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Comparative analysis of conventional treatment methodologies and advanced processing techniques for reutilization of polluted ground water – A comprehensive review

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Abstract

Almost 80% of wastewater goes back into the ecosystem without treatment. Groundwater contamination is the major cause of deaths and diseases worldwide, it accounts for the deaths of approximately 14,000 people on a daily basis and the majority of them are children under the age of 5 years. Irrational utilization of natural water reservoirs appears to be as one of the leading and emerging problems of today's environmental crisis and global water contamination concerns, the solution of which lies in controlled usage and proper management and detoxification of polluted ground water. Uncontrolled human activities, high population density and excessive industrialization including heavy motor vehicles, agricultural sector, nuclear power plants, tannery and chemical units, mining sites and metallurgical industries are major sources of worldwide water pollution that needs to be controlled on an immediate basis to ensure sustainable surroundings. The quality of influent and effluent of municipal wastewater treatment plants plays a significant role in selecting the appropriate treatment technologies and influencing the ecology of receiving water bodies. Therefore, the current review is planned to compile conventional treatment methodologies and advanced processing techniques to comparatively analyse their efficiency in removing pollutants from contaminated ground water along with their merits and demerits. Few traditional treatment methods include filtration, coagulation/flocculation, biological processes, ion exchange resins and adsorption while advanced processing techniques include ultrafiltration, electrocoagulation, reverse osmosis, ultraviolet treatment and photocatalysis among which advanced methods have proved to be more efficient in removing toxicants with high cost effectiveness.

Keywords: Filtration, coagulation/flocculation, ion exchange resins, ultrafiltration, electrocoagulation, reverse osmosis, ultraviolet treatment, photocatalysis

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1. Introduction

Groundwater is considered as one of the most valuable and important natural resources for supporting life, ecological diversity and economic development [1-5]. It is an important channel for transportation of nutrients, hormones, waste products and assists in the movement of food through gastro-intestinal tract [6]. The increase in population and human disruption can greatly increase the demand for groundwater that has resulted in the necessity for protecting groundwater from being contaminated [7]. The overuse integrated with groundwater pollution has threatened the security of drinking water. Groundwater contamination has linked to the transmission of man's harmful diseases such as diarrhea, cholera, dysentery, hepatitis A, typhoid and polio. Inappropriately managed groundwater and sanitation services can lead individuals to severe health risks. Approximately, 829,000 people die every year due to diarrhea as a result of contaminated drinking water, improper sanitation and poor hygiene conditions according to a report of World Health Organization published in the year 2019.

Most of the problems faced by human beings in the present age are due to poor water quality and acute water shortage [8]. These problems are going to be more aggravated in the future by climate change thereby resulting in higher water temperatures, melting of glaciers and an intensification of the water cycle. These problems will provoke more in the future by resulting high water temperatures, climate changes, intensification of water cycles and melting of glaciers [9]. With respect to human health, the most direct and most severe impact is lack of improved sanitation that is directly related to the lack of safe drinking water, which currently affects more than a third part of human population all across the globe. Concerning to human health, the most critical and direct impacts are inavailability of safe drinking water and lack of improved sanitation which is affecting more than the two-third population of the world. Additional threats include exposure to pathogens or to chemical toxicants via food chain that is caused by irrigating plants with contaminated water and because of bioaccumulation of toxic chemicals by aquatic organisms, including seafood and fish or during recreation such as swimming in polluted surface water. Furthermore, some other threats include exposure to harmful pathogens by food that comes in contact with contaminated water or during leisure time [10].

Release of industrial and domestic effluent wastes, marine dumping, leakage from water tanks, radioactive waste and atmospheric deposition are major sources of groundwater pollution [11]. Many industries release large amounts of harmful chemicals like fluorides, ammonia, cyanides and chromium. All these discharged effluents reach the water bodies and affect the human health and life of many other organisms. Pollutants present in groundwater can be categorized as biological, organic and inorganic. Biological pollutants include viruses, bacteria, and parasites which are responsible for many waterborne diseases like typhoid, fever, cholera, dysentery, polio and hepatitis. Inorganic pollutants comprised cations and anions, most of which occur naturally in soils, rocks and sediments. Cations include heavy metals such as chromium (Cr), mercury (Hg), lead (Pb), nickel (Ni), cadmium (Cd) and manganese (Mn). These are highly poisonous and may reach groundwater with mineral dissolution with acidified waters from industrial and mining activities or even after industrial discharge. The anions contaminating the groundwater are nitrite (NO^{-2}), nitrate (NO_3^-), arsenate (AsO_4^{-3}), sulfate (SO_4^{-2}), chloride (Cl^{-1}), arsenite (AsO_3^{-3}) and fluoride (F^{-1}) [12]. Organic pollutants comprise of volatile organic compounds soluble in water such as trihalomethanes, solvents, gasoline components, gasoline oxygenates, medium to highly polar pesticides and personal care items and pharmaceuticals [13].

