**Biochar I: A Renewable and Sustainable Source For Energy**

**Introduction**

Commensurate with 2015, there were around more than 7.3 billion people in the world's population, being provided basic needs like food, clothing, shelter, and education. As the population was increasing day by day production of waste is also increasing along with necessities. In consonance with United Nations, the world population may reach 9.2 billion by 2050.

It's no wonder that as the world population continues to grow, the limits of essential global resources such as potable water, fertile land, forests, and fisheries are becoming more apparent. There is tremendous pressure on the cultivators, food industries, and animal husbandry to continuously develop new technologies to provide quality managed food and meet the same demand. The robust current handling methods steer to pernicious impacts on the ecosystem. The next global challenge towards an environmentally-sound future will be wastewater treatment serving legion treatments and recovery of water, nutrients, and energy resources.

Furthermore, due to the excessive population growth, it is un-viable to produce enough food with only organic plant nutrients. Therefore, the demand for mineral fertilizers is a fact. Thus, many urban areas have adopted wastewater treatment plants to remove the nuisance of human waste. This became evident that future changes, particularly those associated with urbanization and population. Raise the volume of wastewater, and add more stress to the wastewater system performance.

Pharmaceutical and personal care products (PPCPs) embrace numerous organic chemicals, including therapeutic drugs, veterinary drugs, fragrances, cosmetics, diagnostic agents, surfactants, and nutraceuticals. [1] Pharmaceuticals are used to prevent or treat human and animal diseases, while personal care products are used for personal hygiene to improve the quality of daily life. PPCPs are bioactive complex molecules as they can exist as either neutral, anionic, cationic, or zwitter ionic molecules depending on the environmental conditions and octanol/water partition coefficient (Kow) values [2].

Antibiotics in wastewater have gained worldwide attention, thereby these emerging pollutants require adequate consciousness. Novel methods are to be developed for the effecient removal of antibiotics in the wastewater, looking at the possible threats it affects the ocean's biotic flora and reducing the chemical oxygen demand before being discharged into the oceans.

Many antibiotics have been employed to threaten all possible systemic infections caused to human beings in the current era, ultimately leading to municipal sewage waters. Besides, the rapid development of antibiotic- resistant microbes in the last 20 years has also increased treatments with multiple drugs. As a result, many tertiary and quaternary classes of drugs are also found to increase concentration in wastewater. The percolation of antibiotics in the environment, especially in water bodies, has increased antibiotic resistance in the microbial flora, which in the end find their way as potential threats to the health of humans and animals via the food chain.

Besides, treating livestock with antibiotics in the feed has also added to the water antibiotic pollution. It persists in the environment through a complex vicious cycle of transformation and bio-accumulation. Various classes of drugs are used in agricultural practice [3] and animal husbandry regularly. Animals are provided with the drugs through both oral (water and feed) as well as in the form of injections or topical skin creams containing antibiotics in relatively large concentrations. Antibiotics are also administered as preventive measures significantly to curb gastrointestinal tract infections. Widely used drugs include classes of antibiotics such as β-lactams, tetracycline, Macrolides, and Quinolones, steroidal and nonsteroidal anti-inflammatory drugs, and nutrient additives.

The animal reproductive system is managed by using estrogen hormones such as oxytocin, ergonovine, HCG, GnRH, progesterone, and FSH and excessive use of Dewormer, an anthelmintic drug for controlling the growth of the parasite leads to high antibiotic consumption by the animal than the human consumption. The imprudent use of antibiotics in animal husbandry is creating more problems for the environment, especially animal waste which is not treated as compared to human waste.

Many active pharmaceutical residues and compounds have been discovered in almost all environmental matrices on every continent, including sources from surface water, groundwater, wastewater treatment plant (WWTP) effluent, and sludge. Bush et al, categorized the active pharmaceutical compounds into different therapeutic classes which includes (i) anti-inflammatories and analgesics (ibuprofen, paracetamol, diclofenac); (ii) antibiotics (sulfonamides, tetracyclines, penicillins, β-lactams, macrolides, uoroquinolones, imidazoles); (iii) antiepileptics (carbamazepine); (iv) antidepressants (benzodiazepines); (v) lipid-lowering agents ( brates); (vi) antihistamines (famotidine, ranitidine); (vii) β-blockers (metoprolol, atenolol, propranolol); and (viii) other substances (barbiturates, narcotics, antiseptics, and contrast media).[6]

It was observed that antibiotics are the most commonly detected compounds followed by analgesics. Therefore, there is a need to develop newer methods for efficient water treatment.

