ALGAE BASED SEWAGE TREATMENT AND ITS REUSE FOR IRRIGATION AND LANDSCAPING

By

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ABSTRACT

Pakistan is currently facing water shortages in its different cities. Due to continuous rise in population, the water demand has been increased significantly. Since 1990 till now, per capita use of fresh water has been decreased from 5600m^3 to 1000m^3. In Lahore, there are 15 sewerage drains under WASA that are collecting 1810 cusecs municipal sewage and industrial effluents from different localities of Lahore and dumping directly into River Ravi polluting its water. Due to improper or expensive waste water treatment systems and unavailability of fresh water, 26% of the national agricultural land is irrigated with waste water because Pakistan is totally dependent on its single river system for its entire irrigation system. This practice is causing many health problems for the people especially for the farmers. In some areas, use of freshwater for irrigation is causing the unavailability of freshwater for drinking in many other areas. Reuse of waste water after treatment is the only solution of the above mentioned two problems. The role of algae in treating sewage water in oxidation ponds is an economical and efficient way of treating waste water. Algae grow well in waste water and use its nutrients for photosynthesis thus reducing nutrients load on it. Instead of fresh water, this treated water can then safely be used for the irrigation of parks and horticultural areas in Lahore. It will not only reduce the pollution load on River Ravi by reusing this water after treatment but also reduce the use of freshwater for irrigation purposes.

INTRODUCTION

The population of Pakistan has now increased up to 170 million in 2009, which was only 32.5 million at the time of independence in 1947. The increasing population and continuous urbanization in urban areas has posed a serious threat to the limited natural resources of the country. The main reasons for declining water availability are rapid population growth, depleting water storage facilities and contamination of the existing water resources due to discharge of untreated industrial and sewerage effluents into streams and rivers (Kahlown *et al.,* 2006). Pakistan is now a water deficit country suffering from severe water shortfall and pollution problems (PCRWR, 2005). Per capita water availability which was 5300 m^3 has now reduced to 1000 m^3 (WB-SCEA, 2006). Few decades ago, Pakistan was in the list of those countries which had abundance of water resources but then World Bank report in 2008 stated that Pakistan is among the 17 countries that are currently facing water shortage. Major cities of Pakistan, on average, get 3-4 hours water supply which is only 2 hours in some of the small cities. The conditions are becoming worse with the passage of time. To combat this problem, now people have electric motors and pumps in their homes to get water (World Bank report 2008). In Lahore, ground water is the source of water supply. Due to overburden of water demand, the water table of Lahore has declined from 300 feet to 700 feet that means now deeper digging is required to extract water to fulfill increasing demands (WASA, 2005).

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Along with the rapid depletion of water resources, one of the major water problems is the proper disposal of domestic and industrial waste water which is polluting the remaining water resources, affecting the human health, environment and agricultural productivity (Amahmid *et al.*, 2002; Kahlown *et al.*, 2006). Pakistan Council of Research in Water Resources (PCRWR) conducted a detailed study on water quality in 23 major cities in all the four provinces of the country from 2002 to 2006. The results of this study revealed that an average of 84% – 89% of water sources throughout the country have water quality below the recommended standards for human consumption (PCRWR, 2008a). National statistics have revealed that 56% of the total population of Pakistan has access to safe drinking water (Farooq *et al*., 2008). However, when water quality was compared with the international water quality standards, it was estimated that only 25.61% (rural 23.5% and 30% urban) of the population in Pakistan have access to this basic need (Rosemann, 2005).

In Lahore, WASA (Water and Sanitation Agency) is responsible for covering 66% of the Lahore's area to which it provides water and sanitation facilities. There are 15 sewerage drains under WASA which are collecting sewage water from different localities of Lahore and adjacent cities and dispose it off in River Ravi through various pumping stations (WASA, 2005). These 15 drains are: Lakhudair Drain (Mehmood Booti Drain), Sukh Nehr, Shadbagh Drain, Ravi Road Drain, Shahdara Village Drain, Farukhabad Drain, Buddha Ravi Drain, Outfall Drain, Gulshan-e-Ravi Disposal Station, Babu Sabu/Shadman Drain, Hudiara Drain, Jaranwala Drain, Summundri Drain and Gojra Drain (Fig-1). Other than the 15 drains, five irrigation channels and canals, namely Marala Ravi Link Canal, Upper Chenab Canal, Qadirabad Link Canal, Trimu Sidnai Link Canal and Havily Main Line Canal, are also throwing industrial and municipal waste water into the Ravi.

