Modified Orange Peels Biochar as a Sustainable Green Biosorbents for Nitrates and Phosphates in Environmental Waters

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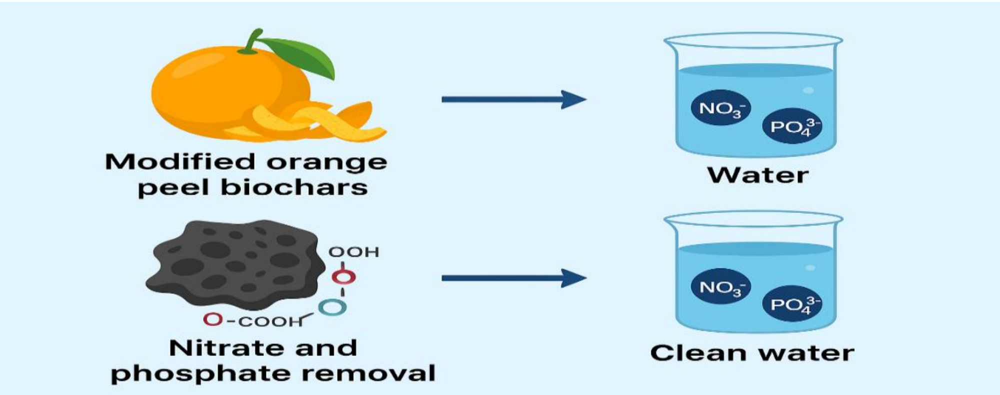
ABSTRACT

Biomass waste utilization has garnered a lot of interest lately, particularly in the purification of environmental water. Water pollution caused by excessive nitrates has become a significant environmental concern globally. The traditional treatment methods often involve costly and energy-intensive processes. This chapter examines the potential of using modified fruit peels, specifically modified orange peels biochars, as natural bio sorbents for the removal of nitrates and phosphates from environmental waters. Biochar, a charcoal-like material produced by heating biomass in an oxygen limited environment, has emerged as a promising tool for water purification due to its unique properties and environmental advantages. Its microporous structure offers a vast surface area decorated with functional groups, ideal for capturing contaminants such as the phosphates and the nitrates. Biochar's purification power works through a combination of mechanisms. It acts like a sponge, using its porous structure to trap contaminants physically through adsorption. The charged functional groups on its surface also act like magnets, attracting and holding onto unwanted ions through ion exchange. Scientists rely on mathematical models like Langmuir and Freundlich isotherms to fully understand how well biochar will work in a particular situation. These models describe how efficiently biochar removes contaminants at varying concentrations either through monolayer adsorption route on homogenous surfaces as in the case of Langmuir or onto heterogenous surfaces as in the case of Freundlich isotherm, providing valuable insights for optimizing biochar-based water treatment systems.

Key words: Green bio sorbents, Biochars, modified orange peel biochars, Biosorption, water treatment methods, Water pollution, Adsorption and Mechanisms.

Graphical abstract



INTRODUCTION

There are substantial amounts of industrial and agricultural waste products as a result of the increase in industrial activity and population growth. When these pollutants and effluents are improperly disposed of, the environment and human health are gravely threatened. (Chowdhury and Balasubramanian, 2014; Lata and Samadder, 2016).

Due to this, the water and wastewater treatment industry's top priorities now include guaranteeing a clean water supply and enhancing water quality. A vital requirement for public health, access to safe drinking water is denied to an estimated 1.2 billion people in poor nations. Limited access to sanitary facilities for 2.6 billion people exacerbates the situation even more. It is frequently not possible to completely eliminate these pollutants using conventional water treatment procedures (Bao *et al*., 2017)considerations for bio sorbents have been on the rise by researchers and scientist.

Bio sorbents are natural or modified materials that have the ability to remove pollutants from water through a process called biosorption (Rangabhashiyam *et al*., 2014). Biosorption is a promising and environmentally friendly method of water treatment that utilizes the binding capacity of certain natural materials to remove various contaminants. One such group of bio sorbents are fruit peels, specifically banana peels and orange peels. Banana peels and orange peels are readily available agricultural waste products that have gained attention as potential bio sorbents due to their abundance, cost-effectiveness, and beneficial properties. These fruit peels contain compounds, such as potassium, phosphorus, and limonene, that exhibit sorption capacities for contaminants commonly found in water, including nitrates, phosphates, and certain organic compounds.

Studies have shown that the surface of orange peels can undergo chemical modifications to enhance their sorption capabilities. These modifications can include physical/chemical treatments such as drying, grinding, and activation processes. Additionally, combining these biosorption methods with other treatment technologies, like filtration or membrane processes, can improve their overall efficiency. Biosorption using modified fruit peels offers several advantages over conventional water treatment methods. It is a renewable, low-cost technology with reduced energy requirements compared to other treatment processes. Moreover, bio sorbents derived from fruit peels are biodegradable, potentially reducing waste disposal issues associated with their disposal and contributing to sustainable practices.

Nitrates is common types of chemical compounds that can be found in water sources(Bhatnagar and Sillanpää, 2011). It is one forms of nutrients that can have significant impacts on water quality and the health of aquatic ecosystems. Nitrates are a combination of nitrogen and oxygen (NO_3^-) that can enter water bodies through a variety of sources, including agricultural runoff, sewage, and the use of fertilizers. While nitrogen is an essential nutrient for plant growth, excessive amounts of nitrates in water can lead to nutrient pollution and cause undesirable effects. When nitrates accumulate in water bodies, they can contribute to the process of eutrophication.