**Ecological and Environmental Risks**

Antimicrobials are chemically complex substances that are generally observed to interact with specific receptors present on cell lines. Each group of antibiotics has a particular mode of action and mechanism, including inhibition of protein synthesis, nucleic acid (DNA/RNA) synthesis, or cell envelope synthesis, which play essential roles. As a result, antibiotic classes of compounds are difficult to avoid or limit as these compounds are designed to treat bacterial infections in livestock and humans. It has been observed that many antibiotics can interact with similar receptors found in organisms of lower and upper phyla in the ecosystem.[4]

The environmental microbes are more prone to non-therapeutic exposure than the aquatic vertebrates, such as fish. Additionally, antibiotic resistance in bacteria and microbial communities, gene expression alterations, abnormal protein and enzyme activities, and growth malformations in rats, fish, and frogs have also been observed. [7,8] Also antibiotic compounds like Oxytetracycline and trimethoprim have induced toxic effects in Daphnia Magna, Pseudokirchneriella subcapitata green algae, and the cyanobacteria Anabaena Flos-aquae.[8,9] The well-known decline of vulture populations in South East Asia is linked to the pharmaceutical active Diclofenac drug.[9,10]

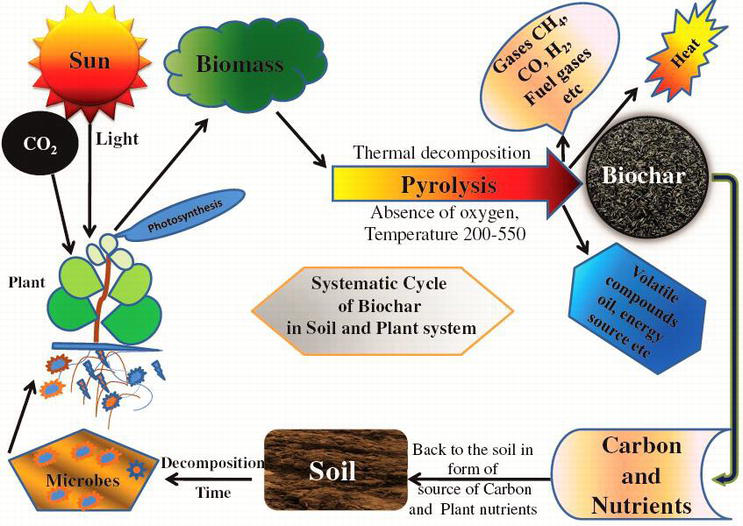
As a consequence, pharmaceutically active compounds in the environment can bring toxic effects on numerous organisms present in the environment. Various treatment methods have been carried out in terms of antibiotic residues in recent years, with significant removal efficiency. Advanced oxidation processes (AOPs) are of great concern due to their powerful

Removal efficiency. [10,11]. Some antibiotics were prohibitive and may produce sub-active toxic by-products. The effectiveness of antibiotic removal in the adsorption process and membrane technology is satisfactory. But these techniques ultimately fail to degrade antibiotics and are significantly damaged by other organic pollutants.

Particularly in antibiotics and drug contamination in water, treatment is generally done using adsorption to remove pollutants from the aqueous phase. To decrease costs and save natural resources, attempts have been made to use wastes as raw materials to produce alternative carbon adsorbents. This approach intends to increase efficiency, and cost-effectiveness and propose an alternative and sustainable way for the valorization/management of residues.

