Current Chemistry Letters 11 (2022) 415–422

Contents lists available at GrowingScience

Current Chemistry Letters

homepage: www.GrowingScience.com

Efficiency of maturation oxidation ponds as a post-treatment technique of wastewater

Mohammed Kaid[a*], Alaa E. Ali[a], Adel Q. S. Shamsan[b], Sara M. Younes[c], Shaban A. A. Abdel-Raheem[d], Mokhtar A. Abdul-Malik[e] and Waheed M. Salem[f]

[a]*Chemistry Department, Faculty of Science, Damanhur University, Damanhur, Egypt*
[b]*Department of Chemistry, Faculty of Education, Taiz University, Taiz, Yemen*
[c]*Chemical Engineering Department, Borg El Arab Higher Institute Engineering and Technology, Alexandria, Egypt*
[d]*Soils, Water, and Environment Research Institute, Agricultural Research Center, Giza, Egypt*
[e]*Department of Chemistry, Faculty of Applied Science, Taiz University, Taiz, Yemen*
[f]*Medical Laboratories Department, Faculty of Applied Health Sciences Technology, Menoufia University, Egypt*

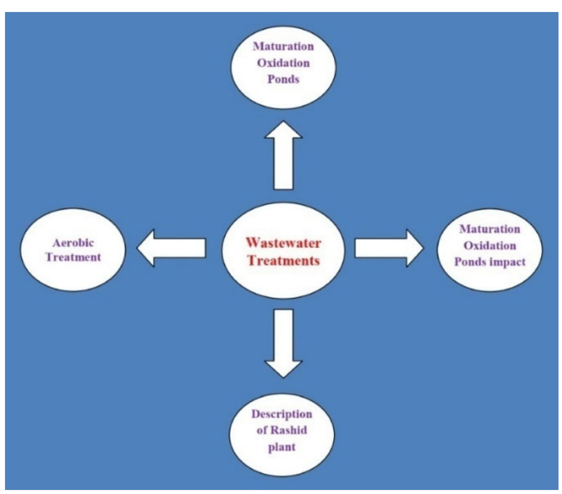
C H R O N I C L E

Article history:
Received February 2, 2022
Received in revised form March 8, 2022
Accepted April 27, 2022
Available online April 27, 2022

Keywords:
Wastewater
Aerobic Treatment
Dissolved oxygen
Environment

A B S T R A C T

In developing countries, it still suffers from endless problems regarding wastewater treatment and the problem of choosing the appropriate treatment system due to lack of proper technology and weak economy. This study highlights the maturity oxidation pond (stabilization) of small communities as an effective, low-cost and simple post-treatment technique for treating wastewater before discharging into an aquatic ecosystem. The Rashid plant was cited as a treatment plant in the city of Rashid-ElBeheira Governorate - Egypt as a model plant for applying this technology in treatment of wastewater. This work also includes the studying of the relationship between climatic conditions, physicochemical parameters and biomass of microorganisms to evaluate the efficiency of its performance.



Graphical Abstract

* Corresponding author.
E-mail address: chemkaied2009@gmail.com (M. Kaid)

doi: 10.5267/j.ccl.2022.4.005

1. Introduction

Water quality has become increasingly worse worldwide and allocation of clean water is amongst the most critical global topics. Different toxic organic and inorganic compounds have been recognized at basic levels in wastewater, ground and surface water. Organic pollution is the term used when great quantities of organic compounds are found in water. It generates from domestic sewage, industrial effluents and agricultural wastewater. Wastewater with organic pollutants contains great quantities of suspended solids which decrease the light offered to photosynthetic organisms. Organic pollutants include hydrocarbons, phenols, plasticizers, pesticides, fertilizers, detergents, oils, pharmaceuticals, carbohydrates and proteins.[1-4] Effective techniques for the removal of very toxic organic compounds from water meet the great attentions. A number of means such as precipitation, coagulation, filtration with coagulation, ion exchange, adsorption and reverse osmosis have been used for the removal of organic pollutants from polluted water and wastewater. These means were limited due to their comparatively great investment and operational cost.

In developing regions, the application of traditional wastewater treatment systems such as activated sludge and tertiary nutrient removal to manage the growing wastewater problems is limited due to the high cost and technological complexity. Therefore, the challenge in the coming years will be to develop integrated concepts and processes for pollution prevention and waste reuse. Presently, aerobic treatment systems are the most frequently used technology for wastewater treatment. These systems comprise the energy-intensive supply of air or even pure oxygen for oxidation of organic matter.[5,6] It should be emphasized here that aerobic wastewater treatment mainly was effective in removing not only organic matter but also soluble and dispersed. Waste stabilization ponds (WSPs) are appropriate for wastewater treatment in the tropics. Waste stabilization ponds represent a possible wastewater treatment choice for areas where the climate is suitable and land is available. An advantage of WSPs compared to other technologies such as activated sludge is that besides COD and suspended solids, also pathogens are removed.[7,8]