2. Global statistics of water pollution

Water is an important source for sustainable socio-economic development, healthier ecosystem and for food and energy production for keeping humans alive. Water also adopts climate changes which serve as an important link between the environment and the society. As the population increases, there is a crucial need to balance all the commercial demands on water resources so that people have enough for their daily needs (UN, 2019). Some global statistics are: (i) about 2.1 billion people do not have access to safe drinking water [14] (ii) almost 4.5 billion people do not have safe sanitation [15] (iii) approximately 340,000 children under the age of five die annually due to diseases caused by diarrhea [16] (iv) shortage of water greatly affects four out of every 10 people [17] (v) about 90% of all natural disasters occur due to water (UNISDR) (vi) almost 80% of wastewater goes back into the ecosystem without treatment [18] (vii) agriculture is mainly responsible for 70% of global water withdrawal [19] and (viii) about 75% of water withdrawals from industries are used for production of energy [20].

3. Sources of groundwater contamination

Water storage tanks may contain oil, chemicals, gasoline or other types of harmful materials which may be present above or below the ground. These storage tanks may crack, corrode and may develop leaks. If these pollutants are leaked out and dissolved in groundwater, serious contamination may occur. Another wastewater disposal system is septic tanks that are used by offices and homes for various purposes that are not directly connected to the city sewer system. Septic systems contain sewerage waste of human beings under the ground at a moderate rate. An improperly constructed septic tank may leak viruses, bacteria, household chemicals and other pollutants in groundwater which may cause serious health issues [21]. Uncontrolled hazardous waste is also a source of groundwater pollution. Places containing hazardous waste may be a source of groundwater contamination if there are containers full of dangerous waste materials. If these containers are leaked, contaminants get mixed up with the groundwater [22].

Landfills are other sources of contamination that are under strict consideration now-a-days. These places contain buried garbage. These places are supposed to contain protective layers at the bottom which prevents the pollutants from getting dissolved into water. If these layers are cracked, harmful contaminants such as car battery acid, paint and household cleaners etc. can make their way into the groundwater [23]. The extensive use of road salts and chemicals is another major source of groundwater pollution. Chemicals may include sprays and other products which kill weeds and insects on lawn and farm fields. During rain, these harmful chemicals may go down into the water. Road salts are used during the winter season to melt ice, these salts get washed off the roads and go straight in the groundwater [24].

4. Harmful consequences and impacts on life

Fluorides present in water are responsible for dental degaradations and weakening bones. The fluoride concentration below 0.5 mg/l causes dental carriers but higher concentration above 0.5 mg/l for 5-6 years can lead to harmful effects to human health which may lead to a condition known as "fluorosis" [25]. Arsenic is another very toxic chemical which reaches the groundwater naturally from the ceramic industry, wastewater of tanneries, insecticides such as lead arsenate, chemical factories and fumes during the burning of petroleum and coal. Arsenic is extremely dangerous and it causes respiratory cancer. Long term exposure to lead may lead to lungs and bladder cancer [26]. Lead is dissolved in the drinking water from fittings, pipes, household plumbing systems and solder. It affects the central nervous system, kidneys and blood in human beings [27]. Mercury is also used in many industries such as manufacturers of batteries, smelters, thermometers, fungicides and pesticides etc. It causes severe aberrations in chromosomes and damages the neurological system. Mercury also shows biological effects in aquatic ecosystems also [28].

Microorganisms play a vital role in the maintenance of water quality. The microorganisms which are responsible for waterborne diseases include *Escherichia coli*, *Vibrio cholera*, *Shigella* sp. and *Salmonella* sp. [25]. All these harmful microorganisms cause diarrhea, typhoid fever, dysentery, cholera and gastroenteritis. The most harmful water contamination occurs when feces get dissolved in the water supply. Many harmful diseases are caused by the faecal-oral route of transmission of pathogens which are only present in human feces [25]. Presence of *Escherichia coli* coliforms in feces indicates presence waterborne pathogens [25]. Groundwater contamination is the major cause of deaths and diseases worldwide, it accounts for the deaths of approximately 14,000 people on a daily basis and the majority of them are children under the age of 5 years. In recent years, the global reports of contaminants in groundwater have greatly increased the public concern about the quality of groundwater. Children are generally more exposed to intestinal pathogens and reports have stated that approximately 1.1 million children die every year due to diseases caused by diarrhea [29].

5. Conventional treatment methodologies

Various physiochemical techniques are applied to water pollutants for their removal from polluted water. Conventional water treatment methodologies include rapid mixing, coagulation, flocculation, biological processes and adsorption, filtration, disinfection, sedimentation or clarification and ion exchange methods. These processes can be used alone or in combination with other schemes depending upon the quality of contaminated water [30].

