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Appraisal of Some Existing Technology on Water Quality: Appraisal and Design

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Abstract: *Water is essential for the maintenance of life, domestic, industrial and agricultural purposes. However, the current global challenge is to find solutions to problems arising from the employment of contaminated water for the listed purposes. It is known that there is more contaminated or polluted water than potable water. Therefore, since the water resources is fixed by nature, efforts towards the provision of potable water must significantly be directed towards water treatment protocols. This review identified various water treatment methods, their comparative advantages as well as disadvantages. The comparison reveals that there is no specific method that can give 100% purity of water. Hence for best results, we recommended the engineering approach for the provision of a purification bed as the best option.*

Keywords: *Water contamination, purification methods, synergism, potable water*

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1.0 Introduction

Water has major domestic, industrial, agricultural and other benefits (Hossain, 2019; Odoemelam *et al*., 2018). However, different applications require different water quality. For example, the quality of water requires for irrigation of farmland may not be suitable as drinking water (Eddy and Ekop, 2007). Water quality assessment parameters are therefore based on the intended purposes (Ighalo and Adeniyi, 2020). Portable water is defined by Eddy and Garg (2021) as water treated or natural water that meets state, Federal or global standards for drinking purposes. This definition can only be sustained if the quality parameters ae within the limits recommended by the respective regulatory bodies. For example, in Nigeria, the Federal Environmental Protection Agency and the Standard Organization of Nigeria are tasked with the responsibilities of providing standards based on recommended minimum requirements or maximum tolerance limits (NIS, 2007). Control of water quality is therefore a major challenge in most developing and developed nations and can rightly be recognised as a global challenge (Moe and Rheingans, 2006). According to the World Health Organization , there is more polluted water than potable water in the world (Ahuja, 2019). The consequence is that as long as the supply of potable water is a challenge, the provision of proper treatment measures is the only solution. Therefore, this paper tends to review some technologies in water treatment and the engineering requirements for a water treatment plant.

2.0 Water Treatment Technologies

2.1 Adsorption technology

Adsorption is a surface process that is significantly useful in the treatment of contaminated water (Uchechukwu *et al*., 2018). The adsorption process involves three major interactions, namely,

(i) Interaction between adsorbent and contaminated water

(ii) Interaction between adsorbent and the adsorbate

(iii) Interaction between adsorbate and the aqueous or solvent phase

It is this interaction that determines the extent of adsorption and hence the removal of the contaminants (Essien and Eddy, 2015; Adedirin et al*.,* 2011). The mechanism of adsorption can be through a chemical reaction (which represents chemisorption) or the formation of a weak bond (physical adsorption) (Eddy *et al*., 2008a-b)). The occurrence of both types of adsorption has been observed in some adsorption studies (Okwunodulu & Eddy, 2014). Adsorption experiments are generally carried out using either the batch (Fig. 1) or column (Fig. 2) methods (Brandani, 2021;Patel, 2019). Batch adsorption is currently receiving numerous research attention because it is simple and has been successfully applied for the removal of several adsorbents from aqueous solution (Asgher & Bhatti, 2012; Bhatti *et al*., 2020). However, one of the limitations of the batch adsorption experiment is the inability to handle the modeling of a flowing solution. generally, from batch adsorption experiments, the percentage removal (R) and equilibrium amount of contaminant removed (by adsorption) can be calculated using equations 1 and 2 respectively (Uchechukwu *et al*., 2015)

$$R\,(\%) = \left[\frac{C_0 - C_e}{C_0}\right] \times \frac{100}{1} \qquad (1)$$

$$Q_e\,(mg/g) = \left[\frac{C_0 - C_e}{C_0}\right] \times \frac{V}{m} \qquad (2)$$

where Q_e is the equilibrium concentration of the dye adsorbed, V is the volume of the solution used for the adsorption experiment while m is the mass of the adsorbent.