2. Treatments

2.1 Aerobic Treatment.

Aerobic wastewater treatment refers to the removal of organic pollutants in wastewater by bacteria that require oxygen to work. Water and carbon dioxide were the final products of the aerobic wastewater treatment process. Processes include trickling filtration, activated sludge, and rotating biological contactors. Bacteria that thrive in oxygen-rich environments work to break down and digest the wastewater inside the aerobic treatment plant or system. This process was called aerobic digestion. Biosynthesis was the most complex and vital energy requiring activity of all living organisms.[9] Biosynthesis was the formation of characteristic chemical components of cells from simple precursors, and the assembly of these components into structures such as the membrane systems, contractile elements, mitochondria, nuclei, and ribosome. Two kinds of ingredients were required for the biosynthesis of cell components: precursors that provide the carbon, hydrogen, nitrogen, and other elements found in cellular structures, and adenosine tri-phosphate (ATP) and other forms of chemical energy needed to assemble the precursors into covalently bonded cellular structure. Pre-treatment stage to remove large solids and other undesirable substances from the waste water; this stage acts much like a septic system, and an Aerobic Treatment System (ATS) may be added to an existing septic tank to further process the primary effluent. Aeration stage is a stage in which the aerobic bacteria digest the biological waste in the wastewater. Settling stage allows any undigested solids to settle. This forms a sludge that must be removed periodically from the system. Disinfecting stage, where chlorine or similar disinfectant is mixed with the water to produce an antiseptic output. The disinfectant typically used was tablets of calcium hypochlorite, which were specially made for waste treatment systems. Unlike the chlorine tablets used in swimming pools, which were stabilized for resistance to breakdown in ultraviolet light, the tablets used in waste treatment systems was intended to break down quickly in sunlight. Stabilized forms of chlorine will persist after the effluent were dispersed, and can kill off plants in the leach field.[10] Since the ATS contains a living ecosystem of microbes to digest the waste products in the water, excessive amounts of items such as bleach or antibiotics can damage the ATS environment and reduce treatment effectiveness. Aerobic treatment units can be an option when insufficient soil was available for the proper installation of a traditional septic tank and soil absorption areas. In these situations, wastewater must receive a high-level of pretreatment before being discharged into the soil environment. Depending on local regulations, the use of an aerobic treatment unit may allow for reductions in the required infiltration area and/or reduction in depth to a limiting soil layer. This ability to produce a high quality effluent may open sites for development that were previously unsuitable because of soil limitations.[11]

An aerobic treatment system or ATS, often called an aerobic septic system, was a small scale sewage treatment system similar to a septic tank system, but which uses an aerobic process for digestion rather than just the anaerobic process used in septic systems. These systems were commonly found in rural areas where public sewers were not available, and may be used for a single residence or for a small group of homes. The aerobic treatment system produces a high quality secondary effluent, which can be sterilized and used for surface irrigation and this allows much greater flexibility in the placement of the leach field, as well as cutting the required size of the leach field by as much as half.[12]

Aeration units were evaluated on the mass of oxygen transferred per unit of air introduced to the water. This was an efficiency rating. The goal was to maximize the mass of O_2 transferred per unit of energy consumed by the device. The most common method of maximizing energy efficiency was to combine mixing with aeration. Turbulent mixing was required to maximize the opportunity for microbes to come in contact with both soluble organic compounds and dissolved oxygen. If steady state conditions can be maintained, the rate of oxygen transfer is equal to the rate of consumption by the microorganisms. Dissolved oxygen DO in the mixed liquor needs to be maintained at 1 to 3 mg/L. For residential strength wastewater the 2 to 7 grams per day of dissolved oxygen were needed for each gram of Mixed liquor volatile suspended solids (MLVSS).[13]

Suspended-growth or attached growth, any unit that maintains saturated and aerobic conditions was generally referred to as an "ATU" - the acronym for aerobic treatment unit. The primary focus of this section was use of ATUs as an engineered, high-rate wastewater treatment process. Trickling filters (such as those found at smaller municipal wastewater treatment plants) and most packed-bed filters typify this type of biological process. The aerobic microbes convert organic compounds into energy, new cells and residual matter. The biological solids settle back into the aeration chamber where they serve as seed for new microbial growth. Settled biomass and residuals will accumulate in the bottom of the chamber and must be removed with periodic maintenance because the biomass creates an oxygen demand. Clarification was an important part of generating a high-quality effluent. The soluble biological oxygen demand BOD_5 of the effluent was generally below 5 mg/L, but the biomass solids carry over may produce an effluent BOD_5 of O_2mg/L or greater.[14]

