

Sustainable water treatment technologies: a review. Tecnologías sustentables de tratamiento de aguas: una revisión.

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ABSTRACT

The sustainability concept is emerged to maintain and strengthen “the ability of future generations to meet their own needs”. The adaptive capacities of the world population can be strengthened by eradication of poverty and provision of healthy living conditions which takes the priority. This can be achieved by provision of education and basic infrastructure to the people, worldwide. Availability of high quality drinking water and assurance of hygienic safety is one of the most basic needs of any community, and subsequently a precondition of sustainable development of rural or municipal areas. Decentralized water management should be seriously taken into account in the present scenario of extremely varying climatic changes affecting the potential water resources of the world. Also the energy requirement of centralized water supply schemes is fueling the energy scarcity. Therefore, effective utilization of ground water resources can be the intelligent step the towards achieving sustainable living conditions. Additionally, the water demand in the agricultural industry has become an important concern, considering that more than 70% of freshwater is used for crop irrigation. Desalination is considered a promising solution for water production challenges, but the sustainability of the same needs a detailed study. The treatment of waste water is another necessary criteria to satisfy the basic demands of good quality water for human life and industrial use. In the present review, different methods of water treatment technologies are studied, to assess their contribution towards sustainable development. Water treatment technologies for drinking purpose, waste water purification and desalination were deliberated and the effectiveness of each in attaining sustainable habitat has been portrayed in this review. It was observed that sustainable technologies for water treatment can be a better solution to face the water scarcity challenges in the world as they are self-reliable while compared to other methods.

Keywords— Sustainability, Ground water, Desalination, Waste water, Biochar.

RESUMEN

El concepto de sostenibilidad surge para mantener y fortalecer “la capacidad de las generaciones futuras para satisfacer sus propias necesidades”. La capacidad de adaptación de la población mundial puede fortalecerse mediante la erradicación de la pobreza y la provisión de condiciones de vida saludables, lo que tiene prioridad. Esto se puede lograr proporcionando educación e infraestructura básica a las personas en todo el mundo. La disponibilidad de agua potable de alta calidad y la garantía de la seguridad higiénica es una de las necesidades más básicas de cualquier comunidad y, posteriormente, una condición previa para el desarrollo sostenible de las zonas rurales o municipales. La gestión descentralizada del agua debe tenerse muy en cuenta en el escenario actual de cambios climáticos extremadamente variables que afectan los recursos hídricos potenciales del mundo. Además, el requisito de energía de los sistemas de suministro de agua centralizados está alimentando la escasez de energía. Por lo tanto, la utilización eficaz de los recursos hídricos subterráneos puede ser el paso inteligente hacia el logro de condiciones de vida sostenibles. Además, la demanda de agua en la industria agrícola se ha convertido en una preocupación importante, considerando que más del 70% del agua dulce se utiliza para el riego de cultivos. La desalación se considera una solución prometedora para los desafíos de la producción de agua, pero la sostenibilidad de la misma necesita un estudio detallado. El tratamiento de aguas residuales es otro criterio necesario para satisfacer las demandas básicas de agua de buena calidad para la vida humana y uso industrial. En la presente revisión, se estudian diferentes métodos de tecnologías de tratamiento de agua, para evaluar su contribución al desarrollo sostenible. Se deliberaron sobre tecnologías de tratamiento de agua para beber, purificación de aguas residuales y desalinización, y en esta revisión se describe la efectividad de cada una para lograr un hábitat sostenible. Se observó que las tecnologías sostenibles para el tratamiento del agua pueden ser una mejor solución para enfrentar los desafíos de la escasez de agua en el mundo, ya que son autosuficientes en comparación con otros métodos.

Palabras clave: sostenibilidad, agua subterránea, desalación, aguas residuales, biocarbón.