Eutrophication occurs when an excessive amount of nutrients stimulates the growth of algae and other aquatic plants(Bhatnagar and Sillanpää, 2011). This excessive growth can lead to oxygen depletion in the water, harming fish and other aquatic organisms. Excessive levels of nitrates in water bodies can have significant consequences for human health as well. When consumed in drinking water, high levels of nitrates can be harmful, particularly for infants and pregnant women, as they can interfere with the ability of red blood cells to transport oxygen, high nitrate level in water may also cause cyanosis or the blue baby syndrome. Furthermore, certain bacteria can convert nitrates into nitrites, which are known to be potentially carcinogenic. Recognizing and managing the presence of nitrates in water is crucial for ensuring water quality and preserving the health of aquatic ecosystems.

Monitoring nutrient levels, implementing agricultural best management practices, and using proper wastewater treatment processes are among the measures taken to mitigate the impacts of nitrates and phosphates in water (Boeykens *et al*., 2017). Phosphates are essential nutrients for animals and plants. They are commonly used in artificial fertilizers, phosphate-based detergents and are a byproduct of sewage treatment (Diaz-Uribe *et al*., 2025). Although they make up a valuable part of the eco-system, too many phosphates in our waters can cause problems and disrupt the delicate balance of animal and plant life. Phosphates end up in our water as run-off from agricultural sites and as part of the organic waste generated by sewage and industrial waste (Diaz-Uribe *et al*., 2025). Although plants need it to survive, too much speeds up eutrophication (which reduces the levels of dissolved oxygen in the water due to an increase in mineral levels).

While certain levels of eutrophication happen naturally (such as lakes developing levels of sediment), there has been an increase in levels due to human behavior and this is having a detrimental impact on rivers, lakes and coastal areas (Boeykens *et al*., 2017). Excessive phosphorous in water can lead to algal blooms, green ‘clouds’ of algae. Although these aren't dangerous in themselves, as bacteria break down dead algae, they consume oxygen *(Daneshvar et al.*, 2018). This can create 'dead spots' in the water where aquatic life can't survive due to a lack of oxygen. These algal blooms are a problem across the world, including the Lake District in England, Lyn Padarn in Wales and Forfar Loch in Scotland, which have all had to cancel water sport and swimming events due to high levels of algae in the water(Daneshvar *et al*., 2018)

Adsorption with Nano sorbents such as the modified orange peel biochar is a very potent and adaptable technique for treating water. It may eliminate a variety of pollutants, frequently doing so completely. Furthermore, the quality of the treated water can be greatly enhanced by Nano sorbents, leaving it odour-free and transparent and ready for possible reuse applications. There exist diverse methodologies for the purification of water some of which are illustrated in Figure 1 below. There are biological and physico-chemical methods for reducing water contamination. Even though there are many different steps involved in treating water, not every method can be included in a single study. Thus, some of the important and pertinent methods have been highlighted in this chapter. These consist of membrane technologies, biological techniques, adsorption techniques, and flocculation and coagulation processes.

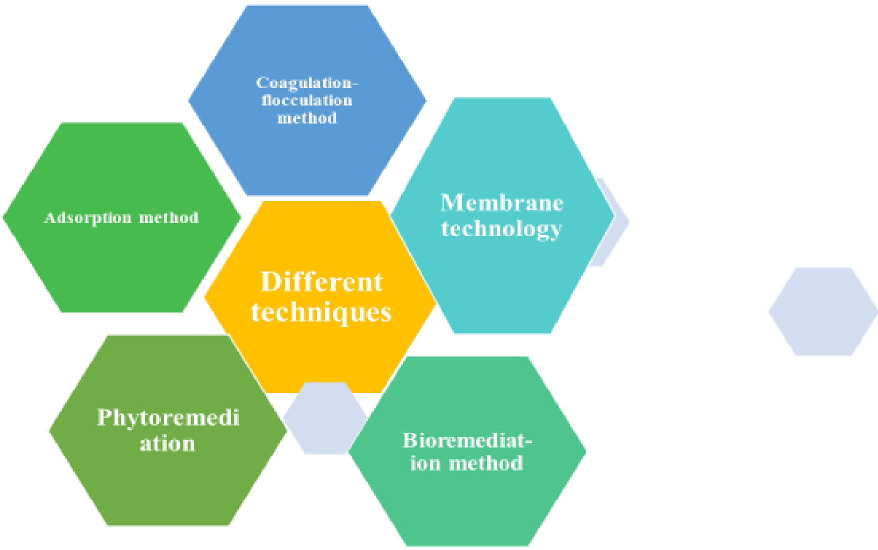


Figure 1: Different kinds of treatment technologies for water treatment.

The use of nanotechnology in water purification marks a dramatic advancement in environmental remediation that will have an effect on ecosystems and people alike. It is anticipated that the application of Nano adsorbents would open the door for new technologies, providing more effective means of preventing, detecting, and resolving different issues related to water pollution, such as wastewater treatment.