2.1.1 Advantage and disadvantage of aerobic treatment.

The aeration stage and the disinfecting stage were the primary differences from a traditional septic system; in fact, an aerobic treatment system can be used as a secondary treatment for septic tank effluent. These stages increase the initial cost of the aerobic system, and the maintenance requirements over the passive septic system. Unlike many other bio-filters, aerobic treatment systems require a constant supply of electricity to drive the air pump increasing overall system costs. The disinfectant tablets must be periodically replaced, as well as the electrical components (air compressor) and mechanical components (air diffusers). On the positive side, an aerobic system produces a higher quality effluent than a septic tank and thus the leach field can be smaller than that of a conventional septic system, and the output can be discharged in areas environmentally sensitive for septic system output. Some aerobic systems recycle the effluent through a sprinkler system, using it to water the lawn where regulations approve.[14] Since the effluent from an ATS was often discharged onto the surface of the leach field, the quality was very important. A typical ATS will, when operating correctly, produce an effluent with less than 30 mg/liter biochemical oxygen demand, 25 mg/liter total suspended solids, and 10000 cfu/mL fecal coliform bacteria. This was clean enough that it cannot support a bio mat or "slime" layer like a septic tank.[15] ATS effluent was relatively odorless; a proper operating system will produce effluent that smells musty, but not like sewage. Aerobic treatment was so effective at reducing odors, that it was the preferred method for reducing odor from manure produced by farms.[16-18] Aerobic treatment systems such as the conventional activated sludge (CAS) process were widely adopted for treating low strength wastewater (< 1000 mg COD/L) like municipal waste water. CAS process was energy intensive due to the high aeration requirement and produces a large quantity of sludge (about 0.4 g dry weight/g COD removed) that has to be treated and disposed off. As a result, the operation and maintenance cost of a CAS system was considerably high. Anaerobic process for domestic wastewater treatment was an alternative that was potentially more cost-effective, particularly in the subtropical and tropical regions where the climate was warm consistently throughout the year.[19]

2.2 Maturation Oxidation Ponds (stabilization ponds) as a post-treatment.

The bio-rotor system, or rotating biological contactor,[20] integrated duckweed and Maturation Oxidation Ponds or water stabilization ponds (WSPs) system,[21] trickling filters,[22] the down-flow hanging sponge reactor,[23] activated sludge,[24] a baffled pond system,[25] dissolved air flotation,[26] sequential batch reactors,[27] submerged aerated bio-filters,[28] reed bed systems,[29] among others the choice depends on the required effluent quality, the available land area, the treatment cost, the simplicity and operational stability of the treatment system, the independence on imported equipment and material, and operational flexibility. Therefore, integration of Maturation Oxidation (water stabilization) ponds system (WSPs) as a post-treatment should be a powerful option for domestic sewage treatment. In most of the developed nations, basic sewage problems were already well addressed and technologies and legislations were being fine-tuned for the control and removal of micro pollutants and various pathogens and in scrutinizing the impacts of pollutants in sensitive areas. On the other hand, developing nations were still strangled in interminable problems regarding sewage treatment, inadequate sanitary infrastructure and dilemma over selection of appropriate treatment system due to the lack of proper technology and poor economy. The Maturation Oxidation Ponds (stabilization) pond is a simple scientifically designed with 2-6 feet depth, where BOD reduction of a wastewater takes place by supporting algal-bacterial growth.[30] Maturation Oxidation Ponds can be defined as a shallow man-made basin which utilizes natural processes under partially controlled conditions for the reduction of organic matter and the destruction of pathogenic organisms in wastewater. Domestic and industrial wastewater includes nearly about 99% liquid waste and only 1% solid waste. These wastes consist mostly of soaps, black water, grey water, toilet paper and detergents. Liquid waste includes showers, baths, toilets, kitchens and sinks draining into sewers. In many areas, domestic wastewater also includes liquid waste from commercial places.[31] The performance of ponds depends on climatological conditions like light, temperature, rain, wind and also the wastewater quality. Primarily these are used as tertiary treatment facilities specially to polish the effluents from conventional treatment plants.[32] These ponds are effective, low cost and simple technology for the treatment of wastewater before it is discharged to an aquatic ecosystem.[33] Oxidation ponds have proved to be one of the most significant devices of economical waste treatment for small communities and isolated industrial units in Tunisia.[34] The occurrence of several species of bacteria,[35] fungi,[36] algae,[37,38] protozoa,[39,40] and viruses[41] in the oxidation pond has been reported. In the earlier years (1946-1964) it was believed that the symbiotic activity of bacteria and algae alone was responsible for the treatment of wastes in oxidation ponds. In addition to bacteria, algae and protozoa, there are also other organisms such as crustacean larvae, insects, viruses, and rotifers, nematodes which interact and compete with each other for food and convert the organic materials of the sewage into simple products in the oxidation ponds. Aerated lagoons treatment system was developed from the traditional waste stabilization ponds (WSPs), where mechanical aeration was installed to increase the oxygen supply inside the ponds system. It was recommended that WSPs be placed after the aerated lagoon to permit the microbial solids to settle and be stabilized. The inorganic elements remaining will stimulate the algae to grow up in the WSPs. The biochemical oxygen demand (BOD) and total suspended solids (TSS) in the effluent will be determined by the algae and not by the microbial solids discharged from the aerated lagoon. It was concluded that a combination of 24 h aerated lagoon and WSP has an area approximately 40% of the area of a traditional WSPs for treating the same volume of sewage. The aerated lagoons have more advantages than the traditional WSPs, in terms of eliminating odor nuisance and less land requirement.[42] In contrast, the aerated lagoons are little more costly than the traditional WSPs and lower in performance, with respect to pathogen removal.[43,44] It was reported that the factors affecting the growth of nitrifying bacteria, are the substrate content, temperature, DO and pH.[45] Maturation ponds or waste stabilization ponds (WSPs) can be used to get rid of most pathogens such as viruses, some species of bacteria, and fungi. Maturation ponds are located after a facultative pond, which may be a primary or secondary pond.[46] With regard to water-quality improvement, an increase in phytoplankton.[47]