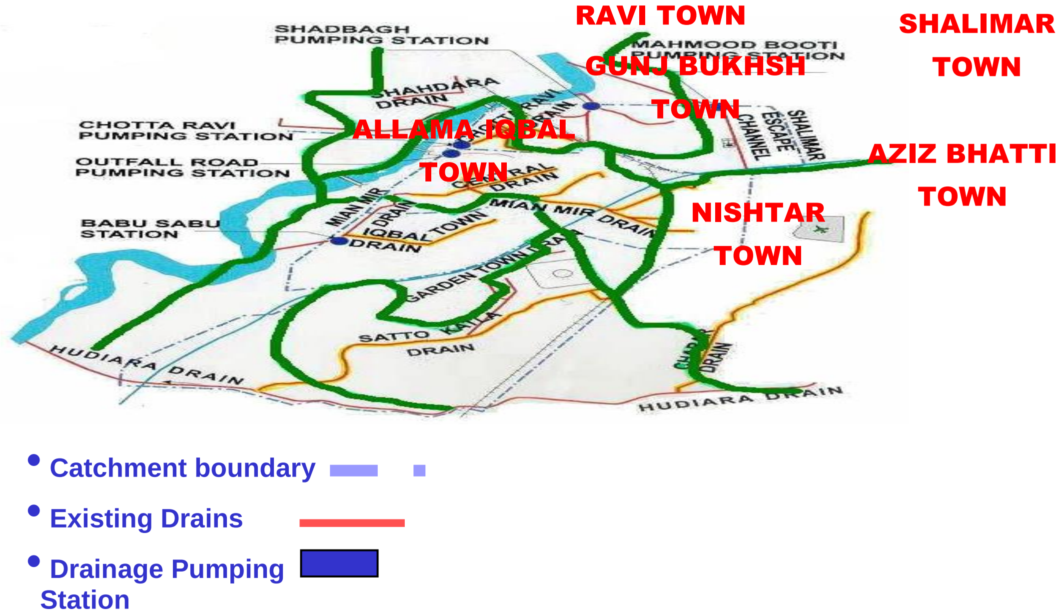

Fig 1: Map of drains in Lahore (WASA reports, 2005)

According to a study carried out by Environmental Protection Department (EPD), Punjab, collectively these drains are discharging about 1,307.08 tonnes hazardous and toxic waste into River Ravi. The load from Lahore is 728.75 tonnes per day which is contributing 56% of the Ravi pollution (Fig-2). It is estimated that, in Pakistan, only 1% of the industrial (MOE-PAK, 2005a) and 8% of urban waste water is treated before entering into the different water bodies (WB-CWRAS, 2005).

Fig-2: Pollution load on River Ravi

USE OF UNTREATED WASTE WATER FOR IRRIGATION: Pakistan is an agricultural country. The water shortage in agricultural sector was 29% in 2010 and will be 33% in 2025 (PCRWR, 2003). Because of it, out of the total national agricultural land about 26% is irrigated with waste water consisted of domestic and industrial waste water for growing crops and vegetables as shown in fig-3 and 4. Waste water contains different microorganisms such as bacteria, viruses and parasites which cause diseases when enter into the food chain. The crop growth and yield is affected by the use of untreated waste water, due to high concentration of nitrogen, phosphorous and potassium. Presence of TDS and heavy metals in waste water cause soil and ground water pollution and prolonged use of waste water is hazardous for soil as it may deteriorate the soil structure (WASA, 2005; Kahlown *et al.*, 2006; Pedreroa *et al.,* 2010).

Fig-3: Irrigation of land with waste water

The irrigation of agricultural land with waste water causes many health problems for the farmers and consumers. The risks from waste water are primarily bacteriological and parasitic. Hookworms and tapeworms, present in human excreta, amoebas and bacteria causing diarrhoea are the major hazards, particularly for the farmers themselves who cannot avoid constant contact with the water they are using. In Pakistan, farmers using raw waste water are five times more likely to suffer from waterborne diseases than those using canal water (Ensink *et al.*, 2004). Consumers are also at risk from leafy vegetables contaminated with pathogens in the irrigation water, and they represent the larger number of people at risk (Scott *et al*., 2004).

Fig-4: (a, b) Discharge of municipal and industrial waste water in drains without any treatment
(c) Effects of sewage application on soil (d) use of municipal waste water for agriculture (Azizullah *et al*., 2010).

CONVENTIONAL WASTE WATER TREATMENT SYSTEMS:

The health and environmental aspects are particularly sensitive before replacing fresh water with the waste water. Waste water cannot be safely used unless it is efficiently treated and all the harmful pathogens and excessive nutrients are fully removed from it. For this, there are many treatment techniques which can be used for the treatment of waste water.