Successes have been reported on the application of the batch adsorption process for the purification of agricultural, domestic and industrial waste water and reported removal efficiency of almost 100% is not strange for the method (Chatterjee *et al*., 2014; Cho, 2020; Eddy, 2009; Ekop and Eddy, 2009; Ekop and Eddy, 2010; Khaled *et al*., 2009; Mafra *et al*., 2013; Mahato *et al*., 2020; Mahmoud *et al*., 2017; Shakoor and Nasar, 2016; Sivarai *et al*., 2001). Geerally, one of the major challenges of the adsorption process is the disposal of the adsorbent, which might have been contaminated after the adsorption of the contaminants. One engineering approach to overcome this challenge is the regeneration of the adsorbent after adsorption. Regeneration bed is often contructed to allowed the desorption of the contaminants from the adsorption and ensure it reused (Huang *et al*., 2012).

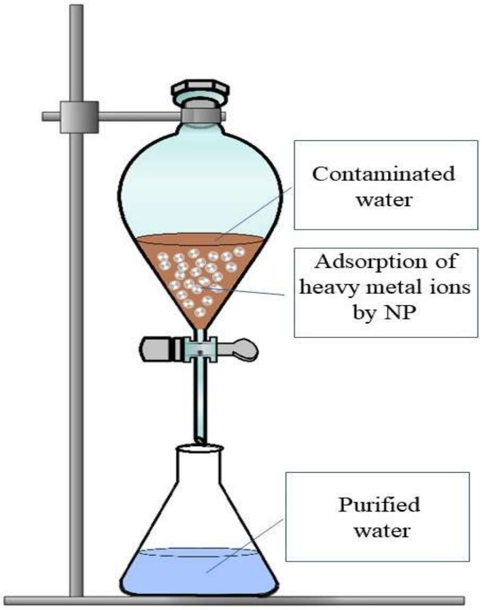

Fig. 3: Setup for a simple Batch Adsorption for removal of contaminants

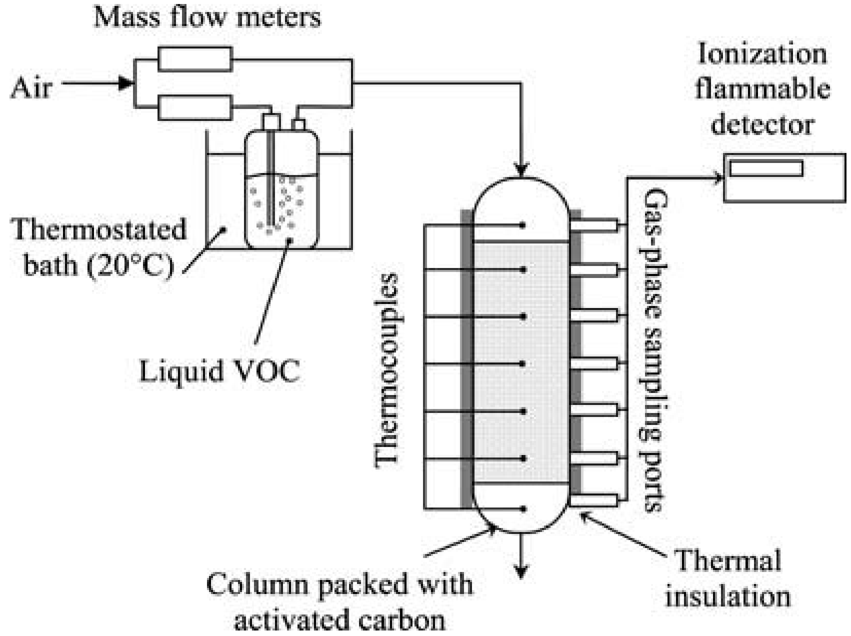

Fig. 2: Schematic diagram for column adsorption studies

2.2 Photodegradation

Adsorption process may not be able to remove some classes of compouds such as emergent contaminants and where they are able to remove them, the process of disposing them may constitute a secondary pollution problem, especially where biomagnification takes place. Photodegradation is a process whereby stable contaminants are degraded by using suitable catalysis. Usually, the degradation leaves environmentally friendly products such as water, nitrogen, etc. According to Eddy and Garg (2021), Compounds with large surface area and largesurface area to volume ratio have uniques size-dependent properties (including porosity high reactivity, high adsorption capacity, high dissolution capacity), high super-magneticity, and quantum confinement effect) (Kamboj *et al*., 2020). Photocatalysis is a beneficial approach towards the treatment of wastewater that is highly contaminated with non-degradable organic matter.

Eddy and Garg (2021) has reported photocatalysis mechanism as follows

(i) Absorption of a photon by the organic compound and subsequent excitation:

$$\text{Org.} + h\upsilon \rightarrow \text{org}^* \qquad (2)$$

(ii) The formation of electron-hole pair formation

$$\text{NP} + h\upsilon \rightarrow e^-(\text{CB}) + \text{H}^+(\text{CB}) \qquad (3)$$