5.1. Filtration

Filtration is a simple technique that is being used in water treatment. It uses porous filter media to allow only the water but does not allow the impurities to pass through. There are different porous materials which can be used as filter media like crushed stone, activated carbon and sand. Sand is widely used as filter media due to its low cost, high efficiency and excessive availability. [31]. In the sand filtration system, water is allowed to move in the downward direction, passed through a filter which composes of a layer of sand. The water filtration range in the sand filtration process is in between 0.1 to 0.4 $m^3/m^2/h$ [32]. Filter beds are made up of very fine grains having 0.15-0.35 mm diameter and 1 m depth. As the filtration process continues, the treatment system contains a higher part of suspended and colloidal particles which arise from contaminated water and as these particles build up with the passage of time they can clog the system and greatly affect its efficiency. Hence, it is beneficial if the top layer of sand is scrapped off to remove the clogging materials. The filtration process is a combination of different processes which include chemical and biological activity, adsorption, mechanical straining and sedimentation for removal of all sorts of impurities [33].

(A) Advantages of filtration

Depending upon the type of filter, contaminated water may have very limited interaction with filtration media which results in only partial removal of impurities. The type of media also greatly affects the number of contaminants that can pass through the filtration process [34].

(B) Disadvantages of filtration

Water with high turbidity cannot be purified with this technique. The filtration surface also requires continuous maintenance. The vast land is required due to its low-flow operation (about 0.03 to 0.10 gallons per minute per square foot [gal/min/ft^2] of filter bed area) [35].

5.2 Coagulation/Flocculation

Coagulation-flocculation is used widely for contaminated water treatment. It is a fundamental step in groundwater treatment used for human consumption. The most important applications of this technique are the removal of colloids and suspended particles of natural organic matter and of metal ions [36]. This treatment can be divided into two processes which should be applied consecutively. The first process is coagulation which destabilizes the colloidal particles. The main purpose of coagulation is to overcome the factors that promote the stability of the system. The second sub-process is known as flocculation that is the induction of destabilized particles to bring them together and form large agglomerates which separate through gravity settling. Coagulation mostly completes in very short time e.g. about 10s, however, flocculation usually occurs over a period of 20-45 minutes [37].

(A) Advantages of coagulation/flocculation

The coagulation/flocculation is one of the most important physicochemical treatment steps in water treatment to reduce suspended and colloidal material. It eliminates the organic matters contributing to the biological oxygen demand (BOD) and chemical oxygen demand (COD) values/contents of water. Coagulant addition destabilizes the particulate matters present in water, which causes the collision among particles and formation of floc that result in sedimentation. Coagulation and flocculation can be used effectively for color removal [38]. The time required for the suspended solids to settle is reduced. This technique is also useful in eliminating very minute particles which otherwise are difficult to remove by other techniques. Coagulation is also an effective technique for the removal of bacteria, protozoa and viruses [39].

(B) Disadvantages of coagulation/flocculation

The main disadvantages of the use of coagulants for the treatment of water are the cost, precise dosing and persistent monitoring. The required dosing depends upon the quality of water which changes rapidly. The coagulation efficiency also depends upon properties of raw water operational factors which include mixing conditions, coagulants used and the pH value [39].

5.3 Biological processes

The biological treatment process is considered as one of the least expensive processes for removal of pollutants in which either aerobic or anaerobic conditions are maintained [40]. Bacteria, fungi and algae of the approximate size of 0.2-10 μm are usually present in water which can be utilized for the treatment of water because these microorganisms use the pollutants as a source of nutrition for their growth [41]. Different processes and treatments like sequencing batch reactors and biological aerated filters can be used for biological treatment of contaminated ground water [42]. This process is usually effective in feed water with COD<400 mg/l, BOD<50 mg/l and concentration of chloride<6600 mg/l [43].

(A) Advantages of biological process

Degradation of water pollutants by a microbial process is an important method because it is low cost and requires gentle operational conditions [44].

(B) Disadvantages of biological process

The major disadvantage of biological treatment is the production of a large quantity of biological sludge. This produced sludge requires separate treatment which lowers the efficiency of this process and more contact time is required. Another major drawback of this process is the static infrastructure which has a large assembly and a long operating time [45].

5.4 Ion exchange method

Ion exchange is a process successfully used for the elimination of heavy metals from contaminated water. An ion exchanger is usually a solid that is capable of exchanging its anion or cation with the surrounding ions. Synthetic organic ion exchange resins are most commonly used ion exchange matrices. Electricity is used in this process which passes a current through an aqueous metal bearing solution containing an insoluble anode and a cathode. The negatively charged cathodes attract the positively charged metal ions leaving behind a metal deposit that is recoverable and strippable [46].

(A) Advantages of ion exchange method

Some important advantages of this technique are simple equipment, easy control and maintenance and well-established test procedures. This treatment process operates easily with other techniques e.g. filtration and precipitation and can be applied to different flow regimes (continuous and batch). It is an efficient and rapid process which produces a high-quality treated effluent. It removes every type of contaminant, particularly metals and minerals, it cleans up to ppb levels of impurities [47].

(B) Disadvantages of ion exchange method

This method has some disadvantages also, for example, it is not suitable for handling concentrated metal solution because the organics and other solids in contaminated water, foul the entire matrix. Ion exchange is highly sensitive to the solution pH and is non-selective in nature. Another limiting factor of this process is corrosion during which electrodes have to be replaced frequently [46].