Sources Of Water Contaminants

Water pollution arises from either Point source pollution or Non-point source pollution. Point source pollution refers to contamination that comes from only one source. Examples include contamination from leaking septic systems, chemical and oil spills, illegal dumping, and wastewater (sometimes called effluent) released legally or illegally by a manufacturing, oil refinery, or wastewater treatment plant. By placing restrictions on what a facility is allowed to release into a body of water, the EPA controls pollution from point sources. Point source pollution can impact kilometres of streams and the ocean, even if it comes from a single location. Diffuse forms of contamination are considered nonpoint sources of pollution. These could include trash blown into waterways from the land or runoff from agriculture or storms. The primary source of water pollution in American waters is nonpoint source contamination, which is challenging to control because there isn't a single, obvious offender(Nalumenya *et al*., 2024)

Types Of Contaminants In Environmental Water

Water contains a variety of different kinds of materials known as contaminants. Contaminants are substances that cause water to become unsafe when their concentrations exceed the advised limits. They pose a serious threat to all living things. Depending on their nature, these contaminants can be classified into several kinds (Qiu *et al*., 2022). They are often divided into four major categories (Figure 2).

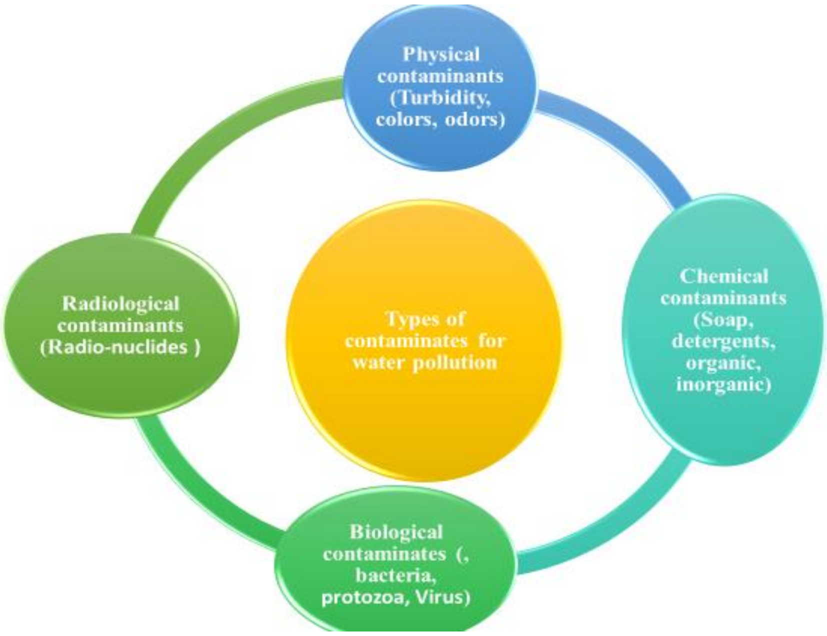


Figure 2: Types of various major contaminants in water

- ✓ **Biological Contaminants**: These include microorganisms like bacteria, viruses, parasites, and protozoa. Common examples are E. coli, Salmonella, and Giardia. They often originate from fecal matter and can cause diseases if ingested.
- ✓ **Chemical Contaminants**: These include a wide range of harmful substances, such as: Heavy Metals e.g Lead, mercury, arsenic for instance Arsenic is a major groundwater contaminant that has been linked to harmful health effects, including cancer. Groundwater contamination by heavy metals and radioactive elements is believed to affect more than 100 countries globally, with Asia having the highest prevalence of contamination, and cadmium, which can come from industrial activities, mining, and natural deposits; Pesticides and Herbicides. Industrial Chemicals Such as solvents, pharmaceuticals, and personal care products that may enter water through industrial discharges or improper disposal.
- ✓ **Physical Contaminants**: These include sediments, sand, and silt that can make water turbid and may carry other contaminants. They often result from erosion or runoff.
- ✓ **Radioactive Contaminants**: These include radionuclides like radon and uranium that can come from natural sources or nuclear activities. They pose health risks due to their radioactive properties. In naturally occurring groundwater, uranium is among the top three harmful pollutants, along with As and Cr (VI). It is a dangerous heavy metal and radioactive element that can harm human health when consumed in excessive quantities. Some of the negative effects include renal failure, reduced bone growth, and DNA damage (Girotto *et al*., 2024)

Water Scarcity

Water scarcity is attributed to water demand exceeding the available supply. It is a global issue, also in countries with sufficient water resources. This is attributed to various factors, such as poor infrastructure, and climate change. Some regions have seasonal variations while others have natural limited water resources that may cause

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water scarcity. This leads to irregular supply of freshwater resources. Water management is essential for the world to achieve sustainable development (UNICEF, 1999). A country is said to experience water scarcity when the available natural water is below 1000m^3 per capita (Kumari and Bhandari, 2022). One of the major water quality issues is water pollution, such as high levels of fluoride in water, which hinders the consumption of clean water. A great percentage of the world's population, around 4 billion people, encounter extreme water scarcity no less than a month yearly with more than two billion people living in countries with inadequate water supply (Mulwa et al., 2021). According to statistics done by UNICEF, "*Some 700 million people could be displaced by intense water scarcity by 2030*."