INTRODUCTION

The effective water supply and sanitation needs to be established worldwide as a first and important step to eradicate poverty, to improve hygienic safety, and to achieve sustainable development in rural and urban areas. The classical water supply and sanitation system will remain useful, but needs to be supplemented by novel ways of serving people. Needed are solutions that provide safe hygienic treatment of water in a very short time period, and for a reasonable price. Various new water supply and sanitation technologies have been proposed, but efficient and reliable application requires more than technological development. The costs must be kept in an affordable range, and

professional service must be provided (Wildere P. A, 2014). Mass production of the components of decentralized systems may greatly reduce costs and should be seriously taken into consideration. The sustainable water treatment not only require better engineering practices, but also economical, administrative and cultural aspects must be considered. Water-borne diseases resulting from unsafe drinking water and poor sanitation are endemic in developing countries (Ali I. 2014, Pandit et al. 2015, Shannonet al. 2008, Gwenzi et al. 2016, Heringet al. 2016). Goal 6 of the United Nations (UN) Sustainable Development Goals (SDGs) seeks to ensure access to water and sanitation for all, implying the need to improve water quality and protect water-related ecosystems (Raj et al. 2020). The 15-year time frame set to achieve the UN SDGs points to the need for rapid synthesis and effective translation of existing scientific and technological advances in water research into practical, frugal solutions through better policy decisions and implementation (Raj et al. 2020). Ironically, developing countries, especially those in Africa and parts of Asia and South America which have lagged behind in technological advances due to weak scientific research and poor funding, will require an even more rapid translation of scientific knowledge into products and services. The major challenges to sustainable water treatment systems in developing countries are (Wilderer P.A, 2014) lack of money, and in some cases small and sparsely distributed populations, (2) lack of technical skills to operate existing technologies, and (3) lack of electricity to operate some existing affordable solutions (e.g., electro-coagulation, reverse osmosis) (Wilderer P.A, 2014).

In the present review various water treatment methods are studied in view point of their sustainability in water conservation activities. The first study is carried out on sustainable drinking water treatment methods. The second study is conducted on sustainable waste water treatment methods. The treatment of waste water is necessary to maintain good-quality water for human life and industrial use. Treated waste water that can be used for different sectors such as agriculture and industry. The beneficial characteristics of both clay minerals and polymers were combined to develop clay polymer Nano composites (CPNs) (Czernik et al. 2004). The multiple applications and large-scale advantages for numerous industries including water purification makes CPNs advantageous while compared to other adsorbents. This present review overviews of the recent advances of CPNs and their application in waste water treatment in terms of sustainability.

The third review considers the desalination technology developments towards achieving sustainable water treatment. Desalination is considered to be a promising solution to face water scarcity challenges. In the present study, the feasibility of a combined membrane based process SWRO-PRO- NF for drinking water, irrigation water, and energy is investigated to achieve sustainable desalination. The feasibility of a combined membrane based process SWRO-PRO-NF for drinking water, irrigation water, and energy is investigated to achieve sustainable desalination has been studied here.

MATERIALS AND METHODS

In the present review, different methods of water treatment technologies are studied, to assess their contribution towards sustainable development. Water treatment technologies for ground water treatment, waste water purification and desalination were studied and the effectiveness of each in attaining sustainable habitat has been portrayed in this review. Firstly, the biochar technological developments towards achieving sustainable drinking water has been reviewed. The existing possibilities of biochar technology and the future innovations which can lead to sustainable environment is considered. In the second review the use of clay polymer Nano composites (CPNs) in waste water treatment has been studied. CPNs using economical and green materials such as agro- waste, green extract, and industrial by-products was found to be the sustainable way to remove harmful contaminants and microbes from water. The potential sustainable solution based on a membrane process that combines seawater reverse osmosis (SWRO), Nano filtration (NF) and pressure retarded osmosis (PRO) to produce drinking water, energy, and water for irrigation has been reviewed in the third study.

RESULTS AND DISCUSSION

Sustainable ground water treatment- biochar technology for removal of contaminant in water-Biochar production: Biochar is an ideal adsorbent for water treatment because of its capacity to remove multiple contaminants in water. Biochars are highly heterogeneous materials formed through high-temperature pyrolysis of biomass under low/no oxygen conditions. The generic properties of these heterogeneous materials determine their applications in contaminant removal. The highly porous micro-structure, high specific surface area (SSA), high cation exchange capacity and pH ranging from near-neutral to alkaline and high amount of fixed carbon relative to feedstock are the major characteristics of biochar. The type of feedstock used for pyrolysis and the process conditions affect these properties. Feedstocks for the production of biochar include a wide range of biomaterials such as crop residues, agro-processing wastes, municipal solid waste, animal wastes and sludge. Based on temperature (T°C) and vapour residence time (VRT), thermochemical processes for the production of biochar can be summarized as: (1) conventional/slow pyrolysis (T° C: 350-800, VRT: sec - hr), (2) torrefaction (T° C: 200-300, VRT: min- hr), (3) fast pyrolysis (T° C: 400-600, VRT: sec), gasification (T° C: 700- 1500, VRT: sec-min), and hydrothermal conversion to produce hydrochars (T° C: 175-250, VRT: hr) (Mohan et al. 2015).