Waste water composition varies from site to site. Organic matter, nitrogen and phosphorous, suspended (SS) or dissolved solids (DS) and microbes are the main components of municipal waste water (Saucedo *et al*., 2006). There are many conventional aerobic and anaerobic treatment facilities available world wide. Aerobic treatments are mostly occurred in the upper layer of the system whereas anaerobic in the lower one. These treatment systems have organic loading of 0.01 kg BOD / m^3 / day and retention time may vary from few to 100 days (Wang, 2005).

ACTIVATED SLUDGE

In the activated sludge process, the dispersed-growth reactor is an aeration tank or basin containing a suspension of the waste water and microorganisms, the mixed liquor. The contents of the aeration tank are mixed vigorously by aeration devices which also supply oxygen to the biological suspension.

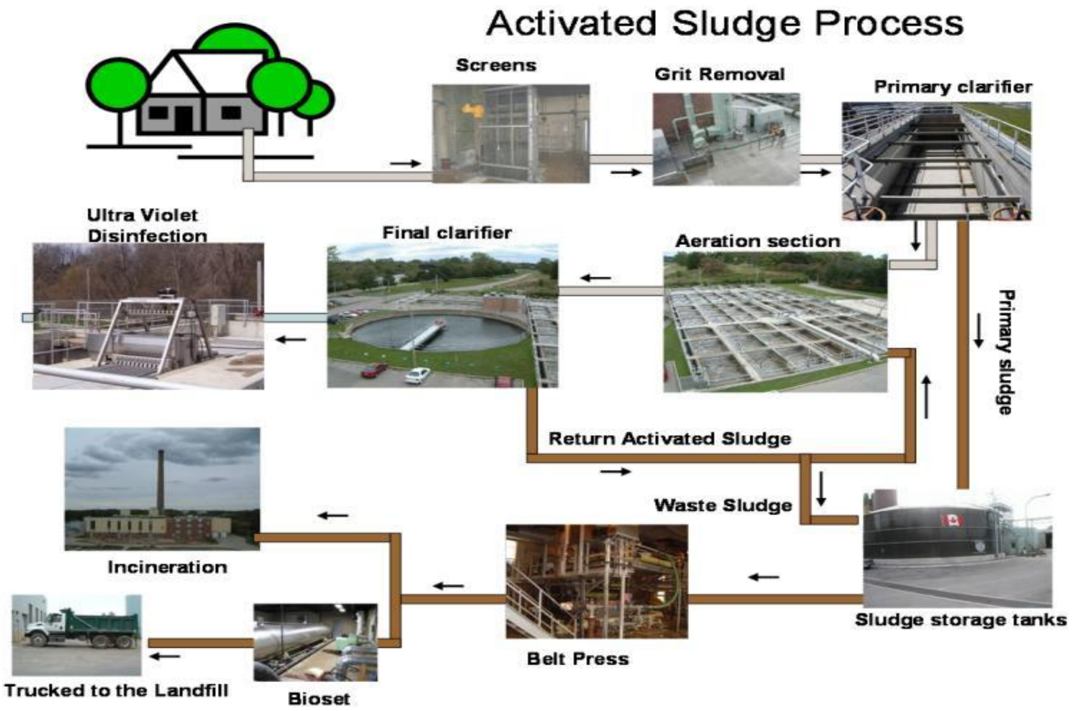

Fig-5: Process of activated sludge treatment (www.london.ca.waste water)

Following the aeration step, the microorganisms are separated from the liquid by sedimentation and the clarified liquid is secondary effluent (fig-5). A portion of the biological sludge is recycled to the aeration basin to maintain a high mixed-liquor suspended solids (MLSS) level. The remainder is removed from the process and sent to sludge processing to maintain a relatively constant concentration of microorganisms in the system. An estimated 1 kg of BOD removed in an activated sludge process requires one kWh of electricity for aeration, which produces one kg of fossil CO_2 from power generation. This CO_2 is a greenhouse gas (Talbot *et al.,* 1991). The US Environmental

Protection Agency (EPA) has specifically categorised this process as major contributor to greenhouse gases. Another problem regarding this process is the production of large amount of hazardous sludge caused by the extensive use of chemicals that has to be disposed off properly in landfills.

UPFLOW ANAEROBIC SLUDGE BLANKET (UASB)

UASB reactors are the most flourishing technology and has performed well from many decades (Seghezzo *et al*., 1998). It has an affinity for BOD and intestine nematode but the suspended and colloidal solids present in the waste water halt the system from operating at increased organic loading rate (OLR), which can in turn cause the deterioration of microbial activity and destroy active biomass (Torkian *et al*., 2003). UASB reactors can be efficiently applied for the pre-treatment of municipal waste water at low temperatures but it requires post- treatment for the removal of COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), ammonia and pathogens (Tawfik *et al*., 2002). The design of UASB reactor is shown in fig-6.

