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Review article

Comparison on efficiency of various techniques in treatment of waste and sewage water – A comprehensive review

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Abstract

In the present scenario, environmental laws have become stringent towards health, economy and reduction of pollution. The pollution is a result of discharge of various organic and inorganic substances into the environment. The sources of pollution include domestic agricultural and industrial water. Conventional techniques such as chemical precipitation, carbon adsorption, ion exchange, evaporations and membrane processes are found to be effective in treatment of waste and sewage water. Recently, biological treatments have gained popularity to remove toxic and other harmful substances. The objective of the paper is to make comprehensive review including the performance of each technique in treatment of waste and sewage water. The research directions are also suggested based on the review.

Keywords: Waste water; Sewage; Conventional treatment; Biological treatment

1. Introduction

Water is one of the most important substances on earth. All plants and animals must have water to survive. If there is no water there would be no life on earth. It covers about 71% of the Earth's surface, and is vital for all known forms of life. But only 2.5% of the Earth's water is fresh water. Rapid urbanization and industrialization releases enormous volumes of wastewater, which is increasingly utilized as a valuable resource for irrigation in urban and peri-urban agriculture. It drives significant economic activity, supports countless livelihoods particularly those of poor farmers, and substantially changes the water quality of natural water bodies [1]. Due to industrialization and urbanization, it is becoming more polluted and risk of this polluted water consumption and its sanitation problem is increasing day to day in most of the developing countries. This growing problem of water scarcity has significant negative influence on economic development, human livelihoods, and environmental quality throughout the world. Hence it has become an essential need for today's environment to protect water from getting polluted or to develop cost effective remedial method for its protection. It is estimated that approximately 1.1 billion people globally drink unsafe water. The World Bank estimates 21% of the communicable diseases, in India, are water related. Of these diseases, diarrhea alone is estimated to have killed over 535,000 Indians in 2004. The major microbial populations found in wastewater treatment systems are bacteria, protozoa, viruses, fungi, algae and helminthes. The presence of most of these organisms in water leads to spread of diseases. The two major chemical pollutants in wastewater are nitrogen and phosphorus. Although there are other chemical pollutants, such as heavy metals, detergents and pesticides, nitrogen and phosphorus are the most frequent limiting nutrients in eutrophication. The various conventional methods for waste water treatment are present since ancient times [2–4] but they are very costly and not economical. The advanced new green technical methods are being introduced to overcome the conventional methods of waste water treatment [4]. The present study is related to new green technical methods which are proving them to be superior over the conventional methods; out of them low cost waste water treatment using microalgae is the potential one. From the literature, it is noted that the new methods of waste water treatment are due to microalgae and they are prone to be efficient in reducing the toxic components. Human development and rapid population growth exert numerous pressures on the quality and access to water resources. This is felt strongest at the interface between water and

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human health; wherein infectious, water borne diseases remain the leading causes of human morbidity and mortality worldwide.

Some techniques deal with reduction of heavy metals whereas other techniques deal with reduction of nitrogen and phosphorus. It is found that the conventional techniques are not efficient in reducing the toxic, heavy metals, nitrogen, phosphorous etc.

There is no unique method to treat most of the compounds in a single step. The main aim of the present paper is to discuss the technological advancements in treatment of waste and sewage water.

2. Background information

Methods of wastewater treatment were first developed in response to the adverse conditions caused by the discharge of wastewater to the environment and the concern for public health. Further, as cities became larger, limited land was available for wastewater treatment and disposal, principally by irrigation and intermittent filtration. Also, as populations grew, the quantity of wastewater generated rose rapidly and the deteriorating quality of this huge amount of wastewater exceeded the self-purification capacity of the streams and river bodies.

Therefore, other methods of treatment were developed to accelerate the forces of nature under controlled conditions in treatment facilities of comparatively smaller size. Although cleanup is necessary to prevent any further discharge of contaminated wastes into the environment, a cost effective technology needs to be developed for industry to use. Traditionally methods employed for wastewater remediation consist of removal of metals by filtration, flocculation, activated charcoal and ion exchange resins [5–7]. In general, from about 1900 to early 1970s, treatment objectives were concerned with: (i) the removal of suspended and floatable material from waste water, (ii) the treatment of biodegradable organics (BOD removal) and (iii) the elimination of disease-causing pathogenic micro-organisms. From the early 1970s to about 1990s, wastewater treatment focused on aesthetic and environmental concerns. The earlier tasks of reduction and removal of BOD, suspended solids, and pathogenic micro-organism were continued, but at larger levels. Removal of nutrients such as nitrogen and phosphorus also began to be addressed, particularly in some of the streams and lakes. Major initiatives were taken around the globe, to achieve more effective and widespread treatment of wastewater to improve the quality of the surface waters. This effort was due to (i) an increased understanding of the environmental effects caused by wastewater discharges and (ii) a knowledge on the adverse long term effects caused by the discharge of some of the specific constituents found in wastewater. Since 1990, because of increased scientific knowledge and an expanded information base, wastewater treatment has begun to focus on the health concerns related to toxic and potentially toxic chemicals released into the environment. The water quality improvement objectives of the 1970s have continued, but the emphases have shifted to the definition and removal of toxic and trace compounds, that could possibly cause long-term health effects and adverse environmental impacts. As a consequence, while the early treatment objectives remain valid today, the required degree of treatment has increased significantly and additional treatment objectives and goals have been added. A typical Dewats system consists of primary and secondary treatments, and disposal (or utilization) of solids and treated water. The primary treatment may be as simple as a septic tank, to remove settleable solids (and provide limited anaerobic treatment), which can be used in areas of poor soil and high groundwater. Modifications of the above system enable aerobic treatment of the effluent and prevent floating solids from entering the secondary treatment. Although cheap and require little maintenance, they are prone to failure and even when operating effectively may still leave a pathogen-rich waste stream. Secondary treatment options, based on sand filters, provide effective removal of pathogens in areas with deep permeable soils, but are ineffective in other locales with highly permeable soil type. There has been a tremendous amount of attention given to the use of biological systems for removal of radio nuclides and heavy metals from solutions. Massoud et al. [8] and Parkinson and Tayler [9] made a comprehensive review on existing treatment methods. All biological-treatment processes take advantage of the ability of microorganisms to use diverse wastewater constituents to provide the energy for microbial metabolism and the building blocks for cell synthesis. This metabolic activity can remove contaminants that are as varied as raw materials and by-products. The content of residual toxic metals in wastewater treatment plants influences the choice of the removal method to be used. Several methods have been applied for final treatment, such as adsorption using activated carbon or other appropriate sorbents, post precipitation, ion-exchange, reverse osmosis, electrochemical treatment and evaporation [10,11].