(iii) Oxygen ion sorption reaction

$$e^-(\text{CB}) + O_2 \rightarrow O_2^* \qquad (4)$$

(iv) Neutralization by proton

$$2O_2 + 2H_2O \rightarrow H_2O_2 + O_2(O_2^*) \qquad (5)$$

(v) Formation of OH* through the decomposition of H_2O_2

$$H_2O_2 + e^-(\text{CB}) \rightarrow OH^- + OH^* \qquad (6)$$

(vi) Splitting of water by photo-hole to produce OH* radical

$$h^+ + H_2O \rightarrow H^+ + OH^* \qquad (7)$$

(vii) Electrophilic attack of the organic compound, leading to the degradation of the organic compounds such as dye

$$O_2^*/OH^* + \text{org.} \rightarrow \text{Degradation product}$$

Some successes have also been reported on the efficiency of photocatalysis process towards the purification of sewage, dye and other chemicals contaminated waste water (Ajmal *et al*., 2014; Al-Mamun *et al*., 2019; Lin *et al*., 2020; Poulopoulos *et al*., 2019; Vanthana Sree *et al*., 2020; Xia *et al*., 2013)

2.3 Biological treatment methods

2.3.1 Bioremediation

Bioremediation is a treatment process that involves the implementation of microorganisms to remove pollutants from a contaminated setting. Bioremediation can be defined as “treatment that implements natural organisms to decompose hazardous materials into less toxic or nontoxic materials (He *et al*., 2017). Some examples of bioremediation-related technologies are phytoremediation, bioaugmentation, rhizofiltration, and biostimulation. The microorganisms implemented to carry out the bioremediation are called bioremediators. However, some pollutants are not easily removed or decomposed by bioremediation. For example, heavy metals such as lead and cadmium are not eagerly captured by bioremediators. Example of bioremediation: fish bone char has been shown to bioremediate small amounts of cadmium, copper, and zinc (ref). Nevertheless, some successes have been reported on the excellent efficiency of bioremediation on the detoxifying some contaminated or polluted water (Idi *et al*., 2015).

2.3.2 Aerobic treatment process

Aerobic treatment procees ues aeration to remove trace organic volatile compounds (VOCs) in water. It has also been employed to transfer a substance, such as oxygen, from the air or a gas phase into the water in a process called “gas adsorption” or “oxidation through the oxidation of iron or Mn. Other successes have been reported for the removal of ammonia from waste water (Ranade and Bhandari, 2014).