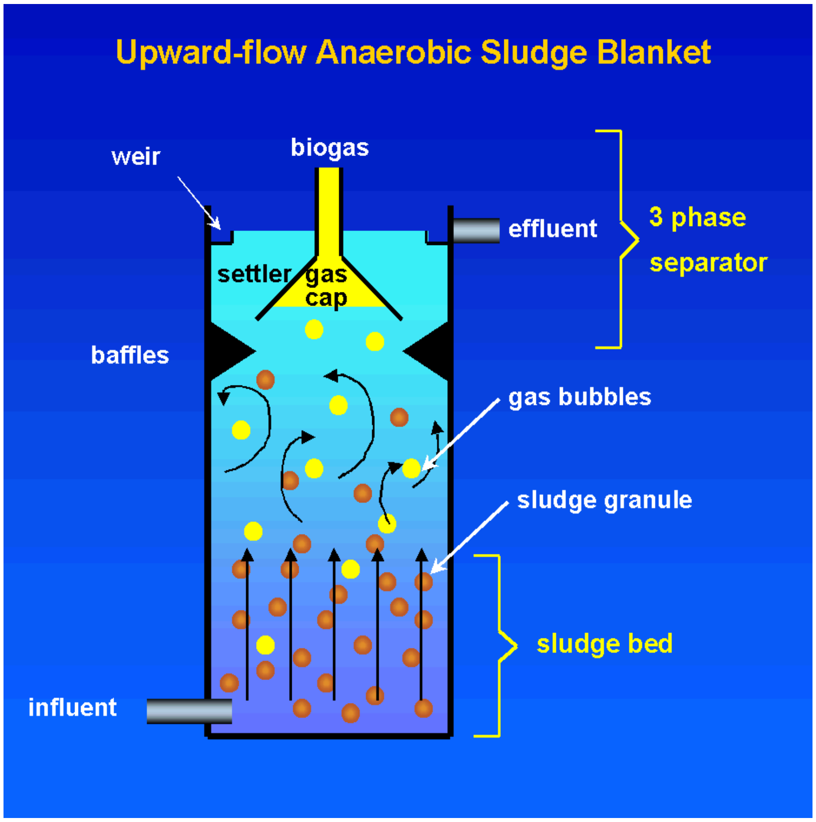

Fig-6: The upflow anaerobic sludge bed (UASB) reactor concept (www.fallingwaterdesigns.com)

TRICKLING FILTERS

A trickling filter or biofilter as shown in the fig-7 consists of a basin or tower filled with support media such as stones, plastic shapes, or wooden slats. Waste water is applied intermittently, or sometimes continuously, over the media. Microorganisms become attached to the media and form a biological layer or fixed film. Organic matter in the waste water diffuses into the film, where it is metabolized. Oxygen is normally supplied to the film by the natural flow of air.

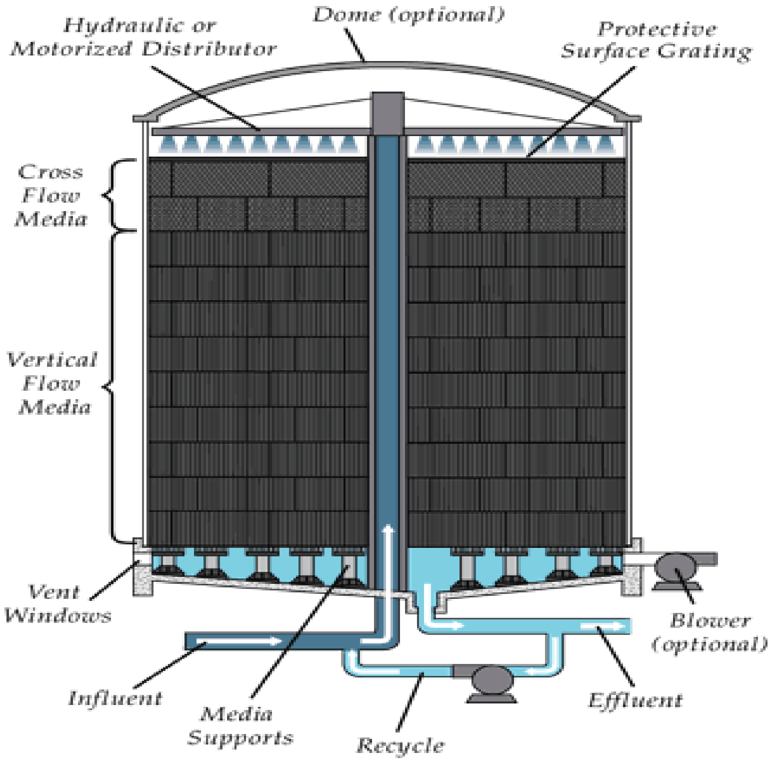

Fig-7: Modern Trickling filter

The thickness of the biofilm increases as new organisms grow. Periodically, portions of the film slough off the media. The sloughed material is separated from the liquid in a secondary clarifier and discharged to sludge processing. Clarified liquid from the secondary clarifier is the secondary effluent and a portion is often recycled to the biofilter to improve hydraulic distribution of the waste water over the filter.