5.5 Adsorption

Organic and inorganic contaminants can also be removed by another useful technique called adsorption which is a surface phenomenon. When absorbable solutes present in a solution comes in close contact with porous surface of solid, the liquid-solid intermolecular forces make the solute particles to get concentrated on the porous surface of solid. The solute which gets concentrated on the solid surface is called adsorbate and the solid is known as adsorbent. This surface accumulation of adsorbate on adsorbent is called adsorption. This creation of an adsorbed phase having a composition different from that of bulk fluid phase forms the basis of separation by adsorption technology [48]. The adsorption process is generally classified as physio-sorption (characteristic of weak Vander Waals forces) or chemisorption (characteristic of covalent bonding). It may also occur due to electrostatic forces of attraction [49].

(A) Advantages of adsorption

The adsorption process uses simple equipment which is adaptable to many treatment formats. A large variety of contaminants and commercial products can be eliminated. It is an effective technique with fast kinetics and excellent quality of treated water. Adsorption is an excellent method for separating out a large number of pollutants, particularly in refractory molecules [50].

(B) Disadvantages of adsorption

This technique requires a high investment cost of the material. The performance of this process depends upon the type of adsorbent material used. It requires several types of adsorbents and chemical derivatives to improve the adsorption capacity of the process. Clogging of reactors (regeneration cost) and rapid saturation also occurs in this process. It is not effective for some metals and dyes. The removal of pollutants requires regeneration or replacement of material and incineration. This technique is absurd for some industries like paper, pulp and textiles because its regeneration is costly and results in the loss of adsorbent media [51].

6. Advanced processing techniques

Advanced water treatment technologies include reverse osmosis, nano-filtration, ultra-filtration, micro-filtration, ozonation, chlorination, ultra-violet irradiation, powdered activated carbon adsorption and advanced oxidation [52]. These methods are discussed with their possible merits and demerits in detail in the upcoming section.

6.1 Ultrafiltration

Ultrafiltration is an advanced remediation method that uses a permeable membrane to concentrate macromolecules, heavy metals and suspended solids from inorganic solution on the basis of molecular weight (1000-100,000 Da) and pore size (5-20 nm). This unique property of ultrafiltration permeates the passage of water and low-molecular weight solutes but retains the passage of macromolecules having a larger size than the size of the pore of the membrane [53]. In comparison to other traditional methods, ultrafiltration is the most efficient technique for the removal of pollutants from water [54]. It is more effective than other methodologies for the elimination of suspended solids, toxic hydrocarbons and hazardous dissolved constituents from polluted groundwater [55].

(A) Advantages of ultrafiltration

A large number of ultrafiltration membranes are available which have wide applications and module configurations. It requires less working area and is rapid, simple and efficient even if high concentrations of the sample are introduced. This technique produces high quality water and does not require any type of chemical addition. Creates less amount of solid waste and concentrates all types of salts, dyes and mineral derivatives. This treatment method removes particles, microorganisms, volatile and non-volatile organic materials, suspended solids, phenols, dissolved inorganic matter, zinc and cyanide [46].

(B) Disadvantages of ultrafiltration

Ultrafiltration requires high investment costs for small and medium industries and high energy consumption. Maintenance and operational costs are higher and these membranes can be clogged. Limited flow rate, low throughput and poor efficiency at low solute feed concentration. The membrane to be used depends on the applications like hardness reduction, potable water production and particulate or total organic carbon removal [47].

6.2 Electrocoagulation

Electrocoagulation is a process to remove the suspended solids from water by using electricity to neutralize the negatively charged particles by the formation of hydroxide complexes in water to gather the suspended solids and to help bridge formation to bind and strengthen the floc for sedimentation due to gravitational forces [56]. This process gathers the suspended solids in water without the use of coagulants where coagulation occur when direct current is applied, it is capable of removing the small particles and setting them into motion [57]. Several factors that influence efficiency of electrocoagulation process are: (i) type of electrodes (ii) inter-electrode distance (iii) number of electrodes (iv) size of electrodes (v) configuration of metals (vi) current density (vii) charge loading (viii) pH of sample (ix) addition of supporting electrolyte and (x) operation time [58]. The electrodes made of iron, aluminium and stainless steel are mostly used for being economical and cost efficient. This pairs of metal sheets are known as anode and cathode [59]. During the electrocoagulation process, the cathode is oxidized (loses electrons) and the water is reduced (gains electrons) that cleans the water and aids to settle the flocs [56].

(A) Advantages of electrocoagulation

It is a nonspecific method which addresses drinking water and wastewater. It combines oxidation, coagulation and precipitation which results in lower capital costs. There is no need for chemical reagents instead of aluminium or iron electrodes are used along with the consumption of a small amount of electricity. Reduced operating cost and reduced risk of secondary pollutants are the major advantages of electrocoagulation. It produces a very low amount of sludge. This process requires very low energy that even solar power can be used to supply the electric current [60].

(B) Disadvantages of electrocoagulation

The electrocoagulation setup needs maintenance with the passage of time. The electrodes passivation occurs over time in this process. It needs high conductivity water for successful completion of process nevertheless it lacks systematic reactor design [61].