2.3 Maturation Oxidation Ponds impact on some physicochemical parameters, Microbiological Significances and heavy metals.

Temperature has been regarded as the most important physical factor affecting the efficiency of water stabilization ponds as it affects the metabolic rate of the micro-organisms in the system, and thus the rate of degradation of organic matter and subsequent stabilization of inorganic nutrients.[48] Previous studies in Europe and America have shown that the nutrient removal efficiency by stabilization ponds was higher in summer than in winter.[49-51] Similarly, Hussainy (1979) reported that the removal efficiency of total ammonia nitrogen, and the rate of nitrification in particular, was higher during summer at Werribee.[52] It was suggested that another mechanism namely ammonia volatilization may also be important in the removal of total ammonia nitrogen in stabilization ponds.[50] The occurrence of heavy metals in industrial and municipal sewage effluents is of interest because they are often present at significant levels and if discharged into surface waters can have severe effects on the aquatic environment and public health. Heavy metals are trace metals with a density at least five times that of water. As such, they are stable elements; meaning they cannot be metabolized by the body and hence they are bio-accumulative and inhibit biological processes.[53] The input of heavy metals from waste waters has been of great concern to regulatory agencies because of possibilities of accumulation in the areas around discharge points and the possible ecological consequences on receiving waters. The results of heavy metal toxicity studies confirm that heavy metals can directly influence behavior by impairing mental and neurological function, influencing neurotransmitter production and utilization, and altering numerous metabolic body processes. Systems in which toxic metal can induce impairment and dysfunction include the blood and cardiovascular, detoxification pathways (colon, liver, kidneys, skin), endocrine (hormonal), energy production pathways, enzymatic, gastrointestinal, immune, nervous (central and peripheral), reproductive, and urinary.[54] Metals like Zinc, Cu, Fe and Cd are common pollutants, which are widely distributed, in aquatic environment. Their sources are mainly from weathering of minerals and solid.[55] atmospheric deposition[56] industrial effluents[57] and spoil heaps.[58] Metals like Cd, Pb, As, Al, Cr, Mn, Co, and Fe were observed in the influent and effluent samples as well as in the receiving stream. The discharge of the effluent from the sewage lagoon into the receiving stream led to increase in the concentrations of most metals downstream and has therefore affected the receiving stream negatively. This is undesirable because lives of fish and aquatic biota in the receiving stream are at risk and the rural dwellers that depend on the water from the receiving stream for various domestic purposes downstream untreated are at great risk of serious health effects due to metals pollution.[59] ponds can be described as self-sufficient treatment units, because the efficacy of treatment is contingent upon the maintenance of the overall microbial communities of bacteria, viruses, fungi, and protozoa,[60] and the proper balance of organics, light, dissolved oxygen, nutrients, algal presence,[61] and temperature. Because ponds are self-sufficient, there is a reduction of operator responsibilities to manage treatment, a reduction in labor costs, and an increase in the potential returns from the tangible products generated by the treatment unit .[62] Ponds can be used for the purpose of 'polishing,' or providing additional treatment to what has been found within conventional treatment methods.[63] Aerobic (high-rate) ponds, also known as high-rate algal ponds, can maintain dissolved oxygen throughout the 30–45 cm-deep pond because of algal photosynthetic activity.[64] Photosynthetic activity supplies oxygen during the day, while at night the wind creates aeration due to the shallow depth of the pond.[65] Aerobic ponds are well known for having high biochemical oxygen demand (BOD) removal potential and are ideal for areas where the cost of land is not expensive. Other characteristics of these ponds include a detention time of 2–6 days, a BOD loading rate between 112 and 225 kg/1000 m^3 day, and a BOD removal efficiency of 95 %.[64]