Children and women are more prone to contaminated water. When more than 25% of renewable freshwater resources are withdrawn by a territory, the area is said to be "water-stressed". Out of 11 regions, five experience water stress levels of over 25%. A UNICEF statistic shows that' "*1 in every 4 children globally will be living in areas of extremely high-water stress by 2040*." The global demand for water may exceed supply by over 40% by 2030 and over 50% in developing countries, mainly in sub Saharan Africa (Mekonnen and Hoekstra, 2016).Population increase is one of the main factors that will lead to the reduction of per capita availability of drinking water. Socio-economic factors also facilitate water scarcity in various developing countries, limiting the provision of adequate sanitation services (Mulwa *et al*., 2021).

People face diverse levels of water scarcity globally. Figure two displays the various levels, ranging from low to severe water scarcity, of the people facing water scarcity globally. The statistics ranges from 0 to twelve months. In one month, roughly 4.3 billion people experience moderate to worse water scarcity while 4 billion people severe water scarcity at least one month yearly (Mekonnen and Hoekstra, 2016).

Number of months per year (*n*)	Billions of people facing low, moderate, significant, and severe water scarcity during *n* months per year				Billions of people facing moderate or worse water scarcity during at least *n* months per year	Billions of people facing severe water scarcity during at least *n* months per year
	Low water scarcity	Moderate water scarcity	Significant water scarcity	Severe water scarcity		
0	0.54	4.98	5.22	2.07	6.04	6.04
1	0.12	0.81	0.66	0.31	4.26	3.97
2	0.12	0.19	0.13	0.37	3.95	3.66
3	0.35	0.05	0.03	0.37	3.55	3.28
4	0.33	0.01	0.001	0.59	3.15	2.91
5	0.30	0	0	0.55	2.56	2.32
6	0.33	0	0	0.27	2.09	1.78

Table 1: Summary of the number of people experiencing different levels of water scarcity globally (Mekonnen and Hoekstra, 2016)

India and China have the highest number of people living under severe water scarcity. This puts the country in a very vulnerable place. Among other countries experiencing severe water scarcity includes United States, Bangladesh, Pakistan, Mexico, and Nigeria.

Kenya is among the water-stressed areas with per capita water availability under 1000m^3 yearly (Lundberg, 2025). Kenya relies on various water catchment sources that are unevenly distributed within the country (Lundberg, 2025). Factors such as geographical landscapes, population distribution, precipitation, and socio-economic activities, may lead to water scarcity.

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Watershed name	Catchment area (ha)	Max. altitude (m)	Gazetted forest area (ha)	Main river
Mt. Kenya	1,253,959	5199	203,145 (4% cropland)	Tana, Athi
Aberdare	1,097,895	4001	104,078 (11% cropland)	Ewaso Ngiro, Athi
Mau Forest Complex	874,746	3098	404,706 (25% cropland)	Mara, Nyando, Yala
Cherangani Hills	212,267	3365	120,841 (19% cropland)	Nzoia, Turkwell
Mt. Elgon	2 49,996	4320	72,547 (15% cropland)	Nzoia, Turkwell

Figure 2: Various water catchment areas in Kenya (Chepyegon & Kamiya, 2018)

31.6% of Kenya's total population utilize improper drinking-water origins, such as exposed dug wells. Moreover, about half of the total rural population utilize improper drinking-water sources (Yu *et al*., 2019).

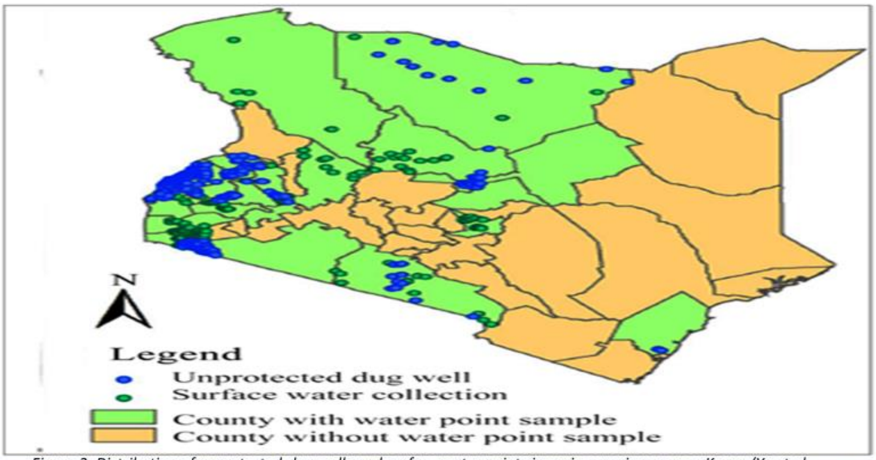

Figure 3: Distribution of unprotected dug wells and surface water points in various regions across Kenya (Yu et al., 2019).

Water scarcity has various impacts such as poor hygiene and sanitation, which poses high health risks, especially in low-income areas, leading to contraction of various diseases. Shortage of water in Kenya is mainly observed in `arid, semi-arid, and rural areas. With water shortage in Kenya, children and women are required to travel long distances to search water, mainly for domestic use. Moreover, Kenya proper monetary, human, and institutional skills essential for provision of sufficient and clean water (Ondigo *et al*., 2018). Children, especially those living in areas with low-income, succumb to diarrhea due to consumption of unsafe drinking water (Mulwa *et al*., 2021).