2.3.3 Oxidation pond

Oxidation ponds consists of an aerobic systems that derived oxygen required by the heterotrophic bacteria (to carried out oxidation) from the atmosphere transfer and photosynthetic algae (which are confined to sunlight zone). Some successes have also been recorded on the application of oxidation pond for the degradation of some organic contaminanats in water (Bengtsson *et al*., 2018)

2.3.4 Bioreactor

A bioreactor is an engineered vessel that is designed to facilitate biochemical reactions (towards the removal of water contaminants) involve microorganisms or biochemical products (such as enzymes). The bioreactors are commonly made of stainless steel, usually cylindrical in shape and range in size from liters to cubic meters. The bioreactors are classified as batch, plug, or continuous flow reactors (e.g., continuous stirred-tank bioreactor). A schematic diagram of membrane bioreactor for waste water treatment is shown in Fig. 3

3.0 Method appraisal and engineering approach

The advantages and disadvantages of the various methods available for the treatment or purification of water are presented in Table 1. It is evident from the information presented in the figure that there is no singular method that can adequately stands alone. Therefore, there is always a synergy for different methods to be adopted in order to achieved a better purification system and thus provision of portable water. An engineering approach therefore involves the construction of a system whereby several steps are progressively implemented as the contaminated water passes through the various stages. This ensure the removal of specific contaominants by at the stage their sensitivities are most magnified. A typical water treatment plant for potable water production will involves stages shown in Fig. 3.

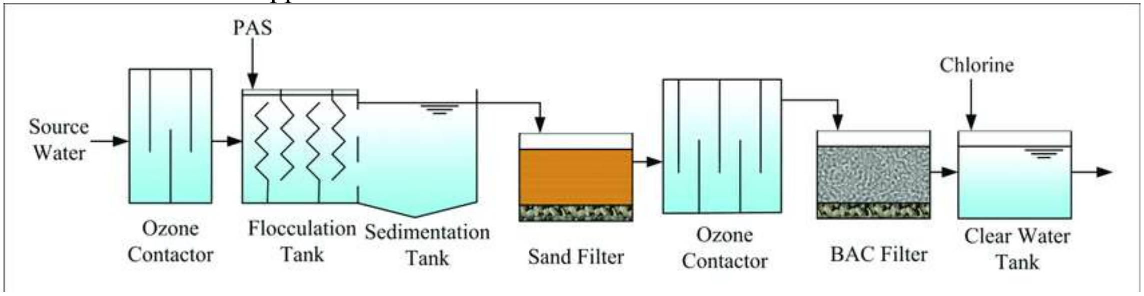

Fig. 3: Schematic scheme of the steps and processes involves in the production of portable

water

Table 1: Appraisal of the efficiency of various water treatment methods

Method	Description	Limitations
Chemical precipitation	Separation of the products formed/uptake of the pollutants	The method is not environmentally friendly because it can leave excess in the water. Also, it is not a very selective method.
Flocculation/ Coagulation	Separation of the products formed/uptake of the pollutants	The method is complex and not very inefficient. The optimum pH required is alkaline
Flotation	Separation process	The method is not cost-effective because it is pH dependent selectivity and requires a high cost of maintenance and operation
Chemical oxidation	Use of an oxidant (e.g., Cl_2, O_3, $KMnO_4$, ClO_2, H_2O_2)	The method needs large amounts of chemicals and the resistance of some contaminants to oxidation can limit its usefulness
Biological treatment	Use of biological (mixed or pure) cultures	Microorganisms are environmentally sensitive. The intermediates formed can destroy microbial cells. The method is not cost-effective and requires excessive time
Filtration Nanofiltration	membrane processes for H_2O and wastewater treatment in addition to other applications such as desalination.	The method requires high energy consumption than UF and MF (0.3 to 1 kWh/m^3). It requires pre-treatment for some heavily polluted waters (pre-filtration 0.1 - 20 microns). .. It displays limited retention for salts and univalent ions. It is not cost-effective compared to reverse osmosis.
Filtration: Ultrafiltration	Involves the use of semi-permeable membrane	Can nor remove odour and soluble salts from the water
Filtration: Carbon filtration	Based on activated carbon filter	The method cannot remove chemicals that can not be adsorbed into carbon. Its optimum operations depend on several variables The method is not suitable for the removal of some pathogens, bacteria and viruses except impregnated activated carbon filter is used.