2.4 Description of Rashid plant as a model plant.

Rashid (Rosetta) city is a port city of the Nile Delta, located 65 km east of Alexandria, in Egypt's Beheira governorate, coordinates: 31°24′16″N 30°24′59″E. It has a present population of approximately 118511 people.[66] People are almost all citizens and a few of them industrial residents. The system was implemented and operated in Rashid wastewater treatment plant. The influent raw sewage was an average of 17000 m^3/day. Maturation Oxidation Ponds system of Rashid plant consists of one or two ponds according to the load required.[6] Each of them is respectively connected after the secondary clarifier basin stage. Each pond has a stretched area equal to 8 acre (1 acre = 4200 m^2). With a capacity depending on the depth of the pond (20–100) cm and the pond that has L shape. The pond will be filled with effluents from the secondary clarifier basin and retain for a time with the wind reactions and the algae effects. The samples were mixed and composed ones from out of two oxidation Ponds (**Fig. 1**).[66]

The study was carried out to investigate the water quality of Rashid plant of wastewater treatment (physiochemical and climatic measurements) and to investigate the bioaccumulation of toxic trace metals (Cu, Pb, Mn and Fe) by planting bean plant with the effluent of Rashid pond and comparing this with another bean plant irrigated with canal water, this will be the reuse of wastewater for irrigation and an important resource for agricultural production. The removal of biodegradable organic loads specially nitrogen and phosphorous are perfectly happens in oxidation maturation ponds which reflects a higher treatment efficiency of the sewage by 98%–99% of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and heavy metals. This work confirms the previous studies about the importance of applied chemistry in different fields.[67-74]

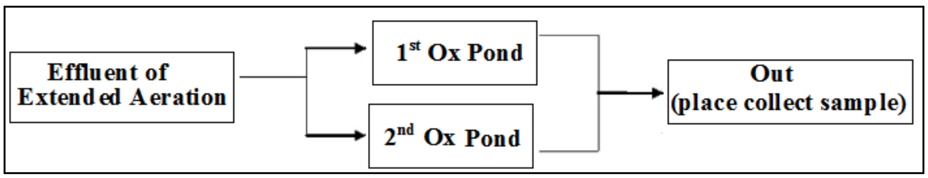


Fig. 1. Rashid oxidation pond diagram

3. Conclusion

Organic pollutants in the ecosystem, mainly persistent organic pollutants (POPs), are one of the most significant environmental problems in the world. The literature reviewed exposed that there has been a great increase in production and utilization of organic pollutants in the past few decades resulting in a large threat of pollution. Efficient techniques for the removal of very toxic organic compounds from water and wastewater have drawn significant interest. Maturation oxidation ponds have become very popular with small communities and are recognized as an effective and low cost technique for the removal of organic pollutants from water and wastewater, and produce high quality treated wastewater.

References

(1) Ali I., Asim M., and Khan T. A. (**2012**) Low cost adsorbents for the removal of organic pollutants from wastewater. *J. Environ. Manage.*, 113 170-183.

(2) Aboul-Enein H. Y., and Ali I. (**2004**) Analysis of the chiral pollutants by chromatography. *Toxicol. Environ. Chem*., 86 (1) 1-22.

(3) Ahmaruzzaman M. (**2021**) Biochar based nanocomposites for photocatalytic degradation of emerging organic pollutants from water and wastewater. *Mater. Res. Bull.*, 140 111262.

(4) Abdelhafeez I. A., El-Tohamy S. A., Abdul-Malik M. A., Abdel-Raheem Sh. A. A., and El-Dars F. M. S. (**2022**) A review on green remediation techniques for hydrocarbons and heavy metals contaminated soil. *Curr. Chem. Lett.,* 11 (1) 43-62

(5) Lawty R., Ashworth J. D. B., and Mara D. D. (**1996**) Waste stabilisation pond decommissioning: a painful but necessary decision. *Water Sci. Technol.*, 33 (7) 107-115.

(6) Ali A. E., Salem W. M., Younes S. M., and Kaid M. (**2020**) Modeling climatic effect on physiochemical parameters and microorganisms of Stabilization Pond Performance. *Heliyon*, 6 (5) e04005.

(7) Abdel Wahaab R. (**2003**) Sustainable Development and Environmental Impact Assessment in Egypt: Historical Assessment. *Environmentalist*, 23 (1) 49-70.

(8) Butler E., Hung Y. T., Suleiman Al Ahmad M., Yeh R. Y. L., Liu R. L. H., and Fu Y. P. (**2017**) Oxidation pond for municipal wastewater treatment. *Appl. Water Sci.*, 7 (1) 31-51.

(9) Oenema O., and Tamminga S. (**2005**) Nitrogen in global animal production and management options for improving nitrogen use efficiency. *Sci. China Life Sci.*, 48 (2) 871-887.

(10) Möller U. (**1983**) German Practice in Land Disposal of Sludge Including Legislation and Health Aspect. *Water Sci. Technol.*, 15 (1) 115-133.

(11) Gil M. I., Gómez-López V. M., Hung Y. C., and Allende A. (**2015**) Potential of electrolyzed water as an alternative disinfectant agent in the fresh-cut industry. *Food Bioproc. Tech.*, 8 (6) 1336-1348.