3. Conventional methods

Conventional methods for removing metals are either becoming inadequate to meet current stringent regulatory effluent limits or are increasing in cost. As a result, alternative, cost effective technologies are in high demand. Conventional techniques for removing dissolved heavy metals include chemical precipitation, carbon adsorption, ion exchange, evaporations and membrane processes [7]. The selection of a particular treatment technique primarily depends on a variety of factors, e.g. waste type and concentration, effluent heterogeneity, required level of cleanup, as well as economic factors. The use of biological materials, including living and non-living micro-organisms, to remove and recover toxic or precious metals from industrial waste waters has gained popularity over the years due to increased performance, availability and low cost of raw materials [12–14], microorganisms including bacteria [15]. Algae [16] and fungi and yeasts [17] can efficiently accumulate heavy metal from their external environment [18–20]. The fundamental reason for the treatment of wastewater is to circumvent the effect of pollution of water sources and protect public health through safeguarding of water sources against the spread of diseases. This is carried out through a variety of treatment systems, which could be onsite treatment systems or offsite treatment systems. This section is therefore aimed at describing the offsite (activated sludge, trickling filters, stabilization ponds, constructed wetlands, membrane bioreactors) wastewater treatment system. All biological-treatment processes take advantage of the ability of microorganisms to use diverse wastewater constituents to provide the energy for microbial metabolism and the building blocks for cell synthesis. This metabolic activity can remove contaminants that are varied as raw materials and by-products.

4. Activated sludge

The activated sludge is a process with high concentration of microorganisms, basically bacteria, protozoa and fungi, which are present as loose clumped mass of fine particles that are kept in suspension by stirring, with the aim of removing organic matter from wastewater. In recent years, biosorption has emerged as a cost-effective and efficient alternative for the removal of heavy metals from wastewaters [21,22]. Many types of biomass in non-living form have been studied for their heavy metal uptake capacities and suitability to be used as bases for bio sorbent development. He and Chen [23] performed a review on biosorption of heavy metals by algal biomass. These include bacteria [12], marine algae [24] and others [25]. Biosorption is a sorption process, where biomaterial or biopolymer is engaged as sorbent. The phenomenon of biosorption was observed in early 1970s when the radioactive elements (also heavy metals) in the wastewater released from a nuclear power station were found to be concentrated by several algae. Early research conducted in laboratory studies had demonstrated that biosorption was a promising and cost-effective technology for the removal of heavy metals from aqueous solutions. Compared with conventional methods such as chemical reduction, ion exchange, precipitation, and membrane separation, biosorption technology possesses several advantages: low operating cost, high efficiency in detoxifying heavy metals that have lower concentrations, less amount of spent biosorbent for final disposal, and no nutrient requirements [26]. The term bio refers to the life which here means the micro organism that can be potentially used to treat waste water treatment. Several microorganisms were employed to remove nutrients and toxic chemicals. Todd and Josephson [27] employed biological methods for treatment of sewage water. Twelve key factors were discussed including mineral diversity, nutrient reservoirs, steep gradients, high exchange rates, mesocosm structure, sub ecosystems, periodic and random pulses, cellular design microbial communities, photosynthetic bases, animal diversity, biological exchanges beyond the mesocosm, and mesocosm/macrocosm relationships. Norström [28] studied the treatment of wastewater using the different biological treatments and efficiency of those systems in removing the inorganic matter which serves as the nutrient for them. They are anoxic tanks, hydroponic tanks, and aerated tanks and algae tanks with planted sand filters.