Biochar is produced from heating organic materials like crop waste, grass, woodchips, and manure in a high temperature, low oxygen process known as pyrolysis. These carbon materials, as well as the derivatives, are found to be physically and chemically diverse. Analyses of over 80 different biochars have shown that the type of biochar used needs to suit the situation and desired outcome. The research found that grass or crop–derived biochars appear to have the best balance of agricultural benefit and carbon stability. [12]

Wood–derived biochars were more carbon-rich, whereas biochars from manures and food wastes recorded higher nitrogen and phosphorus levels. Producing biochar and applying it to soil could create carbon offsets under the Carbon farming Initiative. Adding biochar to soil increases its carbon content and can mitigate greenhouse gas emissions. This mitigation can occur by several means: long-term transfer of carbon into biochar, which would otherwise decompose naturally and emit carbon dioxide and methane, producing syngas and bio-oil, which can be used as energy alternatives to fossil fuels, reduced emissions of nitrous oxide from fertilizer application. Biochar from different sources has porous carbons; the pore network of biochar is typically composed of micropores< 2 nm, mesopores 2-50 nm, and macropores> 50 nm. But micropores and small mesopores (2-20nm) are suggested to contribute the majority to the surface area and excellent adsorption capacity of biochar [13, 14]



**Figure1. Indicates application in soil and enhanced absorption of nutrients by plant system**

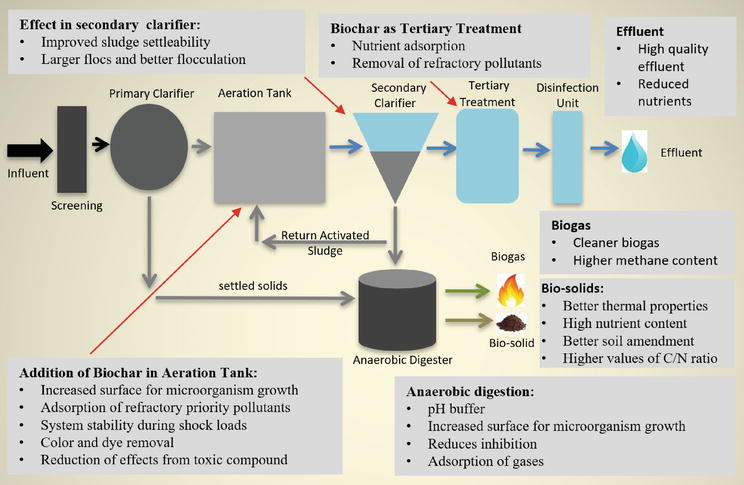
**Removal of various contaminants from water and wastewater by biochar derived from different feedstocks.** (Adapted from Ahmad et al. [15].)

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| --- | --- | --- | --- | --- | --- |
|  | **Biomass feedstock** | **Production method** | **Target contaminant** | **Maximum removal ability** | **Reference** |
| Heavy metals | Malt spent rootlets | Pyrolysis at 850 °C for 1 h | Hg(II) | 103 mg g−1 | 16 |
|  | Malt spent rootlets | Pyrolysis at 300–900 °C | Hg(II) | 130 mg g−1 for MSR750 | 17 |
|  | Waste glue residue | ZnCl2 modification | Cr(VI) | 325.5 mg g−1 | 18 |
|  | Lotus stalks | Zinc borate as flame retardant, pyrolysis at 300, 350, and 400 °C | Ni(II) | 61.7 mg g−1 for 0.5 g ZB/g LS pyrolysis at 300 °C | 19 |
| Dyes | Bamboo cane | Phosphoric acid modification then pyrolysis at 400, 500, and 600 °C | Lanasyn Orange and Lanasyn Gray | 2. 6 ×103 mg g−1 for both dyes | 20 |
|  | Pecan nutshell | Pyrolysis at 800 °C for 1 h | Reactive Red 141 | 130 mg g−1 | 21 |
| Phenols and PAHs | Sewage sludge | Pyrolysis at 500 °C for 1 h/microwave-assisted pyrolysis at 980 W for 12 min | Hydroquinone | 1,218.3 mg g−1/1,202.1 mg g−1 | 22 |
|  | Malt spent rootlets | Pyrolysis at 800 °C for 1 h | Phenanthrene | 23.5 mg g−1 | 23 |
|  | Orange peel | Pyrolysis at 150–700 °C for 6 h | Naphthalene and 1-naphthol | 80.8 mg g−1 for naphthalene and 186.5 mg g−1 for 1-naphthol | 24 |
| Pesticides | Maize straw and pig manure | Pyrolysis at 300, 500, and 700 °C for 4 h | Thiacloprid | About 8.1 mg g−1 | 25 |
|  | Almond shell | Pyrolysis at 650 °C for 1 h with steam activation at 800 °C | Dibromochloropropane | 102 mg g−1 | 26 |
|  | Broiler litter | Pyrolysis at 350 and 700 °C with and without steam activation at 800 °C | Deisopropylatrazine | About 83.3 mg g−1 for BL700 with steam activation | 27 |