ROTATING BIOLOGICAL CONTACTORS (RBCs)

Rotating biological contactors (RBCs) are fixed-film reactors (fig 8) similar to biofilters in the organisms which are attached to support media. In the case of RBC, the support media are slowly rotating discs that are partially submerged in flowing waste water in the reactor. Oxygen is supplied to the attached biofilm from the air when the film is out of the water and from the liquid when submerged. Sloughed pieces of biofilm are then removed (Urkiaga *et al*., 2008, Cheremisinoff, 2002 and Henze, 2002).

RBC system has represented a remarkable choice for sewage waste water treatment. A comparison of single stage and two stage performance of RBC system, operated at same loading rate gives an account that upto 55% and 77% of overall COD removal efficiency, with 14% and 20% of ammonia and 59% and 96% E. coli removal efficiency can be achieved in single stage and two stage RBC systems, respectively. This system has low energy requirements, less retention time, low operational control and effective process control. But the operational flexibility of this system decreases and limited because it is vulnerable to the characteristics of the waste water. This in turn causes the problem in mechanical drive units and shaft bearing maintenance (Tawfik *et al*., 2002).

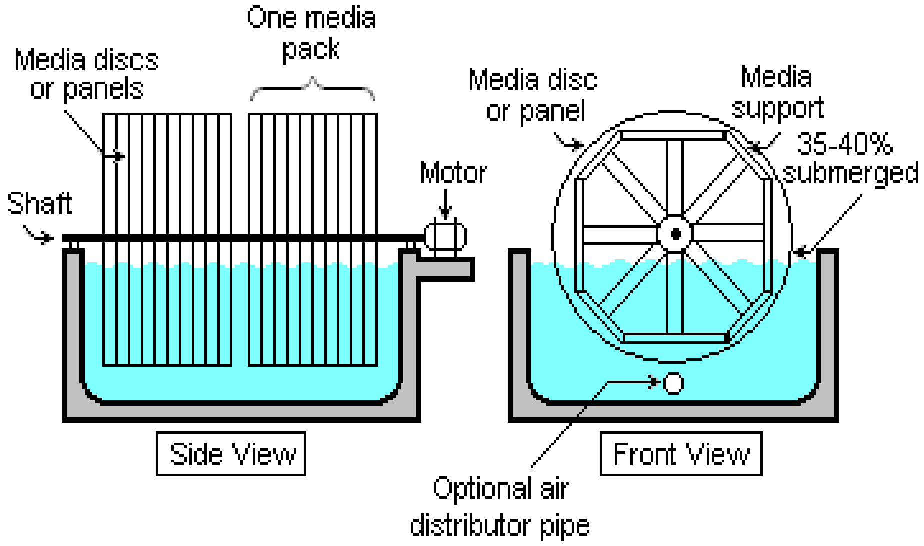

Fig-8: Design of Rotating Biological Contactors

WASTE WATER STABILIZATION PONDS (WWSPs)

Waste water stabilization ponds (WWSPs) are effective and well-functioning especially in warmer climates like Pakistan. The stabilization ponds are further categorized as aerobic, anaerobic, facultative and maturation ponds. Aerobic ponds are large and shallow and use natural processes involving algae and bacteria to treat waste water. In order to achieve optimum results, treatment pumps or surface aerators are used. Anaerobic stabilization ponds are used for the treatment of strong waste water in which anaerobic bacteria are used and sludge is formed, which is then removed after every three to five years. During this treatment due to the decomposition of organic matter some gases are liberated into the atmosphere. The treatment in facultative ponds is facilitated by the stabilization of waste water with the assistance of aerobic, anaerobic and facultative bacteria. They treat water in their respective layers in water. These processes are cost effective and socially beneficial. But they require large area and emit gases which cause global warming. Proper disposal of sludge is another problem with this process (Amahmid *et al*., 2002). A stabilization pond is shown in fig-9.