A combined treatment involving microbiological processes and hydroponics was given for treatment of domestic water. The treatment is found to be effective and the limitation is significant recycling of nitrogen and phosphorus through harvested biomass. The biological treatment especially fungi and bacteria for treating the waste water especially the colored compounds in the molasses based distilleries effluents was studied by Adholeya and Pant [29]. It was mentioned that the biological treatment along with enzymatic digestion is better and safe method when compared to other physical and chemical treatments. Wang [30] performed idle regime (O/A/O/EI) method to increase the phosphorous removing bacteria with the aim of reducing or inhibiting the free nitrous acid emission during the biological degradation of waste by microorganisms. The performance of O/A/O reactors and O/A/O/EI reactors and also the effect of inhibition of free nitrous acid levels on PAO metabolisms between two reactors were compared. The O/A/O/EI reactors showed good result in improving the growth of the phosphorous removing bacteria and also inhibit the free nitrous acid. The effect of inhibitory of free nitrous acid on other metabolism of the waste water is not studied. Wu et al. [31] provided the information about microorganism's vital role in removing the pollutants by consuming the inorganic nutrients in the polluted environment. The microbe cleans the pollutants by assimilation, consumption of organic material, and adsorption. It was mentioned that the biofilm formed by the microbes plays a major role in removing the heavy metals, organic matter, phenol, nitrates, pentachlorophenol, trichlorophenol, sulfates and quinoline. From the waste water the natural foaming bacterial species were isolated and sequenced by Zhang [32]. The factors that cause foam were also determined. The role of bacteria in foaming and activated sludge formation was studied in depth. El-Enany and Issa [33] carried out studies on the metal tolerance cyanobacteria Nostoc linckia and rivularis to grow in the sewage water and estimated its growth rate, its metal absorbance capacity and its cellular content. Nostoc rivularis was found to be effective in absorbance of the heavy metals by producing more metal binding protein. The details related to the status of cyanobacteria and difference between removal of cyano bacteria and bacteria and algae after absorption of heavy metals are found to be lacking in the study.

5. Heavy metal treatment

A wide variety of active and inactive organisms have been employed as biosorbents to sequester heavy metal ions from aqueous solutions. It has been found that biosorbents are rich in organic ligands or the functional groups, which play a dominant role in removal of various heavy metal contaminants. The important functional groups are carboxyl, hydroxyl, sulfate, phosphate, and amine groups. As heavy metals are non-biodegradable, clean-up of contaminated water and soil is rather challenging. It is an emerging need to develop cost-effective technologies that can remove heavy metals from contaminated soil and water. The currently practiced contaminated water and soil technologies are precipitation, adsorption, reduction, coagulation, and membrane filtration. Their performances are generally acceptable; however, they have several drawbacks. In particular, they cannot work very well in treating heavy metals, particularly when concentrations are very high. Sorption process has been extensively used to remove toxic metals from aquatic medium using low cost adsorbents such as agriculture wastes and activated carbon developed from agriculture wastes [34–36]. Among the most promising biomaterial is algal biomass [24,37–46]. The presence of carboxylic (–COOH), sulfonic (–SO3H) and hydroxyl (–OH) groups in the marine algae polysaccharides is observed to be responsible for impressive metal uptake by marine algae [47,48]. Moreover, the macroscopic structures for marine algae present a convenient basis for the production of biosorbent particles suitable for sorption process [49]. Algae are found to absorb heavy metals while treating the waste water. Javadian [50] studied the kinetics of absorption of chromium using Flame atomic absorption spectrometry. A New method was proposed for treating industrial heavy metal water treatment using algae. From the study the doubt arises whether pre-treatment is necessary to make algae as biosorbents. Harja et al. [51] developed the oil extraction from algae waste which was activated by alkaline treatment to remove the cadmium II in batch and column studies. Various models like Langmuir, pseudo second order isotherm, Thomas, Adams, and Yoo–Nelson were used to describe the kinetic models of batch and columns respectively. The treated algae are found to be efficient in removing cadmium II. The limitation is treatment with alkaline, which is difficult for industrial process. Ghorbanzadeh Mashkani [52] has made Azolla as biosorption material by chemical modification and tested to remove the Cs and Sr solutions. The toxicity of those metals in normal algae growth was studied. Micro particle induced X ray emission and FTIR were used to study the absorption isotherm. A new method for chemical mapping at atomic level micrometer size level was used. The best result was obtained at pH 8.8. Even though the results are encouraging every time chemical modification is quite difficult at industry level. Dhaouadi et al. [45] used dried algae culture to estimate the removal of the heavy metals from solutions in batch and continuous reactors. The non linear modelization was used to study the absorption kinetics. The result using the retention time was obtained and very successfully predicted. Obtaining dry powders and culturing is the only difficult step in this study. Marine red alga *Pterocladia capillacea* both normal and activated carbon obtained by acid dehydration form were estimated by EI Nemr [53] to remove hexavalent chromium from solution. Absorbance isotherm was estimated using Langmuir model. The ability of both activated carbon and normal algae in natural, synthetic sea water and waste water was also estimated. Both dried algae and activated carbon are found to absorb the toxic chromium at high pH. They are promising in removing toxic chromium from all types of water and different solutions but obtaining dry powders and activated carbon is not found to be efficient method. The limitation of the study is w.r.t. recycling which is not possible and biomass production.