6.3 Reverse osmosis

Reverse osmosis is a pressure-driven membrane process. The osmotic pressure of the feed solution is suppressed by applying hydraulic pressure which forces permeate (clean water) to diffuse through a dense, non-porous membrane [62]. Reverse osmosis can remove contaminants as small as 0.0001 mm [63]. This is a robust technology for seawater desalination and has been employed in ground water treatment. Reverse osmosis uses electrical energy for its operation. Extensive pre-treatment is required to prevent fouling of the membrane. Product water may require remineralization or pH stabilization to restore SAR values [64].

(A) Advantages of reverse osmosis

It can bear samples with a very high pH value and it is an automated system which reduces the demand for skilled workers. The energy costs can be reduced by installing energy recovery subsystems. It works well for groundwater treatment with an appropriate pre-treatment. This method does not require concentrate treatment because brine produced is usually disposed of. Reverse osmosis water filters remove many pathogens and bacteria from tap water. Disease-causing bacteria such as *Giardia* and *Cryptosporidium* are effectively filtered out from water source, thus eliminating the risks of developing gastrointestinal or other types of illnesses associated with these types of pathogens and bacteria [65].

(B) Disadvantages of reverse osmosis

Reverse osmosis is highly sensitive to inorganic and organic contaminants in aqueous media. The membranes cannot bear feed temperature in excess of 45°C. Reverse osmosis filters demineralized water with these filters but also remove healthy minerals therefore filters of reverse osmosis setup should be used with remineralizes. Reverse osmosis remediation is a slow process in comparison with other types of water filtration methods as this method uses water pressure to remove the effluents [66].

6.4 Ultraviolet treatment

Ultraviolet filtration can be described as invisible radiation. Ultraviolet radiations strike the cell to kill them. The energy of ultraviolet radiations penetrates the outer cell membrane, passes through the cell body and disrupts its DNA thereby preventing its reproduction. The degree of inactivation by ultraviolet radiations is directly related to the amount or dose of ultraviolet radiations applied to the water. The dosage, intensity and exposure time of ultraviolet radiations is measured in microwatt second per square centimeter ($\mu ws/cm^2$). Most of units for ultraviolet radiations are designed to provide a dosage greater than 30,000 $\mu ws/cm^2$ [67].

(A) Advantages of ultraviolet treatment

Ultraviolet purification of water does not require any chemicals like chlorine and does not leave any harmful by products. Ultraviolet radiations do not add any chemical taste or odor to the water. It is considered as one of the most effective ways to kill disease-causing microbes by destroying 99.99% microorganisms. It also uses very less amount of energy. It is a self-automated system i.e. it does not require any work during its operation, just need to change the bulb annually [68].

(B) Disadvantages of ultraviolet treatment

Ultraviolet water purification systems just eliminate the harmful microbes at one point and do not give efficient removal downstream. According to an estimate, a full 100% destruction of microbes is not guaranteed by this technique because if only one bacterium or any other microbe remains unfiltered, it can go straight into downstream and start proliferation. Bacterial cells do not eliminate in ultraviolet treatment unit but are converted into pyrogenes. The killed microorganisms and any other contaminants in the water are a food source for any bacteria that do survive downstream of the ultraviolet unit [69].

6.5 Photocatalysis

The basic principle of photocatalysis is very easy to understand. In this process, a catalyst equipped with ultraviolet radiations from sunlight is used and this process uses this energy for the breakdown of different substances. Photocatalysis is an efficient technique for the breakdown of a wide variety of organic acids and materials, dyes, crude oil, pesticides, estrogens, microbes and inorganic molecules and if combined with filtration or precipitation, it can also remove heavy metal ions. Due to these important applications, photocatalysis with nanoparticles as catalysts can be used to reduce air pollution in addition to water purification [70]. Photocatalysis is also known as the acceleration of a photoreaction in the presence of a catalyst. In catalyzed photolysis, an adsorbed substrate absorbs light. In photocatalysis, photocatalytic activity (PCA) is dependent upon the ability of the catalyst to create electron-hole pairs thereby generating free radicals which are able to undergo secondary reactions [71].

(A) Advantages of photocatalysis

High selectivity forms the catalyst and their composition may be identified easily. This is very advantageous for the mechanistic understanding of catalytic reactions. The photocatalytic reactions can be carried out at very mild conditions of temperature and pressure. This condition is very favorable when products are heat sensitive. At low temperatures, photocatalysis allows the isolation and identification of different reaction intermediates which provides further information about different reaction pathways particularly in homogenous catalysis [72].

(B) Disadvantages of photocatalysis

There are some side reactions occurring in the photochemical process, which may fast back recombination and electron transfer reactions. This disadvantage limits the efficiency of photocatalytic reactions and decomposition of the catalyst can further lead to fast termination of photocatalytic cycles [73].

