerging threat to the entire living ecosystem. Heavy metals and metalloids, such as Cd, Pb, Hg, As, Se, etc. are releasing into the environment by mining, industry and agricultural activities, which leads to threatening environmental and human health (Dixit *et al*., 2015). Due to the acute toxicity of these contaminants, there is an urgent need to develop low-cost, effective and sustainable methods to remove them from the environment or to detoxify. Floating rafts is a plant-based approach, like phytoremediation, which is relatively inexpensive since they are performed in-situ and are natural-driven (Duan *et al*., 2016). Since plants play a crucial role in this method as mention by Paulo *et al*, (2014), can improve water quality by accumulate metals in their harvestable biomass (phytoextraction), to release certain metals in a volatile form (phytovolatilization), to degrade complex compounds into simpler compounds (phytodegradation), filtering the metals

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(rhizofiltration) and so on (Fig. 1). FRWTS may represent a comparatively low cost and sustainable engineered best management practice (BMP) for reducing pollution load in wastewater (Wilson et al., 2006). Evaluating their effectiveness as a BMP is a subject of on-going research at GBPUA&T, Pantnagar, Uttarakhand.

Floating Raft

*Bamboo/PVC pipe, coconut coir, and polyethylene mess may use t*o develop low cost eco-friendly floating rafts (Fig. 2). Open textured coarse peat/soil or coconut coir materials that do not become too heavy or anaerobic once saturated are likely to be the most suitable growth media for plant establishment on floating raft. Floating rafts constructed using lengths of large diameter bamboo interwoven or other materials with mats of natural fiber (coconut coir). "The articulated nature of the bamboo means that it contains sealed chambers of air throughout the stem which is naturally buoyant" (Headley and Tanner, 2006).

Plant roots and rhizomes can spread and grow through the matrix (coconut coir/peat), with their roots extending down into the water below. The matrix would also be incorporate with various plant growth media and potentially also reactive/absorptive media (e.g., zeolites or P-absorbing materials) to enhance contaminants removal efficiency of the system.

Plants can grow on floating raft

Aquatic and some other plants which have bioremediation potential for removal of water pollutants and rapid accumulation of pollutants in their biomass are most suitable for this system. Therefore, plants species namely Pistia (*Pistia stratiotes*), Canna (*Canna indica*), American aloe (*Agave americana*) and Water lily (*Nymphaea L.*) etc. may use for lab and field level study for acclimatization/standardization before transferring these plants to field level study.

Development of biofilms

Submerged roots, stem and leaves are believed to play a key role in treatment processes within floating rafts by virtue of the contact that is afforded as the water passes directly through the network of hanging roots and other plant parts that develop beneath the floating mat. Submerged plant parts, *viz*. roots, stem etc. provide a living surface which lead to batter development of biofilms, comprising different communities of attached-micro-organisms, who are responsible for a number of treatment processes for wastewater remediation such as degradation of complex organic and inorganic molecules/pollutants in the simple form (Fig. 3) (Headley and Tanner, 2006).

The rhizospheric zone and associated biofilms are collectively acted as physical trapping for pollutants and particulates within the water column. There are many pollutants and metals, which are associated with specific microorganisms attached to the biofilm develops in submerged condition. The enhanced form submerged biofilm afforded by FRWTS, may make them particularly effective at removing pollutants with greater efficiency. Complexation of metals with root and submerged plant's biofilms, root exudates, humic compounds and other large molecular weight organics followed by deposition may play an important role in metal removal and their detoxification under this method (Headley and Tanner, 2006).

Working concept behind FRWTS

The following processes occur during phytoremediation:

1. Organic matter degradation by microorganisms such as bacteria and fungi on plant root surfaces (rhizosphere).
2. Plant uptake organic, inorganic substances such as nutrients, heavy metals etc. through phytoextraction.
3. The roots of floating plant promote flocculation and sedimentation of suspended materials and filter out sediment and associated pollutants through rhizofiltration.
4. Degradation of plant material and trapped organic matter releases soluble carbon which allows natural de-nitrification to occur in oxygen limited conditions.

Significance

Floating rafts have been used as a low-cost treatment to remove a wide range of contaminants from polluted waters such as municipal wastewater, effluents from industries, oil refineries waste and agricultural runoff and so on.