Health Effects Of Water Pollution.

Contaminated water can carry pathogens such as bacteria, viruses, and parasites, leading to diseases like cholera, dysentery, hepatitis A, and typhoid fever. According to the World Health Organization (WHO), waterborne diseases account for a significant burden of illness worldwide, particularly in regions with inadequate sanitation and water treatment *(Lo et al*., 2022). Pollutants such as heavy metals (e.g., lead, mercury, arsenic) and industrial chemicals (e.g., pesticides, solvents) can contaminate drinking water. Long-term exposure to these substances is associated with various health issues, including cancer, neurological damage, and developmental problems in children. For example, arsenic contamination is linked to an increased risk of skin cancer and other malignancies (Smith *et al*., 2002). Chemicals like endocrine-disrupting compounds (EDCs), which can be found in polluted water, may interfere with hormonal systems. This disruption can lead to reproductive health problems, developmental issues, and other endocrine-related disorders. Research has shown that EDCs can affect both aquatic and human life, leading to developmental and health problems (Colborn *et al*., 1993). Water pollution can impact food security by affecting the quality of water used for irrigation, which in turn can impact crop yield and nutritional value. Polluted water can also lead to contamination of aquatic food sources, potentially leading to deficiencies in essential nutrients and vitamins (Cairncross *et al*., 2010). There is emerging evidence

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suggesting that exposure to polluted water can have indirect effects on mental health. The stress and anxiety associated with health concerns and the degradation of environmental quality can impact mental well-being. Studies have found associations between environmental stressors and mental health outcomes, highlighting the need for more research in this area.

Figure 4: Major health effects due to water pollution

Chemical Composition and Physical Properties of Orange Peel

The chemical composition of orange peel differs based on location, varieties, level of maturity, and growing conditions. According to Mafra (Mafra *et al.*, 2013). orange peel is 97.83% organic matter and contains carbon, hydrogen, oxygen, nitrogen, sulphur, chloride, and ash. Bampidis further confirmed the organic matter composition of orange peel, reporting that the dry matter of orange peel is mainly organic matter containing proteins and short-chain organic acids no more than four carbons. Others opined that orange peel contains soluble sugar, starch, and fiber, including cellulose, hemicellulose, lignin, and pectin, as well as ash, fat, protein, and about 1% organic acids.

In addition, several studies on the physical properties of orange peel have revealed that it contains cellulose, hemicellulose, lignin, and pectin. Cellulose is the most abundant polysaccharide found in the cell walls of plant biomass (Al-Harahsheh *et al.*, 2014). The chemical formula of cellulose is (C HO) n, where n represents the number of glucose groups, ranging from hundreds to thousands. Cellulose is insoluble in water, dilute acid, and dilute alkali solutions, and is recalcitrant to hydrolyses and enzymatic activities due to their strong hydrogen bonds; the chemical structure of cellulose is presented in Figure 5.

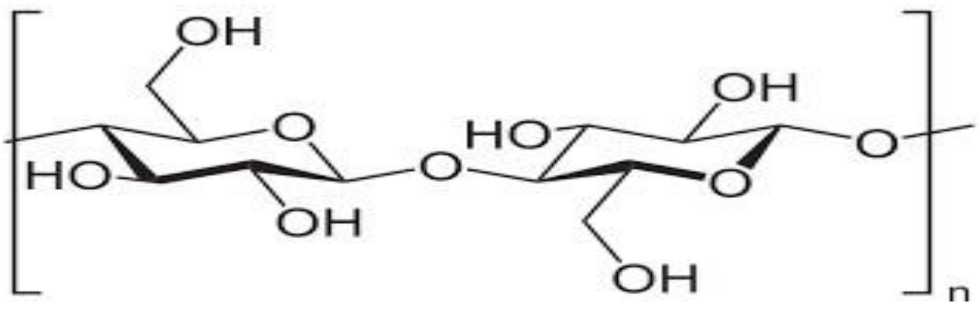

Figure 5: Structure of cellulose.

Unlike cellulose, hemicellulose has a random, amorphous structure composed of various sugar monomers, which have little physical and chemical resistance, and their polymerization degree is between 50–200 °C. Hemicelluloses are mostly soluble in water and dilute in alkali solutions at temperatures above 180 °C, but they are insoluble in water at temperatures below 180 °C and account for about one third of total biomass weight

(Saranyadevi *et al*., 2023). Together with cellulose and hemi-cellulose, lignin is found in the cell walls of plants; it is the second most abundant compound of plant biomass with a complex hydrocarbon polymer that consists of both aliphatic and aromatic compounds. The basic monomeric units of lignin are P-hydroxyphenyl, guaiacyl, and syringyl. Lignin is hydrophobic in nature, totally insoluble in most solvents, and is thermally stable but prone to UV degradation. Pectin is a complex polysaccharide found in the cell walls of plants and contributes to the firmness and structure of plant tissues. They are composed of 1,4 α-D-galacturonic acid (GA) in free or esterified form. The basic monomer of pectin includes rhamnose, galactose, arabinose, glucose, and xylose (Wang *et al*., 2022)

Preparation and modification of orange peel biochar.