The algae biomass Macro (Fucus) and Micro algae (spirulina etc.) were immobilized or encapsulated in the silica sols of three different types by Soltmann [54]. The efficiency of the immobilized biocers was tested for absorbance of nickel, chromium, copper and lead in drinking water. The structure of biocers was analyzed by SEM and light microscope. The gels have good mechanical strength and have high capacity to absorb the metals in gel condition. Hence it is the easy and cost effective method. The limitation of the study is w.r.t. recycling which is not possible and biomass production. Park et al. [55] made the macro brown algae Undaria pinnatifida into chars by both physical and chemical methods and used to absorb the copper metals in solution. The absorption isotherm was studied using pseudo second order kinetic models; even small amount has highest capacity to absorb the metals at low concentration. It is not applicable to industrial scale because of slow growth of macro algae and its process into chars requires more equipment, leading to uneconomical. Daniel [56] tested the biomass containing both algae and bacteria for removing heavy metal (cadmium and copper) from industrial waste. The biomass was cultured in the artificial stream waste water. The biosorption of the metals was estimated and modeled using Langmuir isotherm. The dried biomasses in the batch experiments are observed to be efficiently good in removing the copper and cadmium at maximal rate which shows that microbial biomass has high affinity for metals. The biomass immobilization is not efficient and promising method for treatment. Treatment using live algae and bacteria forms is the alternative.

6. Treatment especially for endocrine disrupting chemicals (EDC)

Conventional wastewater treatment processes are not specifically designed to degrade traces of dangerous organic contaminants, and these are consumed by aquatic organisms, which is a hazard to the whole food chain. Activated sludge systems have been successfully applied to treat a wide variety of waste waters. More than 90% of the municipal and industrial wastewater treatment plants are being used with this treatment. Activated sludge systems have been widely used for the degradation of organic compounds from paper mill waste waters. Several microorganisms, including bacteria, fungi and yeasts, predominantly aerobic microorganisms, are known for their ability to degrade hydrocarbons to carbon dioxide, water and bacterial cells. Contact reactors are methods that use anaerobic processes that are commonly used to treat pulp and paper mill effluents. According to Vidal and Diez [57], the proportion of EDC degradation by primary settling, aerating volatilization, chemical precipitation, and sludge absorption is relatively small; however the majority of EDC degradation from wastewater is regarded as biodegradation. Incomplete removal of EDCs by existing biological wastewater treatment plants (BWTPs) not only results from the fluctuation of EDC levels in the influent, but also from the processes in BWTPs and from operational conditions. The biodegradability by anaerobic treatment is strongly dependent on the characteristics of the wastewater [58]. Further the biodegradation is also influenced by numerous chemical factors, such as structural properties and environmental factors. Integrated algal systems can be used for wastewater treatment and bioremediation to capture carbon, nitrogen and phosphorus from specialty industrial, municipal and agriculture wastes. Algae are therefore an attractive bio factory for establishing a sustainable community such as the one envisioned for Cotton Plant, AR where Green Wisdom Inc. plans to implement an integrated algal production system to recycle agricultural wastes for biofuel.