This paper mainly focused on the basic concept of Floating rafts, its scope, applications and different plant species for removal of different contaminants. Moreover, from the techno-commercial point of view, this paper would be phenomenal for adopting and accelerating concerted efforts of the various concerned organization at the national level, which would be a complimentary efforts for the Namami Gange and Clean India campaign launched by Govt. of India.

Potential advantages of FRWTS

1. Provides design flexibility: Floating raft can be sized to fit into almost any pond, lake, and domestic wastewater drain.
2. *It is eco-friendly- Natural air motion, will allow the raft to move here and there and this movement will add oxygen into the water body to enhance purification efficiency.*
3. Enhances the pollutant removal effectiveness of existing wastewater ponds.

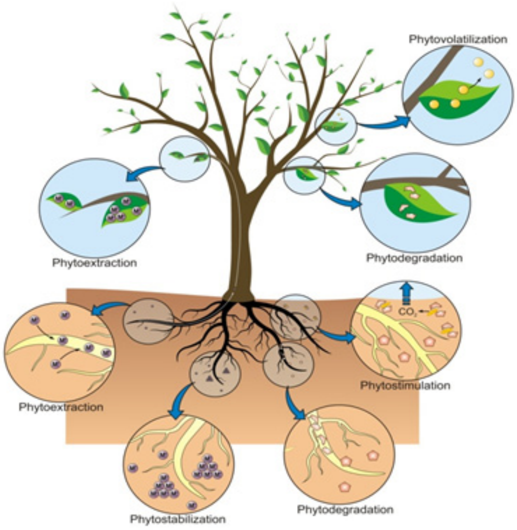

Fig. 1. Pictorial representation of phytoremediation process (Paulo *et al*., 2014)

Fig. 2. Pictorial representation of FRWTS at GBPUA&T, pantnagar

4. Provides a sustainable pollutant removal system and also provides the natural habitat for aquatic animals.
5. Offers resiliency: This system can tolerate storm-event driven water-level fluctuations as long as they are anchored to the bottom or tethered to the shoreline so they are not damaged or lost by flowing through the outlet structure of the pond and rivers.
6. Improves aesthetics: FRWTS can be used to enhance the visual appeal/interest of surface water features like ponds and lakes.
7. One of the key pathways for contaminant removal in floating raft wetland systems is believed to occur via the sequential processes of a release of extracellular enzymes, development of biofilms and promotion of flocculation of suspended matter at the surface of the submerged plant organs.
8. The inclusion of a floating raft wetland over the pond surface provides a barrier against light penetration into the water column, thereby limiting the potential for algae growth.
9. Floating raft wetlands may be perceived to enhance the aesthetic values of a wastewater treatment pond, depending on the shape, structure, and vegetation used.
10. This technique can be utilized profitably for the treatment of wastewater and its reuse by competent authorities of big and small cities as well as cities and towns located on the banks of holy rivers Ganga, Yamuna and others in the country.

Constraints

1. Initial concentrations of pollutants are likely to

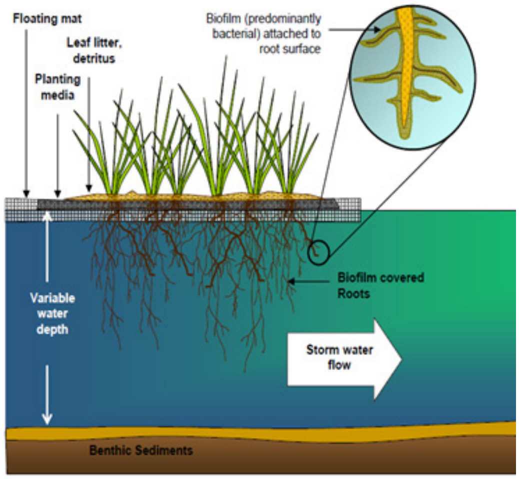

Fig. 3. Development of submerged biofilms (Headley and Tanner, 2006)

decrease the purification efficiency of FRWTS.

2. Hues generation of wastewater is another problem and leads to affect FRWTS's efficiency.

CONCLUSION

Floating raft technology is very easy to install in the village/urban/industrial wastewater pond or river perennially receiving wastewater for their reclamation. It is cost effective and eco-friendly in nature because does not require much maintenance and initial inputs. The output of flowers and value added products from selected plants may lead to additional income source from this wastewater treatment system.

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