Sustainability criteria: Biochar technology is a sustainable low-cost water treatment

method as it provides multiple environmental and agronomic co-benefits, making it attractive in developing countries. The capacity to remove a number of pollutants in water coupled with abundant and readily available feed stocks, makes biochar an ideal adsorbent for decentralized household water treatment systems. A key feature of biochar is its ease of production using pyrolysis systems spanning a range of scales, including pyrolytic stoves for household heating and cooking, kilns of various geometries, and pits similar to those used for charcoal production, to large-scale systems producing about several tonnes of biochar per day (Gwenzi et al. 2017). The conversion of locally available biowastes into biochar has the potential to address multiple interrelated food and livelihoods problems on water, energy, environmental and food problems in developing countries (Duong et al. 2011). The biochar concept is sustainable while compared to current standalone low-cost water treatments system because this technology uses bio wastes which are readily available in large quantities. Table.1 represents the application of biochar produced from different feedstock’s [Mukome et al. 2013].

Table 1. Application of biochar produced from different feedstocks. (Source:Duong and Byeong-Kyu,2011).

Biomass feedstock	Pyrolytic temperature (°C)	Pyrolysis techniques	Contaminants	References
Coconut coir	250–600	Slow pyrolysis	Chromium	[26]
Corn straw	600	Slow pyrolysis	Copper and zinc	[4]
Dairy manure	350	Slow pyrolysis	Pb, Cu, Zn, and Cd	[31]
Rice straw	100–700	Slow pyrolysis	Aluminum	[5]
Sludge	400–700	Slow pyrolysis	Fluoride	[9]
Sugar beet tailings	600	Slow pyrolysis	Phosphate	[32]
Sugarcane bagasse	450	Slow pyrolysis	Sulfamethoxazole	[27]
Wood	200–600	Slow pyrolysis	Fluorinated herbicides	[28]
Rice husk	350	Slow pyrolysis	Pb, Cu, Zn, and Cd	[31]
Corn straw	600	Slow pyrolysis	Copper and zinc	[5]

Also the spent biochar can be used as a soil amendment to improve carbon sequestration, soil quality and crop yields, and consequently livelihoods and food security. Biochar has both direct and indirect impacts on greenhouse gas (GHG) emissions such as CH₄, N₂O, NH₃ and CO₂ through carbon stabilization (Lehmann et al. 2006). Carbon in biochar is more stable and resistant to decomposition than ordinary soil carbon characterized by high turnover and subsequent release of CO₂ (Zimmerman A, 2010, Ackerman F, 2000). Therefore, pyrolysis of bio wastes into more stable carbon in biochar reduces GHG emissions from decomposition of bio wastes in waste repositories (Denault et al. 2004). The net environmental footprint of biochar technology is strongly dependent on the design of both the pyrolysis and the water treatment systems, which can be surmounted by proper design of the system.

Sustainability in waste water treatment using clay polymer nanocomposites--Clay-Polymer Nanocomposites (CPN): Polymers are incorporated in minute quantities (< 5% by weight) into the supporting materials such as nano-sized particles of clay or other nanoparticles (< 100 nm in any dimension) with high aspect ratios (L/H > 300) in order to synthesis clay polymer nanocomposites (Wagner et al. 2004). However, reinforcement is in the order of micrometers in the case of traditional composites, whereas CPNs are in the order of a few nanometers. CPNs also contain filler (1–5 vol. %) in small quantities and thus impart inherent characteristics and stability to pure polymer or resin (Yin et al. 2015).