7. Concluding remarks

Different conventional and advanced treatment methodologies have been reviewed in this article with their possible advantages and disadvantages. It has been observed that the advanced process can remove those biological and chemical pollutants which are almost impossible to be removed by conventional treatment techniques. In some cases, these processes may become very cost competitive, largely owing to stricter regulatory requirements and advances in equipment manufacturing. The use of advanced treatment process can be enhanced by hybrid processes which can be obtained by the combination of advanced methods coupled with some conventional treatment technologies. These hybrid techniques may hold a great advantage in the future because if these techniques are properly used, they can provide the most efficient and economical approach in dealing with environmental challenges.

References

[1] A. McGonigle, A. Aiuppa, G. Giudice, G. Tamburello, A. Hodson, S. Gurrieri. (2008). Unmanned aerial vehicle measurements of volcanic carbon dioxide fluxes. Geophysical research letters. 35(6).

[2] A. Khanam, F. Nadeem, S.M. Praveena, U. Rashid. (2017). Removal of Dyes using Alginated, Calcinized and Hybrid Materials–A Comprehensive Review. International Journal of Chemical and Biochemical Sciences. 12: 130-140.

[3] F. Nadeem, Z. Sajid, M.I. Jilani, A. Raza, F. Abbas. (2016). New Generation Super Adsorbents–A Review. International Journal of Chemical and Biochemical Sciences. 10: 95-105.

[4] A. Raza, F. Nadeem, M.I. Jilani, H.A. Qadeer. (2016). Electrocoagulation and other Recent Methods for Drinking Water Treatment–A Review. International Journal of Chemical and Biochemical Sciences. 10: 60-73.

[5] Z. Sajid, M. Rafiq, F. Nadeem. (2018). Natural Biocomposites for Removal of Hazardous Coloring Matter from Wastewater: A Review. International Journal of Chemical and Biochemical Sciences. 13: 76-91.

[6] C. McAllister, I. Garcia-Romera, A. Godeas, J. Ocampo. (1994). In vitro interactions between *Trichoderma koningii*, *Fusarium solani* and *Glomus mosseae*. Soil Biology and Biochemistry. 26(10): 1369-1374.

[7] A. Baldi-Sevilla, M.L. Montero, J.P. Aguiar-Moya, L.G. Loria-Salazar, A. Bhasin. (2017). Influence of bitumen and aggregate polarity on interfacial adhesion. Road Materials and Pavement Design. 18(sup2): 304-317.

[8] W.W.A. Programme, UN-Water. (2009). Water in a changing world. Earthscan.

[9] T.G. Huntington. (2006). Evidence for intensification of the global water cycle: review and synthesis. Journal of Hydrology. 319(1-4): 83-95.

[10] R.P. Schwarzenbach, T. Egli, T.B. Hofstetter, U. Von Gunten, B. Wehrli. (2010). Global water pollution and human health. Annual Review of Environment and Resources. 35: 109-136.

[11] M. Terauchi, S. Hiramitsu, M. Akiyoshi, Y. Owa, K. Kato, S. Obayashi, E. Matsushima, T. Kubota. (2013). Associations among depression, anxiety and somatic symptoms in peri-and postmenopausal women. Journal of Obstetrics and Gynaecology Research. 39(5): 1007-1013.

[12] J. Aasi, B. Abbott, R. Abbott, T. Abbott, M. Abernathy, K. Ackley, C. Adams, T. Adams, P. Addesso, R. Adhikari. (2015). Advanced ligo. Classical and quantum gravity. 32(7): 074001.

[13] J.A. Rivera-Jaimes, C. Postigo, R.M. Melgoza-Alemán, J. Aceña, D. Barceló, M.L. de Alda. (2018). Study of pharmaceuticals in surface and wastewater from Cuernavaca, Morelos, Mexico: occurrence and environmental risk assessment. Science of the Total Environment. 613: 1263-1274.

[14] U. WHO. (2017). Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Switzerland: World Health Organization.

[15] W.H. Organization Safe management of wastes from health-care activities: a summary; World Health Organization: 2017.

[16] U. WHO, UNFPA, World Bank Group and the United Nations Population Division. Trends in maternal mortality: 1990 to 2015. Estimates by WHO, UNICEF. In UNFPA, World Bank group and the united nations population division: 2015.

[17] S. Postel. (2014). The last oasis: facing water scarcity. Routledge.

[18] S. Labadi, UNESCO, world heritage, and sustainable development: international discourses and local impacts. In Collision or collaboration, Springer: 2017; pp 45-60.

[19] J. Hoogeveen, J.-M. Faurès, L. Peiser, J. Burke, N. Giesen. (2015). GlobWat–a global water balance model to assess water use in irrigated agriculture. Hydrology and Earth System Sciences. 19(9): 3829-3844.

[20] U. UNESCO. (2005). Decade of Education for Sustainable Development: 2005-2014. Draft International Implementation Scheme.

[21] A. Atangana, D. Baleanu. (2017). Caputo-Fabrizio derivative applied to groundwater flow within confined aquifer. Journal of Engineering Mechanics. 143(5): D4016005.

[22] P. Goel. (2006). Water pollution: causes, effects and control. New Age International.

[23] M. Pavlis, E. Cummins, K. McDonnell. (2010). Groundwater vulnerability assessment of plant protection products: a review. Human and Ecological Risk Assessment. 16(3): 621-650.