In the present scenario, waste water treatment is advanced towards the elimination of specific toxic chemicals in the waste water even after water is purified by several chemicals, filters, and osmosis. Activated sludge process cannot remove complicated chemical structure which causes serious health hazards in humans especially in aquatic and animals in terrestrial. The effects are in the hormone systems especially in endocrine systems where these compounds mimic the natural hormone and cause severe reproductive health hazards, breast and prostate cancer [59]. These compounds are present in oral contraceptives, plastics, and personal care products like dyes, shampoos etc which are released daily. Campbell et al. [60] mentioned the list of organisms that are affected by endocrine disruptors especially frogs and fishes which are mostly affected by gonadal abnormalities. Detection of this compound and elimination before it occupies the whole environment is a must. Campbell et al. [60] also expressed the biological monitoring of this compound by various assays like non cellular, cellular assays and whole organism assays. Hence this proves that EDC compounds travel in organism and cause biological and physiological changes. The commonly used waste water treatment does not remove those chemicals. Zhang and Zhou [61] analyzed mainly six estrogen disturbing compounds like bisphenol A (BPA), diethylstilbestrol (DES), 17a-ethynylestradiol (EE2), 17b-estradiol (E2), estriol (E3), and estrone (E1) in six municipal waste waters and also analyzed the efficiency of plants in treating the estrogen compounds. The compounds were analyzed using GCMC. The ordinary effluent treatment is also found to have efficiency in treating the endocrine disrupting compound. Still the toxicity of the compounds and concentration of the compound prevail. Treatment is costly and requires three level processing treatments. Westerhoff [62] estimated the removal of many EDC and personal and Pharmacare products in the normal drinking water treatment plants by inducing the 10–250 mg/l of 62 different EDC and Pharmacare products in the water sample using GCMS and LCMS. The treatments include chemical treatments, powder activated carbon, ozonation, chlorination and oxidant quenching. Each treatment removes the compounds in its own way to a large extent. This is failure model because of over usage of chemicals which affects the quality of drinking water. This is costly and the process produces the degraded products which is again an EDC compound. Thus normal physical and chemical treatments are not suitable for these compounds. Balabanic [63] collected the pilot plant samples installed in paper mill before and after treatment for the estimation of seven endocrine disrupting chemicals before and after treatment of GCMC. The pilot plant A consists of anaerobic biodegradation and aerobic biodegradation followed by ultra filtration and reverse osmosis filtration. The pilot plant B consists of anaerobic reactor followed by Membrane reactor and Reverse osmosis. They also used lab scale treatment like Fenton reaction, Photo Fenton reaction, Photocatalysis with TiO_2 and Ozonation. The reverse osmosis, Photo Fenton reaction and membrane bioreactor are found to be effective in removing the EDC compounds effectively. The activated sludge was also found to be efficient in treating these chemicals. The treatment is costly and cannot be implemented in industries. Large scale establishment of photo Fenton reaction is very difficult. Liu [58] made the comparison of wastewater treatment both biodegradation and chemical oxidation in removing the EDC compounds. Thus the biological degradation is most efficient, safe and less costly when compared to chemical method which is costly and gives toxic byproducts. Gattullo [64] studied on the reduction of 1 mg/l 4 Nonylphenol in water using the ryegrass and radish in the presence of Humic acid and River natural organic matter at different concentration ratio using HPLC. They experimented on the both the stages of plant (germination and growth). They studied the effect of humic acid and natural organic matter in helping the plant to remove the nonylphenol and also studied the level of residual nonylphenol in the plant. Both the plants were able to successfully remove the nonylphenol at almost equal to 1 mg/l at the early stages of their germination and also have tolerance to nonylphenol. Only few nonylphenols resided in the plant. Humic acid and natural organic matter have helped the plant in synthesizing the more nonylphenol degrading enzyme. When compared to bisphenol, a removal by ryegrass and radish, the nonylphenol was removed less efficiently due to hydrophobicity of nonylphenol. Humic acid was said to show little toxicity but the studies about the toxicity are lacking. The field studies of plant and its efficiency in removing the nonylphenol are lacking. Gulnaz and Dincer [65] isolated the Aeromonas bacteria from oil spilled soil and obtained algae culture from Algae Culture Laboratories, Faculty of Fisheries, Turkey. They studied the bisphenol a degrading capacity of algae and bacteria. Bisphenol concentration and their intermediate products were studied using GC and GCMS. The endocrine disrupting activity of bisphenol using yeast assay was also studied. Both algae and bacteria have shown to degrade the bisphenol. Almost completely and their degraded product also does not show any estrogenic activity. They can be successfully applied at industrial level. The comparative studies of normal bacteria and algae with bisphenol added bacteria and algae are found to be less. The algae have superior characteristics to remove the toxic chemicals and organic chemicals. Ying [66] used four microalgae *Chlamydomonas reinhardtii*, *Scenedesmus obliquus*, *Chlorella pyrenoidosa* and *Chlorella vulgaris* to treat waste water to remove organic compounds, metals and estrogenic compounds along with the combination of activated sludge. The results showed good removal of all the organic compounds, metals and estrogenic compound and various other contaminants when combined with activated sludge. The *Scenedesmus* was found to be efficient in treating the estrogenic compounds completely. Thus harmful EDC compounds can also be removed by algae remediation which is easy and cost efficient method. Among various micro algae, *Chlorella minutissima*, *Scenedesmus* spp. and *BGA (Nostoc)* and their consortium proved to be very effective in reduction of BOD_5, COD, NO_3, NH_4, PO_3 and TDS in sewage wastewater. Bio-treatment with microalgae is particularly attractive because of their photosynthetic capabilities, converting solar energy into useful biomasses and incorporating nutrients such as nitrogen and phosphorus causing eutrophication.

7. Advantages of using algae

The advantage of using algae is that some compounds can be produced which are potentially useful for the environment. Thus there is mutual benefit while treating the waste water with algae [67–70]. Mahapatra [71] collected wastewater from the inflow channels (Bellandur Lake, Koramangala region, South of Bangalore, India) and allowed to settle for 2 days and is used to grow algae of nearly directly fed with 20 species. The nutrient removal efficiencies and lipid content were studied using Gas chromatography and mass spectrometry (GC–MS). The nutrient removal efficiencies are 86%, 90%, 89%, 70% and 76% for TOC, TN, NH4-N, TP and OP, respectively, and lipid

Table 1
Typical investigations carried out by various researchers on waste water/sewage treatment.