Fig-9: Waste water Stabilization Pond (www.adad-get.com)

OXIDATION PONDS

These problems are overcome by growing algae in the ponds and tanks where waste water treatment is carried out. Oxidation ponds grown with algae are suitable for tropical countries like Pakistan where temperature is warmer and sunlight is optimum. Algal growth with optimum photosynthetic activity in different climates has been extensively studied during the last few decades (Oswald and Golueke, 1960; Weissman and Goebel, 1987; Tillett, 1988; Walker, 2002, 2009; Melis, 2009). Oxidation ponds treat waste water naturally without adding any substance i.e., chemicals. These ponds have large and shallow basin involving both algae and bacteria as a natural source of treatment in suspension. The algae grown in waste water ponds are shown in fig 9. The main goal of these ponds is to increase the production of oxygen and algae so that aerobic conditions prevail throughout the depth of the pond. Algae play a remarkable role in the treatment of municipal waste water at small and medium scale (Oswald, 1987, 1988; Haglund, and Lindstrom, 1995; Park *et al*., 2011).

Fig-9: Algal Ponds (www.fallingwaterdesigns.com)

Many studies indicated that it has a potential for nitrogen and phosphorous removal by uptake into the cells. Moreover it also removes pathogens, organic contaminants and heavy metals from the domestic waste water ((Lau *et al*., 1994; Luz *et al*., 2004; Muñoz and Guieysse, 2006). It has many advantages of its use, as it provides the possibility of recycling the acclimatized phosphorous and nitrogen into the biomass of algae as a fertilizer. This can avoid the problems regarding the handling and disposal of sludge. The algal biomass produced from the treatment can be harvested and then could be converted through various methods to biofuels for example anaerobic digestion to biogas, transesterification of lipids to biodiesel, fermentation of carbohydrate to bioethanol and high temperature conversion to bio-crude oil (Mata *et al*., 2010).

It does not require any external source of oxygen rather it produces its own oxygen by utilizing CO_2 produced by bacteria, thus reducing the carbon load on environment. During the treatment process, carbon dioxide uptake by algae was measured and concluded that the process is a net carbon dioxide fixer (Reith *et al.,* 2004). Thus it is helpful in greenhouse gases reduction in atmosphere. It also removes heavy metals and pathogens from the waste water. A pH of 9.2 for 24 hours provides a 100% kill of E.coli and most pathogenic bacteria and viruses (Rose *et al*., 1996).

In oxidation ponds, algae have a symbiotic relationship with bacteria (fig 10). It provides the necessary oxygen to aerobic bacteria to biodegrade the organic contaminants of waste water while in turn it utilizes carbon dioxide from bacteria and energy from the sunlight for the synthesis of food. But they do not limit their relation of interaction to a simple oxygen and carbon dioxide exchange (Muñoz and Guieysse, 2006, Luz *et al*., 2004 and Shi *et al*., 2007). Algae has harmful effects on the activity of bacteria too by increasing the dissolved oxygen, pH or even by the secretion of inhibitory metabolites.

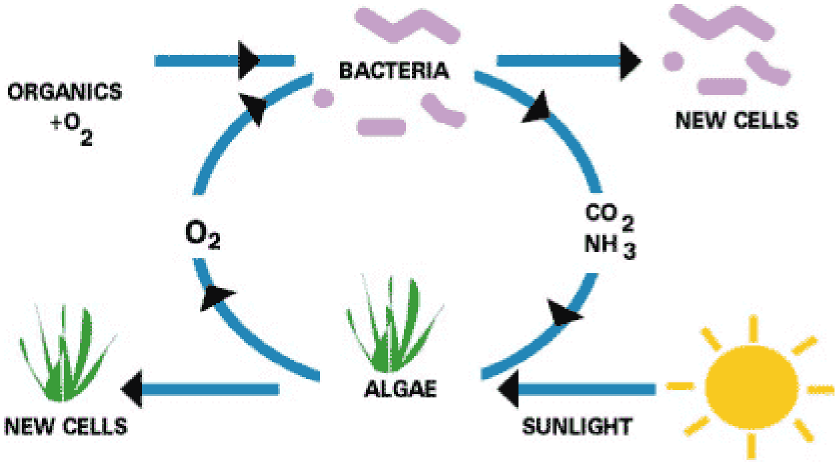

Fig-10: Algae-bacteria Symbiosis (www.thewatertreatments.com)

Different studies have shown that different types of algae have different tendencies for the removal of nutrients from the waste water. Three microalgae, *Chlorella vulgaris* (Lau *et al*., 1994; Luz *et al*., 2004) *Scenedesmus rubescens* and *Stigeoclonium stagnatile* helped to remove about >90% phosphorous from the sewage in oxidation ponds in the time of about 6-12 hours (Bogan, 1961). *Gracilaria birdiae*, a macroalgae, reduced the amount of the nutrients e.g., PO_4^{3-} by 93.5%, NH_4^+ by 34% and NO_3^- by 100% from aquaculture waste water over the period of about 4 weeks (Marinho *et al.,* 2009). A combination of different algae e.g, *Ulva sp., Gracilaria verrucosa* and *Hypnea cornuta* proved to be the best grown species in saline waste water and efficiently removed nutrients from the waste water (Haglund and Lindstrom, 1995).