[24] H. Badrzadeh, R. Sarukkalige, A. Jayawardena. (2013). Impact of multi-resolution analysis of artificial intelligence models inputs on multi-step ahead river flow forecasting. Journal of Hydrology. 507: 75-85.

[25] L. Adetunde, R. Glover. (2010). Bacteriological quality of borehole water used by students' of university for development studies, Navrongo campus in upper-east region of Ghana. Current Research Journal of Biological Sciences. 2(6): 361-364.

[26] H. Bu, X. Tan, S. Li, Q. Zhang. (2010). Temporal and spatial variations of water quality in the Jinshui River of the South Qinling Mts., China. Ecotoxicology and environmental safety. 73(5): 907-913.

[27] J. Yisa, T. Jimoh. (2010). Analytical studies on water quality index of river Landzu. American Journal of Applied Sciences. 7(4): 453.

[28] J. Friberg. (1974). A simple and sensitive micro-method for demonstration of sperm-agglutinating activity in serum from infertile men and women. Acta Obstetricia et Gynecologica Scandinavica. 53(S36): 21-29.

[29] T.S. Steiner, A. Samie, R.L. Guerrant, Infectious diarrhea: new pathogens and new challenges in developed and developing areas. In The University of Chicago Press: 2006.

[30] S. Vigneswaran, M. Sundaravadivel. (2003). Wastewater recycle, reuse, and reclamation. Conventional Water-treatment technologies. 2.

[31] J. Tournebize, C. Chaumont, Ü. Mander. (2017). Implications for constructed wetlands to mitigate nitrate and pesticide pollution in agricultural drained watersheds. Ecological Engineering. 103: 415-425.

[32] M. Adewumi, J. Erb, R. Watson, Initial Design Considerations for a Cost Effective Treatment of Stripper Oil Well Produced Water. In *Produced Water*, Springer: 1992; pp 511-522.

[33] L. Huisman, W.E. Wood. (1974). Slow sand filtration. Geneva: World Health Organization: pp.

[34] C. Binnie, M. Kimber, G. Smethurst, G. Smethurst. (2002). Basic water treatment. Thomas Telford: pp.

[35] T. Brief, Slow Sand Filtration. In A National Drinking Water Clearing House Fact Sheet: 2000.

[36] D.H. Bache, R. Gregory. (2007). Flocs in water treatment. iwa publishing: pp.

[37] N. Tzoupanos, A. Zouboulis In Coagulation-flocculation processes in water/wastewater treatment: the application of new generation of chemical reagents, 6th IASME/WSEAS International Conference Greece, 2008; 2008.

[38] S. Borchate, G. Kullkarni, V. Kore, S. Kore. (2014). A review on applications of coagulation-flocculation and ballast flocculation for water and wastewater. International Journal of Innovations in Engineering and Technology. 4(4): 216-222.

[39] J. Bratby. (2016). Coagulation and flocculation in water and wastewater treatment. IWA publishing: pp.

[40] F. Günther. (2000). Wastewater treatment by greywater separation: Outline for a biologically based greywater purification plant in Sweden. Ecological Engineering. 15(1-2): 139-146.

[41] M. Lu, Z. Zhang, W. Yu, W. Zhu. (2009). Biological treatment of oilfield-produced water: A field pilot study. International Biodeterioration & Biodegradation. 63(3): 316-321.

[42] A. Fakhru'l-Razi, A. Pendashteh, L.C. Abdullah, D.R.A. Biak, S.S. Madaeni, Z.Z. Abidin. (2009). Review of technologies for oil and gas produced water treatment. Journal of Hazardous Materials. 170(2-3): 530-551.

[43] F. Ludzack, D. Noran. (1965). Tolerance of high salinities by conventional wastewater treatment processes. Journal (Water Pollution Control Federation). 1404-1416.

[44] A. Adel, J. Lalung, A. Efaq, N. Ismail. (2015). Removal of cephalexin antibiotic and heavy metals from pharmaceutical effluents using *Bacillus subtilis* strain. Expert Opin Environ Biol. 4: 2.

[45] R. Kumar, P. Kumar. Bioinformatics Analysis of Alternative Splicing in *Chlamydomonas Reinhardtii*. Miami University, 2010.

[46] T.A. Kurniawan, G.Y. Chan, W.-H. Lo, S. Babel. (2006). Physico–chemical treatment techniques for wastewater laden with heavy metals. Chemical Engineering Journal. 118(1-2): 83-98.

[47] Y. Anjaneyulu, N.S. Chary, D.S.S. Raj. (2005). Decolourization of industrial effluents–available methods and emerging technologies–a review. Reviews in Environmental Science and Bio/Technology. 4(4): 245-273.

[48] I. Ali, M. Asim, T.A. Khan. (2012). Low cost adsorbents for the removal of organic pollutants from wastewater. Journal of environmental management. 113: 170-183.