Author(s)	Investigation	Interpretation/remarks
Guo et al. [32]	Microbial communities of foam, foaming activated sludge (AS) and non-foaming AS in a sewage treatment plant. Deep sequencing of the taxonomic marker genes 16S rRNA and mycobacterial rpoB and a meta genomic approach were employed for analysis	This study explains the extended use of taxonomic width of potential foam formers towards forming process. Their results indicated the dominant foam former which is a novel species related to the prototypical *G. amarae*. The study was carried out by collecting samples at two points only.
Symonds et al. [74]	Determined the efficiency of a benchtop electrocoagulation (EC) unit with aluminum sacrificial electrodes to reduce the concentrations of biological and chemical pollutants from raw and tertiary treated domestic waste water.	It is found from the experiments that by using benchtop EC, concentrations of phosphate, microbial surrogates and several personal care products in domestic waste water were significantly reduced. The mechanism behind the reductions and to optimize the EC configurations are to be studied
Venkatesan [75]	Analyzed sewage sludge samples to assess high production volume chemicals. The goal of the study is to forecast ecological and human health risks of manmade chemicals. Nationally representative samples of sewage sludge were analyzed for 231 contaminants of emerging concern, of which 123 were detected.	Ten of top 11 most abundant CECs in sewage sludge are found to be high production volume chemicals, eight priority chemicals, three surfactants and two antimicrobials. A relation is established between chemicals that bio accumulate in humans and those that persist during waste water treatment and accumulate in sludge based on limited analysis of limited samples. This is to be further validated to fix the limits.
Atkinson [76]	A novel copper alginate bead to reduce pathogen loading in waste streams and incorporation in swirl flow bioreactor was proposed and implemented for pathogen reduction in waste streams. This approach provided effective reduction of viable coliforms in waste streams containing high color, COD and TSS.	This technique is to be further improved to scale up. The integrity and longevity of the beads require continuation studies to verify for higher COD and TSS waste streams. This technique resembles like a 3-D printer and found to be economically cheaper as it can be made with locally available materials.
Zhu et al. [73]	Proposed a numerical optimal approaching procedure (NOAP) for the calibration of activated sludge models. The NOAP consists of (i) global factor sensitivity analysis, (ii) pseudo global parameter correlation analysis, and (iii) genetic algorithm	The validity of the model is verified with the experimental results and the NOAP can be extended to other ordinary differential equation models. At present NOAP is a decision making tool and is expected to make fully automatic calibration system in future.
Zhang and Zou [61]	Discussed the methodologies for removal of endocrine disrupting chemicals (EDC) in a sewage treatment plant by photo degradation with a catalyst.	It was found that with UV photo degradation is more efficient than solar irradiation due to the strong absorbance of UV energy by EDCs.
Kolpin et al. [77]	Made survey on occurrence of pharmaceuticals, hormones and other organic waste water contaminants (OWCs) in US streams. Five newly developed analytical methods were employed to measure concentrations of 95 OWCs in water samples from a network of 139 streams across 30 states during 1999 and 2000	From the study, it is observed that the most frequently detected compounds were coprostanol (fecal steroid), cholesterol (plant and animal steroids), N,N-diethyltoluamide (insect repellant), caffeine (stimulant), triclosan (antimicrobial disinfectant), tri(2-chloroethyl) phosphate (fire retardant), and 4-nonylphenol (nonionic detergent metabolite)
Gattullo et al. [64]	Assessed the removal of the endocrine disruptor 4-nonylphenol (NP) at a concentration of 1 mg/l by ryegrass and radish during germination and growth. At the end of germination and growth, residual NP was measured by chromatographic analysis. Although NP phytotoxicity was evidenced when water was added with natural organic matter (NOM) at the two concentrations, both plants were still able to remove a significant amount of NP as a function of NOM concentration and plant species	This study demonstrated that both ryegrass and radish possess a relevant capacity to remove the endocrine disruptor NP from water also in the presence of different organic fractions, thus suggesting their use in the decontamination of real aquatic systems
Gulnaz and Dincer [65]	Bisphenol A (BPA), a raw material used in plastic industry and released into environment by industrial applications. Biodegradation of BPA by *Aeromonas hydrophila* and *Chlorella vulgaris* was investigated and the result showed that BPA was easily biodegraded by *A. hydrophila* at 60 and 120 mg/l concentrations within 6 days and *C. vulgaris* at 20 mg/l concentrations within 7 days.	First-order kinetic model was fit well to the algal and bacterial biodegradation of BPA. The primary degradation products were 1(3-methylbutyl)-2,3,4,6-tetramethylbenzene and 4-(1-hydroxy-2-methylprop-1-enyl)phenol.
Zhou et al. [66]	Experiments were carried out for 7 days to investigate the simultaneous removal of various organic and inorganic contaminants including total nitrogen (TN), total phosphorus (TP), metals, pharmaceuticals and personal care products (PPCPs), endocrine disrupting chemicals (EDCs), and estrogenic activity in wastewater by four freshwater green microalgae species, *Chlamydomonas reinhardtii*, *Scenedesmus obliquus*, *Chlorella pyrenoidosa*, and *Chlorella vulgaris*. After treatment for 7 days, 76.7–92.3% of TN, and 67.5–82.2% of TP were removed by these four algae species.	The estrogenic activity in wastewater was also significantly reduced after treatment by these algal species. Similar removal patterns were observed between the activated sludge treatment and algal treatment due to similar removal mechanisms. This implies that algae species can be applied in the treatment of wastewater containing cocktails of inorganic and organic contaminants.

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Table 1 (*continued*)