Ion exchange	Nondestructive process	The cost of installation, maintenance and operation is very high
Incineration / Thermal oxidation	Destruction by combustion	High cost of installation and operation
Electrochemistry	Electrolysis (E)	The cost of installation, maintenance and operation is very high
Membrane filtration	Nondestructive separation	Not economical for for small and medium-sized industries and requires high energy input.
Evaporation	The separation process, Thermal process and Concentration technique,	The method is not cost-effective for high volumes of wastewater and small and medium-sized industries.
Liquid–liquid (solvent) extraction	Separation technology	Expensive equipment does not make the method to be cost-effective
Advanced oxidation processes (AOP) Photolysis	Emerging processes, Destructive techniques	The method is not cost-effective for medium and small-sized industries and the throughput is low

3.1 Analytical methods and quality appraisal

The basic step required for the determination of the potability of the water is to carry out the analysis of the water samples and obtained results that can be compared to existing standards. Table 2 summarises analytical methods for major water quality standards.

Table 2. Analytical methods *for some* water quality parameters

Parameters	Analytical method	Reagents
Phenolphthalein alkalinity	Titrimetric	Na_2CO_3, H_2SO_4, ethyl alcohol, phenolphthalein
Total alkalinity	Titrimetric	Na_2CO_3, H_2SO_4, ethyl alcohol, bromocresol indicator, methyl orange indicator
Aluminum	Spectrophotometric	Eriochrome cyanide R, HCl, $AlK(SO_4)_2$, sodium acetate, standard aluminum solution, ascorbic acid, acetic acid, solochrome cyanide, bromocresol green, EDTA, sodium hydroxide
Bicarbonate	Titrimetric	Na_2CO_3, H_2SO_4, ethyl alcohol, bromocresol indicator, methyl orange indicator, phenolphthalein
Biochemical oxygen demand	Bioassay	Phosphate buffer solution, KH_2PO_4, $Na_2HPO_4.7H_2O$, NH_4Cl, $MgSO_4.7H_2O$, $CaCl_2$, $FeCl_3.6H_2O$, H_2SO_4, NaOH,

		glutamic acid, glucose glutamic acid.
Boron	Spectrophotometric	HCl, ethyl alcohol boric acid, curcumin, ion exchange resin, boron solution, oxalic acid, and boric acid
Calcium	EDTA titrimetric	Standard calcium solution, EDTA, HCl, Murexide indictor, NaCl, NaOH, $CaCO_3$ and NH_4OH
Carbonate	Titrimetric	Na_2CO_3, H_2SO_4, ethyl alcohol, bromocresol indicator, methyl orange indicator, phenolphthalein
Chemical oxygen demand	Open reflux	Standard $K_2Cr_2O_7$, H_2SO_4, Ag_2SO_4, $FeSO_4.7H_2SO_4$, 1, 10-phenanthroline monohydrate and $Fe(NH_4)_2\ (SO_4)_2.6H_2O$
Chloride	Titrimetric (Argentometric)	NaCl, $AgNO_3$, $AlK(SO_4)_2.12H_2SO_4$ $AlNH_4(SO_4)_2.12H_2O$, NH_4OH and $Al(OH)_3$
Chlorophyll-a	Spectrophotometric	Acetone, $Mg(CO_3)_2$
Faecal coliform	Elevated temperature fermentation	Tryptose, trypticase, bile salts, bile salts, dipotassium hydrogen phosphate, potassium dihydrogen phosphate, and sodium chloride
Total coliform	Standard multiple tube fermentation	Tryptose, lactose, dipotassium hydrogen phosphate, potassium dihydrogen phosphate, sodium chloride, and sodium lauryl sulfate
Colour	Visual comparison	K_2PtCl_6 crystallized cobaltous chloride and HCl
Dissolve oxygen	Titrimetric (Winkler azide modification)	$MnSO_4\ .4H_2O$, $MnSO_4.2H_2O$, $MnSO_4.H_2O$,alkali-iodide-azide, NaOH, KOH, NaI, KI, NaN_3, sulphuric acid, starch, salicylic acid, standard sodium thiosulphate titrant, $Na_2S_2O_3.5H_2O$, NaOH, standardize with bi-iodate solution, $KH(IO_3)_2$
Conductivity	Potentiometric (Conductivity cell)	Chromic/sulphuric acid, chloroplatinic acid, $H_2PtCl_6.6H_2O$) and lead acetate
Flouride	Electrometric (Ion-selective electrode)	NaF, NaCl, NaOH, Glacial acetic acid, 1,2-cyclohexylenediaminetetraacetic acid
Total hardness	Titrimetric (EDTA)	NH_4Cl, NH_4OH, EDTA, eriochrome black, $CaCO_3$
Iron	Spectrophotometric	HCl, ammonium acetate, Hydroxylamine, sodium acetate, 1,10-phenanthroline monohydrate, H_2SO_4, ferrous ammonium sulfate, $KMnO_4$, and standard iron solution
Magnesium	Titrimetric	NH_4Cl, NH+OH, EDTA, eriochrome black, $CaCO_3$, Standard calcium solution, EDTA, HCl, Murexide indictor, NaCl, NaOH, $CaCO_3$ and NH_4OH
Manganese	Spectrophotometric	$HgSO_4$, HNO_3, $(NH_4)_2S_2O_8$, $KMnO_4$,