Orange peel, or OP as it is now commonly called, is a cheap, plentiful, and easily accessible biomass waste from the orange juice manufacturing industry. OP is mostly composed of low molecular weight substances (such as limonene), cellulose, hemicellulose, lignin, pectin, and chlorophyll pigments. Considerable environmental harm could result from improper disposal of this biomass. Its therefore considered as a green alternative to preparation of biochars for environmental remediation such water purification. Biochar is a carbon-rich and stable carbon dominant product that may formed through pyrolysis in an oxygen deficient reactor chamber. It has the potential of carbon sequestration, soil enhancement and waste management (Otieno et al., 2024).The orange peels were collected, cleaned and crushed into a fine powder after which the biochar was prepared according to the specifications of (Liu *et al*., 2023) with some modifications of using Aluminum tri-chloride to enhance the surface porosity and increase the selectivity to the contaminants.

FIG 6:Orange peels cuttings.

FIG 7: Preparation of modified orange peel biochar (MOPB)

Various Approaches To The Application Of Modified Orange Peel Biochar(Mopb)

Conventional water treatment methods often fall short of removing these contaminants. By their very nature, industrial effluents are complex mixtures of diverse pollutants with varying chemical properties, making them particularly challenging to treat (Sathya *et al*., 2022).To effectively address this issue, a multi-pronged approach combining techniques like extraction, filtration, biological treatment, physicochemical methods, sorption, and catalytic oxidation is necessary to transform these effluents from highly contaminated streams to ones that meet discharge standards. Among these techniques, sorption techniques play a crucial role in wastewater treatment by removing contaminants through adsorption and absorption processes. Adsorption involves the accumulation of molecules at the liquid-solid interface, with act MOPB being a widely used adsorbent due to its high surface area and effectiveness in removing organic pollutants (El Gheriany *et al*., 2020). On the other hand, absorption entails the dissolution and diffusion of substances throughout another material, as seen in using granular activated carbon (GAC) to eliminate taste and odor compounds from drinking water (Hardyanti *et al*., 2023). These methods are essential for reducing pollutants in water sources.

The process of sorption is essential for eliminating contaminants from water systems. The sorption process is influenced by multiple mechanisms, including hydrogen bonding, hydrophobic interactions, and electrostatic interactions (Vujić *et al*., 2023). For many organic contaminants, hydrophobic interactions predominate, drawing non-polar molecules to the sorbent's carbon-rich surface. Generated as a result of shared oxygen and hydrogen atoms between the sorbent and the contaminant. The characteristics of the contaminant determine how successful these systems are. sorbent, along with the pH and ionic strength of the water matrix. Recognizing these mechanisms is necessary to create effective pollution removal techniques and optimize adsorbents methods of elimination. In wastewater treatment, sorption is influenced by a number of important factors. The effectiveness of pollution removal is affected by the starting concentration of the pollutant; larger concentrations accelerate clearance until saturation. The sorption capacity is determined by the sorbent properties, such as surface area, pore size distribution, and surface chemistry. pH values in wastewater has an impact on sorbents and contaminants' charges, which influences electrostatic correspondences (Jagadeesh and Sundaram, 2023). There is a role for temperature and sorption. Temperature increases usually result in a loss in efficiency. Furthermore, the existence of dissolved ions or organic debris, among other competing substances, can obstruct the sorption process by vying for available sorption spots

Adsorption Properties of Modified Orange Peel biochar (MOPB).

Rich in Functional Groups: MOPB contain a variety of functional groups, such as hydroxyl, carbonyl, and carboxyl groups. These functional groups are capable of forming chemical bonds with nitrates and phosphates through ion and exchange, electrostatic attraction, hydrogen bonding, and coordination, facilitating the biosorption process (Mafra *et al*., 2013). The components of orange peel, including cellulose, hemicellulose, lignin, and pectin, are the reason for the smooth surface structure. Smooth surfaces have low adsorption uptake due to the reduced number of active sites available for the adsorption of contaminants, and do not allow significant binding of contaminants, hence the reason for the low biosorption uptake of orange peel (El Gheriany *et al*., 2020). High Surface Area: MOPB have a porous structure, providing a large surface area for interaction with nitrates. This increased surface area allows for more contact points, enhancing the adsorption capacity and efficiency of nitrate removal (Singh *et al*., 2017). Roughness and porosity are usually linked to the high sorption capacities of biomass because they provide more active sites for adsorption than smooth surfaces. However, studies have shown that the adsorption capacities of a biomass can be improved by increasing the surface roughness and porosity using different modification methods, including physical, chemical, and thermal methods. Hence, the aim of the modification process is to improve the structural properties of the biomass, resulting in an increased binding site and biosorption uptake of the biomass. Negatively Charged Surface: The surface of MOPB is typically negatively charged. This negative charge can attract and bind positively charged nitrate ions through electrostatic interactions, enhancing the biosorption efficiency and affinity for nitrates(Bhatnagar and Sillanpää, 2011).It is observed that the removal efficiency of modified orange peel biochar for nitrate and phosphate ions provides critical insight into its suitability as a sustainable biosorbent for nutrient remediation. In this study, modified orange peel biochar achieved an optimum removal of 89% nitrate removal and 85% phosphate removal under optimized conditions as presented in Figure 8, demonstrating strong

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affinity for both anionic contaminants. These efficiencies fall within the upper range reported for biochar-based sorbents and significantly outperform many unmodified agricultural wastes