Algae based waste water treatment system in oxidation ponds is a cost effective way of treatment. It has a low energy cost, lower operation costs and in the end, algae biomass can be used for the production of biofuels (Oswald, 1987, 1988; Ogbonna *et al*., 2000). High operation costs make waste water treatment conventionally unviable in many countries. The cost, use of renewable and nonrenewable energy sources, environmental load and energy yield of conventional waste water treatment systems and algae based treatment systems was compared and it was concluded that algal based treatment systems can significantly reduce the ecological footprint (Groenlund *et al*., 2004).

REUSE OF TREATED WASTE WATER FOR IRRIGATION AND LANDSCAPING:

Waste water can be considered as s a resource that can be used in a more beneficial way rather than being wasted. Reusing waste water for agricultural and landscape irrigation is an opportunity that can potentially reduce the use of canal water for irrigation and helps to save the remaining fresh water resources (Murray and Ray, 2010). In the present time, when Pakistan is currently experiencing a great shortfall of safe drinking water in many of its regions, fresh water must only be used for the domestic purposes and not for the irrigation purposes (Urkiaga *et al.*, 2008).

WASTE WATER RECYCLING OPTIONS

A complete list of the waste water reuse options include:

- Agricultural irrigation: crop irrigation, commercial nurseries
- Landscape irrigation: parks, gardens, green-belts, golf courses, football fields and highway landscaping, school yards, cemeteries
- Recreational/environmental uses: Lakes and ponds, snowmaking
- Aquaculture
- Ground water recharge
- Aquifer recharge for the prevention of seawater intrusion
- Non potable urban uses: fire protection, air conditioning, toilet flushing.
- Industrial uses: cooling, boiler feed, process water (fig 10) (Shuval, 1977; Urkiaga *et al.,* 2008).

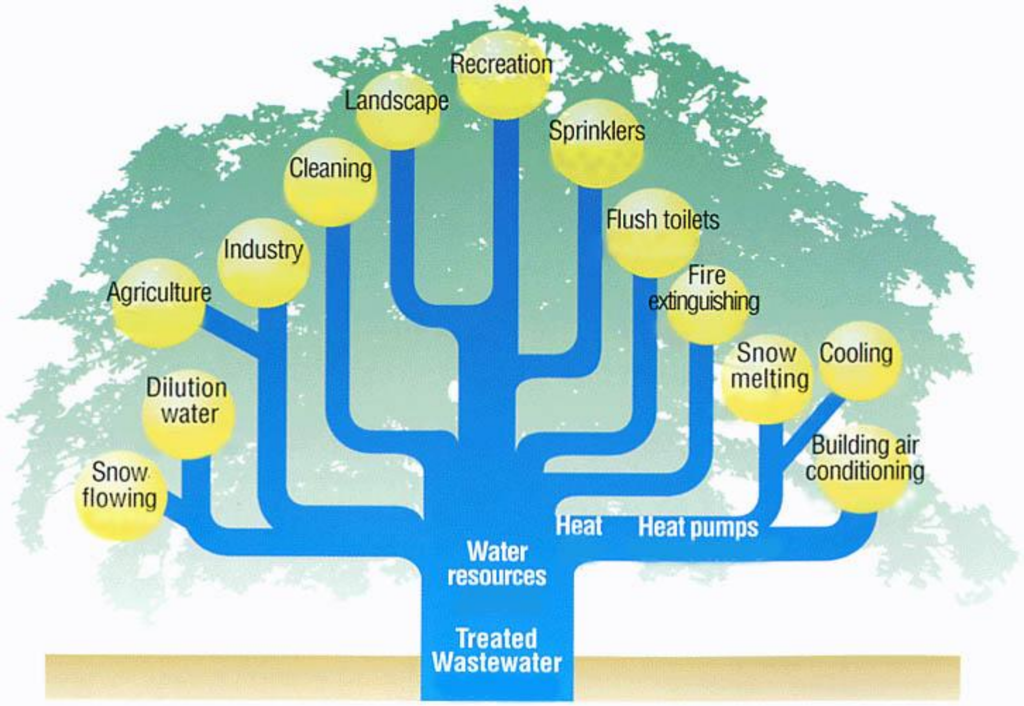

Fig-10: Tree of water resources recycling (MLIT, 2001)

REUSE IN AGRICULTURE

Agricultural irrigation is important for improving the quality and quantity of production. Worldwide, agriculture is the largest user of water. Agriculture receives 67% of total water withdrawal and accounts for 86% of consumption in 2000 (UNESCO, 2000). By 2025, agriculture is expected to increase its water requirements by 1.2 times (Shiklomanov, 1999). Large-scale irrigation projects have accelerated the disappearance of water bodies, such as the Aral Sea, the Iraqi Marshlands, and Lake Chad in West Africa. Thus, more efficient use of agricultural water through waste water reuse is essential for sustainable water management.