The removal of contaminants from aqueous systems using CPNs mainly involves adsorption processes. The adsorption of contaminants such as heavy metals, metalloids, dyes, and other organic depends on: (1) the surface area, surface functional groups, and surface charge of the CPN adsorbents, and (2) the pH, temperature, ionic strength of the medium, initial concentration of the contaminants in question, and the concentrations of co-existing ions/compounds. Electron donor-acceptor interaction, electrostatic attraction, hydrogen bonding, chemisorption, ion-exchange, and pore-space filling by precipitation or complex formation are the main mechanisms during adsorption of inorganic, organic, and biological contaminants onto different CPN adsorbents.

Sustainability criteria: The addition of clay minerals to a biopolymer has found to improve the adsorption capacity of the polymer–clay nanocomposite for organic and inorganic contaminants. Polymer nanocomposites are widely used for water purification, gas separation, and desalination because of their enhanced mechanical stability, flexibility, small footprint, and low preparation cost (Kononova et al. 2018, Unuabonah et al. 2018.). Clay–polymer nanocomposites (CPNs) can be used as membranes, flocculation or coagulation agents, and in columns and barriers for decontaminating wastewater of harmful organic, inorganic, and biological pollutants (Fig.1) (Czernik et al. 2004).

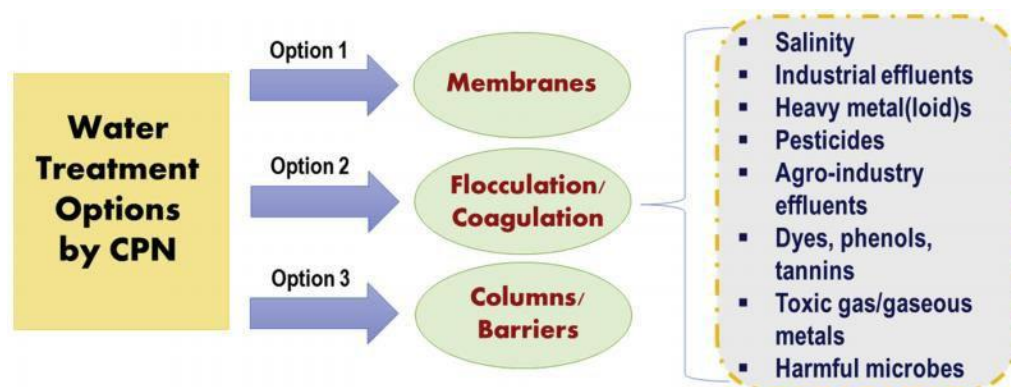


Fig.1 Possible options for water remediation using CPNs. (Source: Denault and Labrecque, 2004)

In addition, incorporation of naturally available clay minerals into a polymer matrix may also minimize the cost of the product. However, green leaf extract has been used with clays to minimize the cost of production and maintain environmental sustainability (Khaled et al. 2020). Overall, selection of low-cost suitable clay minerals, green leaf extract, and inexpensive raw materials as filler and polymers can be used for the economical preparation of low-cost efficient CPNs to maintain environmental sustainability.

SUSTAINABLE DESALINATION TECHNOLOGY -SWO-PRO-NF TECHNOLOGY

The Sea Water Reverse Osmosis-Pressure Retarded Osmosis-Nanofiltration (SWRO-PRO-NF) Process

The SWRO-PRO-NF process is composed of three parts as shown in Fig. 2. First the the seawater desalination sub-system by SWRO followed by the energy recovery sub-system via PRO and the treatment of waste water effluents to produce water for irrigation through a NF sub-system. The advantage of this configuration manifests in the fact that PRO feed and draw solutions do not require pretreatment as they are derived from feed solutions previously pretreated by NF and SWRO Processes. The energy consumption of the combined process was first compared to the total standalone NF and RO energy consumption (Khaled et al. 2020).