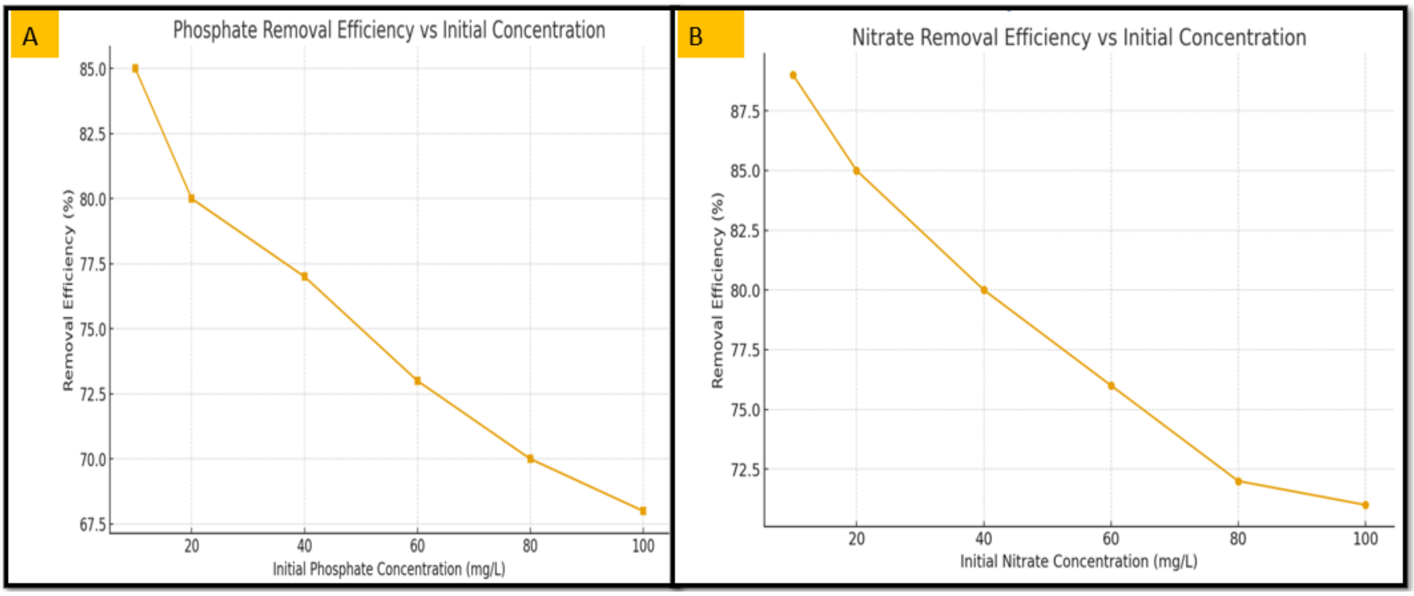

Figure 8: Phosphate removal efficiency (A) and Nitrate removal efficiency (B)

Summary on parameters affecting Adsorption Process

Adsorption process can be affected by several factors that need optimization to maximize the adsorption capacity and adsorbate removal.

Effects of Temperature

Le Chatelier's principle explains that adsorption is an exothermic (Pandey *et al*., 2010). Effects of temperature on adsorption process is due to the bonds formed and properties of the adsorbents and adsorbate sites. Adsorption increases at low temperature as a result of strong bonds. However, when the adsorbent's temperature is high, desorption occurs and the adsorbate molecules are withdrawn due to weak bonds. This shows that an increase in temperature leads to a decrease in the adsorption process.

Effects of Dosage

To calculate the adsorption capacity, the mass of the removed adsorbate is evaluated per the adsorbent mass. The adsorption rate increases with an increase in the adsorbent dosage, which increases the sorption sites on the adsorbent's surface. The effects of dosage are done through preparation of various mass of the adsorbent to a fixed adsorbate concentration(Otieno *et al*., 2024).

Effects of Adsorbent size

The rate of adsorption increases due to a larger surface area. Moreover, a small particle diameter and size, caused by mass transfer and internal diffusion, leads to the penetration restraint of the adsorbate to the adsorbent. This makes equilibrium be attained more quickly, increasing the adsorption capacity.

Effects of PH

PH is a critical parameter since it controls the level of electrostatic charges from ionized adsorbates. It also governs the fluoride concentration mobility in groundwater. The adsorption rate varies with medium PH but not in a regular pattern. However, the adsorption capacity of cations and anions decreases and increases respectively at low PH values(Chowdhury and Balasubramanian, 2014). When the PH increases, the electrostatic repulsion of the adsorbent and adsorbate cations decreases leading to an increase in the surface's charge density.

Effects of Contact time

Adsorption performance is affected by the contact time between the adsorbate and adsorbent. The adsorption capacity tends to increase with an increase in contact time to a certain point. After that, saturation hinders an increase in adsorbate intake caused by increased contact time. The equilibrium time establishes the amount of adsorbate removed or adsorbed from the adsorbent. The maximum adsorption capacity is represented by the amount of adsorbate adsorbed.

Effects of Initial Concentration

An increase in initial concentration of the adsorbate leads to an increase in the overall removal and a decrease in adsorption capacity. To determine the effect of initial concentrations, an adsorbate solution is prepared at varying concentrations under a constant temperature, contact time, and ph. This will help study and understand the relation between the adsorbent and adsorbate, using isotherm models.