		$Na_2C_2O_4$, H_2SO_4, and $KMnO_4$
Nitrogen nitrate	Spectrophotometric	Stock Nitrate solution, KNO_3, $CHCl_3$ nitrate Solution, and HCl,
Nitrogen nitrite	Spectrophotometric	phosphoric acid, sulphanilamide, N-(1-naphthyl)-ethylenediamine dihydrochloride, sodium oxalate, $Na_2C_2O_4$, $NaNO_2$, $CHCl_3$, $KMnO_4$, H_2SO_4, and NO_2^- solution
Phosphorus as ortho phosphorus	Spectrophotometric	Sulphuric acid, Potassium antimonyl tartrate, ammonium molybdate solution, ascorbic acid, H_2SO_4, anhydrous KH_2PO_4, and standard phosphate solution
Total phosphorus	Spectrophotometric	Ammonium molybdate solution, persulphate, Sulphuric acid, Potassium antimonyl tartrate, ammonium molybdate solution, ascorbic acid, H_2SO_4, anhydrous KH_2PO_4, and standard phosphate solution
Potassium and sodium	Flame emission photometric	Standard solution of the metal
Sulfate	Nephelometry	magnesium chloride, sodium acetate, potassium nitrate, acetic acid, sodium sulfate, barium chloride, sodium carbonate, and sulphuric acid
Heavy metals (Co, Ni, Cr(VI), Pb, Cd, As, Se, V, Hg, Cu)	Spectrophotometric	Standard solution of the respective metals
Dyes (Sudan I dye, Methyl blue, Basic red 9 dye, crystal violet dye, dispersed red 1 dye, reactive and some azo dyes.	Spectrophotometric	Standard solution of the respective dyes
Antibiotics (tetracycline, ampicillin, amoxicillin,	Spectrophotometric	Standard solution of the respective antibiotics
Organic pollutants (phenol, crude oil, fertilizers)	GCMS	Standards

4.0 Conclusion

The foregone review indicates that treatment of contaminated water is the only measure that can quarantee the avialablity of potable water for human appliations. Although there are different purification methods, no single method seems to be optimal toward the provision of potable water. Therefore, a synergy of various methods can be achieved through complimentary engineered systems.

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Conflict of Interest

The authors declared no conflict of interest