Author(s)	Investigation	Interpretation/remarks
Chekroun et al. [78]	Presented an overview of the potential of microalgae species for phytoremediation of organic pollutants in aquatic ecosystems. Bioremediation of petroleum hydrocarbons, bioremediation of polychlorinated biphenyls (PCBs), bioremediation of polycyclic aromatic hydrocarbons (PAHs), bioremediation of explosives (TNT), bioremediation of pesticides, the roles biosurfactants in bioremediation, role of genetic engineering in developing microalgae for phytoremediation of organic pollutants	It is noted that the application of microalgae in biomonitoring and restoration of aquatic systems favors the phytoextraction and biodegradation of many organic pollutants. To improve the absorption and bioremediation of many organic pollutants and increase microalgal tolerance to these pollutants, genetic engineering will be useful. It is also necessary to study and to control different parameters of aquatic ecosystems such as temperature, pH, nutrient availability and other environmental parameters to increase the absorption, accumulation and biodegradation of different pollutants by microalgae, thus accelerating the bioremediation process and reducing the time of decontamination of an aquatic ecosystem.
Abdel-Raouf [79]	Performed extensive review on the role of micro-algae in the treatment of wastewater. From the comprehensive review, it is observed that (i) algae can be used in wastewater treatment for a range of purposes, including: reduction of BOD, removal of N and/or P, inhibition of coliforms, removal of heavy metals	The high concentration of N and P in most wastewaters also means these wastewaters may possibly be used as cheap nutrient sources for algal biomass production. This algal biomass could be used for: methane production, composting, production of liquid fuels (pseudo-vegetable fuels), as animal feed or in aquaculture and production of fine chemicals.
Balabanic et al. [63]	Evaluated the treatment performance of different wastewater treatment procedures, namely, biological treatment, filtration, advanced oxidation processes for the reduction of chemical oxygen demand and seven selected endocrine disrupting compounds (EDCs) (dimethyl phthalate, diethyl phthalate, dibutyl phthalate, benzyl butyl phthalate, bis(2-ethylhexyl) phthalate, bisphenol A and nonylphenol) from wastewaters from a mill producing 100% recycled paper. The treatments such as: (i) anaerobic biological treatment followed by aerobic biological treatment, ultrafiltration and reverse osmosis (RO), and (ii) anaerobic biological treatment followed by membrane bioreactor and RO were compared. Moreover, at lab-scale, four different advanced oxidation processes (Fenton reaction, photo-Fenton reaction, photocatalysis with TiO_2, and ozonation) were applied.	The results indicated that the concentrations of selected EDCs from paper mill wastewaters were effectively reduced (100%) by both combinations of pilot plants and photo Fenton oxidation (98%), while Fenton process, photocatalysis with TiO_2 and ozonation were less effective (70%–90%, respectively). It is also found that among the selected wastewater treatment methods, reverse osmosis (RO), the photo-Fenton reaction, and membrane bioreactor were the most efficient for COD and selected EDC removal, while the Fenton process, photocatalysis with TiO_2 and ozonation were less effective. It is further noted that biological treatment has proven to be the most cost effective process. However, its removal efficiency for dangerous substances such as EDCs is not high enough. Human health and environmental quality risks associated with the presence of EDCs in industrial effluents necessitate the utilization of new methods for their efficient reduction.
Campbell et al. [60]	Presented available biologically based assays (BBAs) used to measure estrogenic endocrine disrupting compounds (e-EDCs) in the environmental samples relating to fate and transport of e-EDCs. It was found from the review that estrogenic EDCs appear to be almost ubiquitous in the environment, despite low solubility and high affinity of organic matter. It is mentioned that potential transport mechanisms generally include: (1) transport of more soluble precursors, (2) colloid facilitated transport, (3) enhanced solubility through elevated pH, and (4) the formation of micelles by longer-chain ethoxylates.	From the comprehensive review, it is noted that further research is needed in (i) adaptation of BBAs into field portable biosensors, source control strategies to reduce the mass of e-EDCs introduced into the waste stream, tertiary treatment strategies for wastewater treatment plants, continued large scale characterization of e-EDC contamination, and finally approaches to environmental remediation of e-EDC contaminated sites, and (ii) on remediation and restoration approaches for habitats disturbed by elevated e-EDC concentrations
Westerhoff [62]	Three drinking water supplies were spiked with 10–250 ng/l of 62 different endocrine-disrupting compounds (EDCs) and as pharmaceuticals and personal care products (PPCPs) ; one model water containing an NOM isolate was spiked with 49 different EDC/PPCPs. Compounds were detected by LC/MS/MS or GC/MS/MS. It is found from the study that conventional treatment (coagulation plus chlorination) would have low removal of many EDC/PPCPs, while addition of PAC and/or ozone could substantially improve their removals.	Existing strategies that predict relative removals of herbicides, pesticides, and other organic pollutants by activated carbon or oxidation can be directly applied for the removal of many EDC/PPCPs, but these strategies need to be modified to account for charged (protonated bases or deprotonated acids) and aliphatic species. Some compounds (e.g., DEET, ibuprofen, gemfibrozil) had low removals unless ozonation was used.
Ye et al. [59]	Concentrations of six endocrine-disrupting compounds (EDCs), bisphenol A (BPA), estrone (E1), 17b-estradiol (E2), estriol (E3), 17a-ethynylestradiol (EE2) and diethylstilbestrol (DES) were assessed in influents, effluents and excess sludge in ten municipal wastewater treatment plants (WWTPs) in the Three Gorges Reservoir (TGR) area, Chongqing, China. Three types of activated sludge treatment processes, oxidation ditch (OD), reversed anaerobic–anoxic–oxic (rA2/O) technology and sequential batch reactor (SBR) were used in the surveyed WWTPs.	All analytes were extracted by solid-phase extraction (SPE) in the dissolved phase and by accelerated solvent-based extraction (ASE) in sludge. Gas chromatography ion of aquatic systems favouuth begins with ″ mass spectrometry (GC-MS) was employed for the analysis of EDCs. Among these EDCs, BPA was the most frequently detected and abundant compound (100.0–10566.7 ng L1 , 15.5–1210.7 ng L1 and 85.0–2470.4 ng g1 with respect to the influents, effluents and excess sludge samples). In view of economy, further elimination of EDCs can be achieved by altering the existing operational parameters of secondary treatments, without the high costs of membrane filtration and advanced oxidation techniques.