(12) Meegoda J. N., Hsieh H. N., Rodriguez P., and Jawidzik J. (**2012**) Sustainable community sanitation for a rural hospital in Haiti. *Sustainability*, 4 (12) 3362-3376.
(13) Tchobanoglus G., Burton F., and Stensel H. D. (**2003**) Wastewater engineering: Treatment and reuse. *J. Am. Water Works Assoc.*, 95 (5) 201.
(14) Burgess J. E., Parsons S. A., and Stuetz R. M. (**2001**) Developments in odour control and waste gas treatment biotechnology: a review. *Biotechnol. Adv.*, 19 (1) 35-63.
(15) Jansen Z. B. (**2009**) Variable load related problems in projecting wastewater treatment plant in Bykle Commune at Hovden (Master's thesis, University of Stavanger, Norway).
(16) Baykuş N., Karpuzcu M., and Yurtsever A. (**2022**) An investigation into the role of treatment performance and soil characteristics of soil-based wastewater treatment systems. *Water Sci. Technol.*, 85 (1) 125-140.
(17) Stazi V., and Tomei M. C. (**2018**) Enhancing anaerobic treatment of domestic wastewater: State of the art, innovative technologies and future perspectives. *Sci. Total Environ.*, 635 78-91.
(18) Tolfrey K., Campbell I. G., and Batterham A. M. (**1998**) Aerobic trainability of prepubertal boys and girls. *Pediatr. Exerc. Sci.*, 10 (3) 248-263.
(19) Nykova N., Muller T. G., Gyllenberg M., and Timmer J. (**2002**) Quantitative analyses of anaerobic wastewater treatment processes: identifiability and parameter estimation. *Biotechnol. Bioeng.*, 78 (1) 89-103.
(20) Boix-Fayos C., Martínez-Mena M., Calvo-Cases A., Castillo V., and Albaladejo J. (**2005**) Concise review of interrill erosion studies in SE Spain (Alicante and Murcia): erosion rates and progress of knowledge from the 1980s. *Land Degrad. Dev.*, 16 (6) 517-528.
(21) Bott M. (**1997**) Anaerobic citrate metabolism and its regulation in enterobacteria. *Arch. Microbiol.*, 167 (2) 78-88.
(22) Chernicharo C. A. L. and Nascimento M. C. P. (**2001**) Feasibility of a pilot-scale UASB/trickling filter system for domestic sewage treatment. *Water Sci. Technol.*, 44 (4) 221-228.
(23) Rintala J., and Lepistö R. (**1993**) Thermophilic Anaerobic–Aerobic and Aerobic Treatment of Kraft Bleaching Effluents. *Water Sci. Technol.*, 28 (2) 11-16
(24) Larmie S. A., Osafo R. A., and Ayibotele N. B. (**1991**) Surface Water Quality Monitoring and Pollution Control in Ghana. *Water Sci. Technol.*, 24 (1) 35-59.
(25) Tawfik A., Temmink H., Zeeman G., and Klapwijk B. (**2006**) Sewage treatment in a rotating biological contactor (RBC) system. *Water Air Soil Pollut.*, 175 (1) 275-289.
(26) Eriksson P. (**1995**) Developmental Neurotoxicology in the Neonate-Effects of Pesticides and Polychlorinated Organic Substances. *Toxicol. Lett*., 78 (S1) 6-6.
(27) Strous M., Kuenen J. G., and Jetten M. S. M. (**1999**) Key physiology of anaerobic ammonium oxidation. *Appl. Environ. Microbiol.*, 65 (7) 3248-3250.
(28) Spiridon I., Duarte A. P., and Belgacem M. N. (**2001**) Enzymatic hydrolysis of Pinus pinaster kraft pulp. *Appita J.*, 54 (5) 457-459.
(29) Watanabe T., Kuniyasu K., and Ohmori H. (**1993**) Anaerobic and aerobic submerged bio-filter system for small scale on-site domestic sewage treatment. *Water Sci. Technol.*, 27 (1) 51-57.
(30) Hosetti B. B., and Rodgi S. S. (**1985**) Influence of depth on the efficiency of oxidation ponds for wastewater treatment. *Environ. Ecol.*, 3 (3) 324-326.
(31) Eisenberg D., Soller J., Sakaji R., and Olivieri A. (**2001**) A methodology to evaluate water and wastewater treatment plant reliability. *Water Sci. Technol.*, 43 (10) 91-99.
(32) Sarner E. (**1985**) Oxidation ponds as polishing process of the wastewater treatment plant in Lund. *Vatten*, 41 186-192.
(33) Mahajan C. S., Narkhade S. D., Khatik V. A., Jadhav R. N., and Attarde S. B. (**2010**) Wastewater treatment at winery industry. *Asian J. Environ. Sci.*, 4 (2) 258-265.
(34) Ghrabi A., Ferchichi M., and Drakides C. (**1993**) Treatment of wastewater by stabilization ponds-application to Tunisian conditions. *Water Sci. Technol.*, 28 (10) 193-199.
(35) Marais G. V. R. (**1974**) Fecal bacterial kinetics in stabilization ponds. *J. Environ. Eng.*, 100 (1) 119-139.
(36) Siokwu S., and Anyanwn C. U. (**2012**) Tolerance for heavy metals by filamentous fungi isolated from a sewage oxidation pond. *Afr. J. Microbiol. Res*., 6 2038-2043.
(37) Kawai H., Grieco V. M., and Juredini P. A. (**1984**) Study of the treatability of pollutants in high rate photosynthetic ponds and the utilization of the proteic potential of algae which proliferate in the ponds. *Environ. Technol*., 5 (1-11) 505-515.
(38) Henry J. G., and Prasad D. (**1986**) Microbial aspects of the inuvik sewage lagoon. *Water Sci. Technol.*, 18 (2) 117-128.
(39) Rivera F., Lergo A., Ponnce J., Lares F., and Ortiz R. (**1986**) Zooflagellates in an anaerobic waste stabilization pond system in Mexico. *Water Air Soil Pollut.*, 27 (1) 199-214.
(40) Nair G. (**1997**) Role of organisms in sewage treatment I: Types of organisms. *Proc. Acad. Environ. Biol.*, 6 (1) 19-26.
(41) Prado T., de Castro Bruni A., Barbosa M. R. F., Garcia S. C., de Jesus Melo A. M., and Sato M. I. Z. (**2019**) Performance of wastewater reclamation systems in enteric virus removal. *Sci. Total Environ.*, 678 33-42.
(42) Uhlmann D. (**1980**) Limnology and performance of waste treatment lagoons. *Hydrobiologia*, 72 (1) 21-30.
(43) Mara D. D. (**2001**) Appropriate Wastewater collection, treatment and reuse in developing countries. *Proceeding of the institution of CE&ME.*, 145 (4) 299-303