The use of MOPB Nano sorbents in adsorption is a particularly potent and adaptable technique for treating water. It may eliminate a variety of pollutants, frequently doing so completely. Furthermore, the quality of the treated water can be greatly enhanced by Nano sorbents, leaving it odour-free and transparent and ideal for possible reuse applications (Muhammad *et al*., 2016).

Biosorption capabilities of modified orange peels biochar (MOPB).

Biosorption is a type of physiochemical process, which uses biological materials to bind over the contaminants onto its cellular structure. The use of biomass in environmental cleanup especially in environmental waste waters has been in practice for a while, and scientists and engineers are hoping this phenomenon will provide an economical alternative for removing toxic heavy metals, disastrous ions like nitrates, phosphates and fluorides from industrial wastewater and aid in environmental remediation (Al-Harahsheh *et al*., 2014). It is proven a cost-effective method for the removal of various ions in the water (Angelova *et al*., 2011).

Most studies indicate that orange peels are used as effective bio sorbents for the removal of nitrates and Phosphates in the water. The orange peel biochars have maximum removal efficiency of ammonia and nitrates at a concentration of 4gm. The optimum biosorption of ammonia and nitrate over MOPB bio sorbent was obtained at pH = 5.5, contact time = 60 min, and temperature= 35 °C (Angelova *et al*., 2011). Recent studies indicated that the use of synthesized environmental waste materials for the removal of excess chemical constituents in the water became popular because of economy factor. Various researchers worked on the removal of nitrates by using environmental waste bio sorbents like Bael leaves (Aegle marmelos), Mausmi peel powder, Green algal powder, Barks and stems of annoma squamosal, banana peels and Greenish clay rich in free silica etc. The removal efficiencies varied from one material to another depending upon their pH, contact time, adsorbent dosage, time of equilibration, initial concentrations and temperature ranges.

Qualities of Optimal Bio sorbent Substance.

The contact angle (CA) is a direct representation of surface wettability. Super-bio sorbents, as defined by (Srinivasulu, 2023)are rough surfaces that have a small contact angle hysteresis value and a high-water contact angle of ≥150°.Surface roughness amplifies a material's hydrophobic and oleophilic properties, supporting Wenzel's wettability theory that the contact angle rises with porosity and material surface roughness. Plants with naturally occurring superhydrophobic surfaces, such lotus leaves, cotton fibers, and kapok fibers, have high water contact angles. Lotus leaves have a structure made up of a combination of two scale roughness levels of 10 μm (rough), with a water contact angle (CA) of 161°.

The hydrophobic nature of lotus leaves arises from a combination of the epicuticular wax secreted from the leaf itself and the roughness. Kapok fibre has a water contact angle (CA) that ranges from 138.6° to 151.2° depending on the location, making it a superhydrophobic surface (Dong and McCarthy, 2017). Some researchers have reported that kapok fibre is mainly composed of cellulose, lignin, and pentosan, while others have opined that kapok fibres comprises of cellulose, lignin, xylene, and high levels of acetyl groups. Kapok fibres possess waxy coatings and a large hollow structure that gives it a porosity of 80%, which is responsible for the hydrophobic nature of kapok leaves. According to studies, the water contact angle of cotton fiber is 100°, cotton fibres is about 90% cellulose, and the non-cellulose part includes proteins, waxes, pectin, inorganics, and other substances; however, the composition of cotton fibres differs based on location and maturity

Future Prospects For Modified Orange Peel Biochars.

Modified Orange peel biochar has a promising future prospect due to several factors: For instance; It can enhance soil fertility by improving soil structure, increasing water retention, and providing essential nutrients. Its use in agriculture could help in sustainable farming practices. Utilizing modified orange peels, a common agricultural and food waste, for biochar production helps in waste reduction and resource efficiency. Biochars sequester carbon, potentially mitigating climate change by reducing the amount of CO2 released into the atmosphere and this is helpful in mitigating the global warming due to creation of the ozone hole. Modified Orange peel biochar (MOPB) has shown potential in adsorbing contaminants from water and soil, aiding in environmental cleanup efforts. And as technology advances and production scales up, the cost of producing biochar may decrease, making it a more attractive option for various applications. Therefore, research and development are likely to continue focusing on optimizing the production process, modification for better selectivity and sensitivity and expanding applications to fully realize these benefits.

CONCLUSION

In conclusion, modified orange peel biochar represents a sustainable and multifunctional material with significant potential. From an environmental perspective, biochar contributes to carbon sequestration, helping to mitigate climate change by capturing and storing carbon. Its application in pollution remediation further underscores its versatility, as it can adsorb contaminants from soil and water, aiding in environmental cleanup efforts. As research advances and production techniques become more efficient, the economic feasibility of orange peel biochar is expected to improve, potentially leading to wider adoption. The growing interest in sustainable practices and circular economy principles will likely drive further exploration of its applications and benefits. MOPBs could become a key component in sustainable practices, offering ecological and economic advantages. Modified orange peel biochar therefore holds considerable promise for enhancing soil health, managing waste, and addressing environmental issues, making it a valuable asset in the pursuit of sustainability and resource efficiency.

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