(*continued on next page*)

Table 1 (*continued*)

Author(s)	Investigation	Interpretation/remarks
Liu [58]	Reviewed removal of EDCs from three aspects, namely, physical means, biodegradation, and chemical advanced oxidation (CAO). From the review, it is noted that it is not possible for physical means or chemical advanced oxidation to be widely used in conventional wastewater treatment. However, with more and more shortages of drinking water all over the world, the use of the effluent of wastewater treatment plants as a drinking water source or recycling of effluents for special use in some regions and countries seems just a question of time. In these cases, physical means and chemical advanced oxidation may be advantageous for their simple operation and high removal efficiency.	From the comprehensive review, it is noted that control of all micropollutants, not only EDCs, in wastewaters is urgent and necessary. However, in this time of a growing energy crisis and concerns over the greenhouse effect, removal efficiency cannot be the only objective. Sustainable development on the whole must be considered
Zhao et al. [30]	An efficient process for wastewater treatment, i.e., the oxic/anoxic/oxic/extended-idle process to mitigate the generation of FNA and its inhibition on PAOs. The results showed that this new process enriched more PAOs which thereby achieved higher phosphorus removal efficiency than the conventional four-step (i.e., anaerobic/oxic/anoxic/oxic) biological nutrient removal process (41 6 7% versus 30 6 5% in abundance of polyphosphate accumulating organisms (PAOs) and 97 6 0.73% versus 82 6 1.2% in efficiency of phosphorus removal).	It was found from experiments that wastewater treatment regime based strategy did not decrease but slightly increase the nitrogen removal performance. Considering the huge quantities of wastewater treated daily, this strategy has a significant consequence from an ecological perspective. It should also be emphasized that full scale tests are required to fully evaluate the feasibility and potential of this strategy though excellent results have already been obtained in our laboratory experiments.

content varied from 18% to 28.5% of dry algal biomass. Biomass productivity of 122 mg/l/d (surface productivity 24.4 g/m2/d) and lipid productivity of 32 mg/l/d were recorded. The decomposition of algal biomass and reactor residues with an exothermic heat of 123.4 J/g provides the scope for further energy derivation. Development of lipid production from single species study is still lacking. Udom [72] described a method for harvesting microalgae that have grown in wastewater. Algae were grown in semi-continuous culture in pilot-scale photo bioreactors under natural light with anaerobic digester centrate as the feed source. Algae suspensions were collected and the optimal coagulant dosages for metal salts (alum, ferric chloride), cationic polymer (Zetag 8819), anionic polymer (E-38) and natural coagulants (Moringa Oleifera and Opuntia ficus-indica cactus) were determined using jar tests. The relative dewater ability of the algae cake was estimated by centrifugation. Several coagulants, including ferric chloride, alum and cationic polymers, could achieve >91% algae recovery in jar tests without pH adjustment. Ferric chloride had the highest cost but the lowest environmental impacts, while the cationic polymer had the lowest cost but the highest environmental impacts. Belt presses are recommended for dewatering because they can meet the solids content requirements for downstream processing with lower energy consumption and GHG emissions than other dewatering technologies. There is no suggestion for reducing the cost level. Effect of addition of coagulant on algae is also lacking. The new numerical optimal approaching procedure (NOAP) was developed by Guo [73] for systemic calculation. It includes the global factor sensitivity, correlation analysis followed by estimation through genetic algorithm. It was tested against the practical experiments in batch and continued stirred tank reactors. The result was successfully obtained for two differential systems and compared with experiments. It is best for automation and can be used for activated sludge models and other differential equation models. From the overall study it can be inferred that the treatment with algae is found to be very efficient.

Table 1 presents typical investigations carried out by various researchers on wastewater/sewage.

8. Summary and concluding remarks

Organic and inorganic substances which were released into the environment as a result of domestic, agricultural and industrial water activities lead to organic and inorganic pollution. The normal primary and secondary treatment processes of these wastewaters were introduced in a growing number of places, in order to eliminate the easily settled materials and to oxidize the organic material available in wastewater. The pollution is a result of discharge of various organic and inorganic substances into the environment. The sources of pollution include domestic agricultural and industrial waters. Conventional techniques such as chemical precipitation, carbon adsorption, ion exchange, evaporations and membrane processes are found to be effective in treatment of waste and sewage water. Recently, biological treatments have gained popularity to remove toxic and other harmful substances.

From the literature, it is noted that the new methods of waste water treatment are due to microalgae and they are prone to be efficient in reducing the toxic components. It is found that the conventional techniques are not efficient in reducing the toxic, heavy metals, nitrogen, phosphorous etc. There is no unique method to treat most of the compounds in a single step. Quantification of metal–biomass interactions is fundamental to the evaluation of potential implementation strategies, hence sorption isotherms, ion-exchange constants, as well as models used to characterize algal biosorption are found to be very important towards treatment of waste.

Among the various wastewater treatment methods, reverse osmosis (RO), the photo-Fenton reaction, and membrane bioreactor were noted to be the most efficient for COD and selected EDC removal, while the Fenton process, photocatalysis with TiO_2 and ozonation were observed to be less effective.

It is suggested that algae can be used in wastewater treatment for (i) reduction of BOD, (ii) removal of N and/or P, (iii) inhibition of coliforms, and (iv) removal of heavy metals. Further, algal biomass can be employed for (i) methane production, (ii) composting, (iii) production of liquid fuels (pseudo-vegetable fuels), (iv) as animal feed or in aquaculture, and (v) production of fine chemicals.

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