Reuse of waste water for agricultural irrigation is practiced today in almost all the arid zone areas of the world. Many countries like India, Tunisia, the Republic of South Africa, the Hashemite Kingdom of Jordan and Israel have made national water resources planning policies based on maximum recycling of urban waste water for agricultural purposes. Waste water reuse in agriculture is a common practice in Spain and Greece where almost all the waste water that is produced is treated and reused in agriculture (Pedrero *et al.,* 2010). In Pakistan, where crops are not grown at its maximum potential because of unavailability of water, treated waste water can be used for irrigation. It has a reliable supply so the farmers can water the crops easily at the right time. The water shortage problem which was about 29% in 2010 and increasing day by day can be resolved. Other than this, the diseases caused by use of untreated waste water in agricultural lands can be reduced. This can be an attractive solution both for the country and for its agricultural land (Asano, 1998; Carr, 2003; Metcalf and Eddy, 2003; Urkiaga *et al.,* 2008).

ADVANTAGES

Advantages of waste water reuse for agriculture include the following:

- It will help to conserve freshwater resources and their wise use particularly in areas under water stress.
- It will avoid surface water pollution caused by the release of untreated waste water in rivers and lakes.
- Reduced prevalence of diseases which are caused by the use of untreated waste water for irrigation where water is unavailable for the cultivation of crops.
- Contribution to better nutrition and food security for many households (WHO, 1989).

LANDSCAPING:

In urban areas there is a high potential for waste water reuse and different reuse options may play a significant role in controlling water consumption and reducing its pollutant load on the environment. A large percentage of water used for landscaping does not need quality as high as that of drinking water. Dual distribution systems (one for drinking water and the other for reclaimed water) have been utilized widely in various countries, especially in highly concentrated cities of the developed countries. This system makes treated waste water usable for various urban activities as an alternative water source in the area, and contributes to the conservation of limited water resources (Japan Sewage Works Association, 2005).

Landscape irrigation includes the irrigation of parks, play grounds, golf courses, freeway medians, landscaped areas around commercial, office, and industrial developments and landscape areas around residences. Lahore is the city of gardens like Shalimar Gardens, Hazuri Bagh, Iqbal Park, Mochi bagh, Model Town Park, Racecourse Park, Nasir Bagh Lahore, Jallo Park, Wild Life Park, and Changa Manga an artificial forest near Lahore in the Kasur district and many more. These parks are irrigated with fresh water on daily basis. These parks and other landscaping areas can be irrigated with the treated waste water.

Recreational uses involve a number of non-potable uses related to land-based water features such as the development of recreational lakes, marsh enhancement, and stream-flow augmentation. Reclaimed water impoundments can be incorporated into urban landscape developments. Man-made lakes, golf course storage ponds, and water traps can be supplied with reclaimed water. Aquaculture and fish farming is a growing industry in Pakistan contributing about 1% to the GDP of Pakistan. Treated waste water can be used for this industry as well. It will provide food to the people and will help to grow export to foreign industry ((Asano, 1998; Carr, 2003; Metcalf and Eddy, 2003; Urkiaga *et al.,* 2008).

ADVANTAGES

The advantages of waste water reuse for landscaping include the following:

- The key advantage for using waste water for landscaping is the increased availability of water for the management of parks and recreational areas which will help to increase the aesthetic beauty of the city and to maintain its greenery. It will provide public benefits such as aesthetic enjoyment and support ecosystem recovery.

- The creation of artificial ponds and lakes with reclaimed water can be beneficial for the revival of aquatic life such as fish, insects, crawfish and shellfish and creating comfortable urban spaces and scenery. The recovery of water channels has great significance for creating ‘ecological corridors’ in urban areas (UNEP Report).

CONCLUSION:

- Waste water can be considered as a precious resource that can be used to fulfill our growing demands of water. Due to scarcity of canal water, waste water, after adequate treatment, must be used for irrigation of agricultural lands and landscaping.
- Waste water recycling and reuse is an economically attractive strategy to conserve water resources and nutrients for the urban and industrial waste water stream as a significant supplement to the water resources of an area.
- Treatment of waste water in oxidation ponds in the presence of algae is an efficient and economical way of treating waste water. Oxidation ponds require no external source of energy i.e., aerators, pumps rather they utilize natural source of light i.e., sun and produce oxygen by algae during photosynthesis which facilitates the growth of bacteria in optimum way. Thus they are economically feasible for treating waste water.
- Oxidation ponds do not require any special skill or expertise for handling so they are easy in operation and management than the advance mechanized treatment facilities.

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