(44) Pearson H. W. (**1996**) Expanding the horizons of pond technology and application in the world. *Water Sci. Technol.*, 33 (7) 1-9.

(45) Lettinga G. (**1996**) Sustainable integrated biological wastewater treatment. *Water Sci. Technol.*, 33 (3) 85-98.

(46) Zimmo O. R. N. P., van der Steen N. P., and Gijzen H. J. (**2003**) Comparison of ammonia volatilization rates in algae and duckweed-based waste stabilization ponds treating domestic wastewater. *Water Res.*, 37 (19) 4587-4594.

(47) LAI P. C. C., and LAM P. K. S. (**1997**) major pathways for nitrogen removal in wastwater stabilization ponds. *Water Air Soil Pollut.*, 94 (1) 125–136.

(48) Sanz J. L., and Köchling T. (**2007**) Molecular biology techniques used in wastewater treatment: an overview. *Process Biochem.*, 42 (2) 119-133.

(49) Toms I. P., Owens M. and Hall J. A., and Mindenhall M. J. **(1975**) Observations on the performance of polishing ponds at a large regional works. *J. Water Pollut. Control Fed.*, 74 (4) 383–401.

(50) Pano A., and Middlebrooks E. J. (**1982**) Ammonia nitrogen removal in facultative wastewater stabilization ponds. *J. Water Pollut. Control Fed.*, 54 (4) 344–351.

(51) Santos M. C. R., and Oliveira J. F. S. (**1987**) nitrogen transformations and removal in waste stabilisation ponds in protugal: Seasonal Variations. *Water Sci. Technol.*, 19 (12) 123-130.

(52) Hussainy S. U. (**1979**) Ecological studies of lagoons at Werribbe: removal of biochemical oxygen demand, nitrogen and heavy metal. *Prog. water technol.*, 11 (4/5) 315–337.

(53) Burrows W. D., Schmidt M. O., Carnevale R. M., and Schaub S. A. (**1991**) Nonpotable reuse: development of health criteria and technologies for shower water recycle. *Water Sci. Technol.*, 24 (9) 81-88.

(54) Islam M. S., Proshad R., Asadul Haque M., Hoque M. F., Hossin M. S., and Islam Sarker M. N. (**2020**) Assessment of heavy metals in foods around the industrial areas: Health hazard inference in Bangladesh. *Geocarto Int.*, 35 (3) 280-295.

(55) Samdahl D. M., and Robertson R. (**1989**) Social determinants of environmental concern: Specification and test of the model. *Environ. Behav.*, 21 (1) 57-81.

(56) Markert B. (**2007**) Definitions and principles for bioindication and biomonitoring of trace metals in the environment. *J. Trace Elem. Med. Biol.*, 21 77-82.

(57) Beesley L., and Marmiroli M. (**2011**) The immobilisation and retention of soluble arsenic, cadmium and zinc by biochar. *Environ. Pollut*., 159 (2) 474-480.