[49] T.A. Kurniawan, W.-h. Lo. (2009). Removal of refractory compounds from stabilized landfill leachate using an integrated H_2O_2 oxidation and granular activated carbon (GAC) adsorption treatment. Water Research. 43(16): 4079-4091.
[50] S. Babel, T.A. Kurniawan. (2004). Cr (VI) removal from synthetic wastewater using coconut shell charcoal and commercial activated carbon modified with oxidizing agents and/or chitosan. Chemosphere. 54(7): 951-967.
[51] A. Aklil, M. Mouflih, S. Sebti. (2004). Removal of heavy metal ions from water by using calcined phosphate as a new adsorbent. Journal of Hazardous Materials. 112(3): 183-190.
[52] S. Snyder, E. Wert, D. Rexing, S.N.W. Authority, P. Westerhoff, Y. Yoon In Conventional and advanced water treatment processes for the removal of endocrine disruptors and pharmaceuticals, Water Quality Conference, 2004; 2004; pp 247-264.
[53] H. Shon, S. Vigneswaran, I.S. Kim, J. Cho, H. Ngo. (2004). The effect of pretreatment to ultrafiltration of biologically treated sewage effluent: a detailed effluent organic matter (EfOM) characterization. Water Research. 38(7): 1933-1939.
[54] Y. He, Z.-W. Jiang. (2008). Technology review: treating oilfield wastewater. Filtration & Separation. 45(5): 14-16.
[55] T. Bilstad, E. Espedal. (1996). Membrane separation of produced water. Water Science and Technology. 34(9): 239-246.
[56] N.A. Fagnekar, P. Mane. (2015). Removal of turbidity using electrocoagulation. International Journal of Research in Engineering and Technology. 4(6): 537-543.
[57] A. Koohestanian, M. Hosseini, Z. Abbasian. (2008). The separation method for removing of colloidal particles from raw water. American-Eurasian Journal of Agricultural and Environmental Science. 4(2): 266-273.
[58] O. Can, M. Kobya, E. Demirbas, M. Bayramoglu. (2006). Treatment of the textile wastewater by combined electrocoagulation. Chemosphere. 62(2): 181-187.
[59] G. Roopashree, K. Lokesh. (2014). Comparative study of electrode material (iron, aluminium and stainless steel) for treatment of textile industry wastewater. International journal of environmental sciences. 4(4): 519.
[60] M.Y.A. Mollah, R. Schennach, J.R. Parga, D.L. Cocke. (2001). Electrocoagulation (EC)—science and applications. Journal of hazardous materials. 84(1): 29-41.
[61] P.K. Holt, G.W. Barton, C.A. Mitchell. (2005). The future for electrocoagulation as a localised water treatment technology. Chemosphere. 59(3): 355-367.
[62] K. Spiegler, O. Kedem. (1966). Thermodynamics of hyperfiltration (reverse osmosis): criteria for efficient membranes. Desalination. 1(4): 311-326.
[63] W. Mark, The Guidebook to Membrane Desalination Technology: Reverse Osmosis, Nanofiltration and Hybrid Systems Process, Design, Applications and Economic. In L'Aquila Desalination Publications: 2007.
[64] P. Xu, T. Cath, G. Wang. (2009). Critical Assessment of Implementing Desalination Technologies. Water Research Foundation.
[65] F.R. Spellman. (2013). Handbook of water and wastewater treatment plant operations. CRC press.
[66] E.T. Igunnu, G.Z. Chen. (2012). Produced water treatment technologies. International Journal of Low-Carbon Technologies. 9(3): 157-177.
[67] S.A. Malik, T.T. Swee, N.A.N.N. Malek, M.R.A. Kadir, T. Emoto, M. Akutagawa, L.K. Meng, T.J. Hou, T.A.I.T. Alang. (2017). Comparison of standard light-emitting diode (LED) and 385 nm ultraviolet A LED (UVA-LED) for disinfection of *Escherichia coli*. Malaysian Journal of Fundamental and Applied Sciences. 13(4-2): 430-437.
[68] V. Adam, R. Dreiskemper, M. Kessler. (2010). Comparison of UV power measurement of low pressure UV-lamps by a worldwide round robin test. IUVA News. 12: 2009.
[69] M.P. Akgün, S. Ünlütürk. (2017). Effects of ultraviolet light emitting diodes (LEDs) on microbial and enzyme inactivation of apple juice. International journal of food microbiology. 260: 65-74.
[70] D. Rickerby, M. Morrison. (2007). Report from the workshop on nanotechnologies for environmental remediation. JRC Ispra. 16.
[71] N. Daneshvar, D. Salari, A. Khataee. (2004). Photocatalytic degradation of azo dye acid red 14 in water on ZnO as an alternative catalyst to TiO_2. Journal of photochemistry and photobiology A: chemistry. 162(2-3): 317-322.
[72] S.-Y. Lee, S.-J. Park. (2013). TiO_2 photocatalyst for water treatment applications. Journal of industrial and engineering chemistry. 19(6): 1761-1769.
[73] J.H. Pan, H. Dou, Z. Xiong, C. Xu, J. Ma, X. Zhao. (2010). Porous photocatalysts for advanced water purifications. Journal of Materials Chemistry. 20(22): 4512-4528.