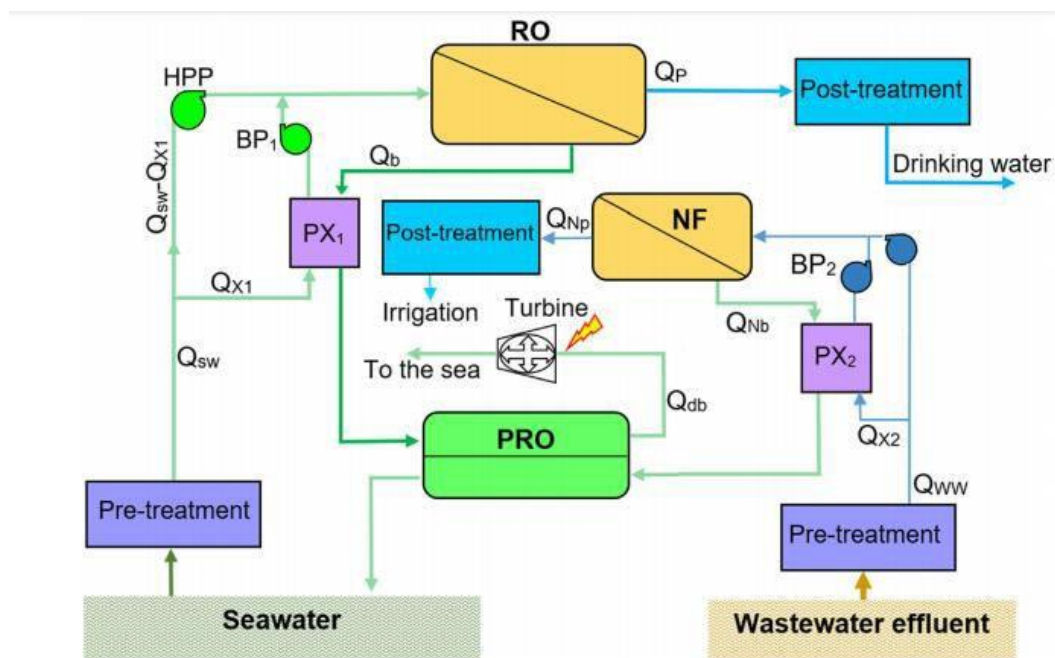


Fig.2 .SWRO-PRO-NF Process (Source: Khaled et.al, 2020)

Sustainability: The SWRO-PRO-NF combined process showed that the system has great potential in achieving important energetic and economic gains, with further environmental benefits in reducing the impact of desalination brine and waste water effluents on discharge basins. The four parameters controlling the economic viability of the process are the PRO membrane price, the PRO membrane performance, the mitigation of detrimental effects, and the process capacity. Simultaneously, PRO membrane performance and detrimental effects mitigation control the PRO membrane price. The viability of the process in terms of membrane price can be improved if the membrane performance is optimal and detrimental effects are well controlled.

CONCLUSIONS

The provision of high quality drinking water and assurance of hygienic safety is one of the most basic needs of any society, and hence an essential factor for the sustainable development of rural or municipal areas. Decentralized water management should be seriously taken into account in the present scenario of extremely varying climatic changes and the resulting drying up of the potential water resources of the world. The energy requirement of centralized water supply schemes is fueling the energy scarcity, which also necessitates the development of decentralized technologies for water treatment. The three different approaches of water treatment: 1) for ground water 2) waste water and 3) Salt water has been studied in this review in terms of sustainability. Biochar technology for ground water treatment yields triple public health benefits like reduction of indoor emissions that cause respiratory diseases, provision of a low cost adsorbent for water treatment, and provides food security and nutrition benefits through use of spent biochar as a soil amendment for improving soil quality and crop yields. The synthesis of biochar using pyrolytic or gasification stoves purifies the drinking water to household heating and cooking. The spent biochar fertilizers enrich inherently poor soils, increase carbon sequestration and crop yields. The waste water treatment methods using metal-doped CPNs with less toxic metals such as Cu, Zn, and Fe should be promoted for water treatment in place of Ti and Ag, which are harmful and toxic to living organisms residing in water. A valid standardized methodology must be developed to evaluate environmental safety and sustainability at an international level. The preparation of innovative CPNs using economical and green materials such as agro-waste, green extract, and industrial by-products should be promoted. Desalination treatment improvement using a combined SWRO-PRO-NF process in the water-energy nexus has revealed that it has the potential to produce a considerable amount of energy that may reduce the overall energy consumption of the combined process. Also the energy consumption was reduced by almost 15% and the the combined process is more economic which provides a mean water price lower than the standalone processes.

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Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), 10(X), 2022:
<http://dx.doi.org/>

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Received: 30th January 2021; Accepted: 13th March 2021; First distribution: 01th April
2021