(58) Ogunfowokan A. O., Adenuga A. A., Torto N., and Okoh E. K. (**2008**) Heavy metals pollution in a sewage treatment oxidation pond and the receiving stream of the Obafemi Awolowo University, Ile Ife, Nigeria. *Environ. Monit. Assess.*, 143 (1) 25–41.

(59) Hosetti B. B., and Frost S. (**1995**) A review of the sustainable value of effluents and sludges from wastewater stabilization ponds. *Ecol. Eng*., 5 (4) 421–431.

(60) Amengual-Morro C., MoyaNiell G., and Martinez-Taberner A. (**2012**) Phytoplankton as bioindicator for waste stabilization ponds. *J. Environ. Manage.*, 95 S71–S76.

(61) Hosetti B., and Frost S. (**1998**) A review of the control of biological waste treatment in stabilization ponds. *Crit. Rev. Environ. Sci. Technol.*, 28 (2) 193–218.

(62) Veeresh M., Veeresh A. V., Huddar B. D., and Hosetti B. B. (**2010**) Dynamics of industrial waste stabilization pond treatment process. *Environ. Monit. Assess.*, 169 (1) 55–65.

(63) Verbyla M. E., and Mihelcic J. R. (**2015**) A review of virus removal in wastewater treatment pond systems. *Water Res*., 71 107-124.

(64) Bielefeldt A. R. (**2013**) Pedagogies to achieve sustainability learning outcomes in civil and environmental engineering students. *Sustainability*, 5 (10) 4479-4501.

(65) Abd El-Kawy W., Abd El-Hameed A., Saleh T., and Aziz B. A. (**2020**) Sustainability of old cultivated soils in EL-Fayoum governorate, Egypt. *Plant Arch*., 20 1469-1476.

(66) Murthi M. K., Nithiyanandam Dr. S., Srinivasan Dr. Pss., Sivakumar D., and Ashok T. (**2015**) The effect of karanja oil and its blend with additive on performance and emission from a diesel engine. *Int. J. Sci. Eng. Res.*, 10 (1) 59–68.

(67) Kamal El-Dean A. M., Abd-Ella A. A., Hassanien R., El-Sayed M. E. A., and Abdel-Raheem Sh. A. A. (**2019**) Design, Synthesis, Characterization, and Insecticidal Bioefficacy Screening of Some New Pyridine Derivatives. *ACS Omega*, 4 (5) 8406-8412.

(68) Abdel-Raheem Sh. A. A., Kamal El-Dean A. M., Hassanien R., El-Sayed M. E. A., and Abd-Ella A. A. (**2021**) Synthesis and characterization of some distyryl-derivatives for agricultural uses. *Eur. Chem. Bull.*, 10 (1) 35-38.

(69) Abdel-Raheem Sh. A. A., Kamal El-Dean A. M., Zaki R. M., Hassanien R., El-Sayed M. E. A., Sayed M., and Abd-Ella A. A. (**2021**) Synthesis and toxicological studies on distyryl-substituted heterocyclic insecticides. *Eur. Chem. Bull*., 10 (4) 225-229.

(70) Tolba M. S., Sayed M., Kamal El-Dean A. M., Hassanien R., Abdel-Raheem Sh. A. A., and Ahmed M. (**2021**) Design, synthesis and antimicrobial screening of some new thienopyrimidines. *Org. Commun.*, 14 (4) 334-345.

(71) Abdel-Raheem Sh. A. A., Kamal El-Dean A. M., Hassanien R., El-Sayed M. E. A., and Abd-Ella A. A. (**2020**) Synthesis and biological activity of 2-((3-Cyano-4,6-distyrylpyridin-2-yl)thio)acetamide and its cyclized form. *Alger. j. biosciences*, 01 (02) 046-050.

(72) Abdel-Raheem Sh. A. A., Kamal El-Dean A. M., Abdul-Malik M. A., Hassanien R., El-Sayed M. E. A., Abd-Ella A. A., Zawam S. A., and Tolba M. S. (**2022**) Synthesis of new distyrylpyridine analogues bearing amide substructure as effective insecticidal agents. *Curr. Chem. Lett.*, 11 (1) 23-28.

(73) Bakhite E. A., Abd-Ella A. A., El-Sayed M. E. A., and Abdel-Raheem Sh. A. A. (**2017**) Pyridine derivatives as insecticides. Part 2: Synthesis of some piperidinium and morpholiniumcyanopyridinethiolates and their Insecticidal Activity. *J. Saud. Chem. Soc.*, 21 (1) 95–104.
(74) Kamal El-Dean A. M., Abd-Ella A. A., Hassanien R., El-Sayed M. E. A., Zaki R. M., and Abdel-Raheem Sh. A. A. (**2019**) Chemical design and toxicity evaluation of new pyrimidothienotetrahydroisoquinolines as potential insecticidal agents. *Toxicol. Rep.*, 6 (2019) 100-104.