**Application of Biochar in the wastewater treatment process**

Biochar water treatment has several potential merits compared to existing low- cost methods (i.e., sand filtration, boiling, solar disinfection, chlorination): (1) biochar is a low-cost and renewable adsorbent made using readily available biomaterials and skills, making it appropriate for low-income communities; (2) existing methods predominantly remove pathogens, but biochars remove chemical, biological and physical contaminants; (3) biochars maintain organoleptic properties of water while existing methods generate carcinogenic by-products (e.g., chlorination) and/or increase concentrations of chemical contaminants (e.g., boiling). Biochar has co-benefits, including the provision of clean energy for household heating and cooking, and soil application of spent biochar improves soil quality and crop yields. Seven hypotheses for future research are highlighted under three themes: (1) design and optimization of biochar water treatment; (2) ecotoxicology and human health risks associated with contaminant transfer along the biochar-soil-food-human pathway, and (3) life cycle analyses of carbon and energy footprints of biochar water treatment systems.

Biochar could be used at different stages of wastewater treatment (Figure2 ) to improve the treatment efficiency and recovery of value-added by-products.[28]



Use of Biochar at different stages of wastewater treatment (adapted from Pokharel et al.).[28]

**Antibiotic removal by agricultural waste biochars**

Adsorption is considered one of the most appropriate technologies because it is safe, economical, and simple. Several adsorbents have been tested to adsorb LEV or TC, such as chitosan, montmorillonite, and graphene-based materials.[29] To achieve low-cost, corn husks, agricultural waste was selected as a significant part of the adsorbent. It could not only reduce antibiotic pollution but also supply an additional method for corn husks reuse. In addition, corn is a worldwide and plentiful crop, which makes it cheap and easy to obtain. For adsorption capacity enhancement and recovery improvement, the corn husks were transformed into biochar, and Fe, which was magnetic and non-toxic, was employed for the biochar modification.

Contamination of water bodies due to human activities results in the pollution of water. Water bodies include oceans, aquifers, lakes, rivers, and groundwater.

**Sources of water pollution:-**

Major sources of water pollution are industrialization, population growth, domestic sewage, pesticides, fertilizers, urbanization, and weak management system .[30] Deeply Developed and industrial areas are responsible for the generation of organic pollutants [31]. The leaching of toxic elements into drinking water through geological composition is responsible for drinking water pollution. Some of the elements leached into drinking water are arsenic, fluoride, selenium, and a few others, such as chromium and uranium.

Mining activities are also responsible for depositing the contaminant in the water and making water polluted [32, 33]. Municipal wastewater is also a source of water pollution [34]. Domestic sewage is the primary source of water pollution. Most of the domestic sewage is untreated. Domestic sewage includes toxicants, solid waste, plastic litter, and bacterial contaminants as water pollutants.

Industrial effluents from industries like sugar, textile, electroplating, pesticides, pulp, and paper cause water pollution [35]. Industrial sewages primarily cause surface water and groundwater contamination [36]. Polythene bags and plastic waste are key sources of pollution [37]. Pesticides used in agricultural sectors are the direct source of water pollution. The excess content of pesticides in the water is hazardous to the ecosystem and human health [38, 39]. The presence of pharmaceutical compounds even at trace levels in water also causes water pollution.

Storm water runoffs are also the primary source of water pollution. Runoffs from agricultural land contain pollutants such as pesticides, fertilizers, and animal waste. Runoffs from the road and parking area include oil and gasoline as water pollutants. Industrial discharge and accidental spills are responsible for water pollution at a larger level [40]. Radioactive substances from industrial, medical, and nuclear power plants and scientific processes are also causing water pollution. Improper disposal of radioactive waste causes severe water pollution.

Four types of basic contaminants associated with water pollution are inorganic contaminants, organic contaminants, biological contaminants, and radiological contaminants [41]. The major source of water contaminants are pesticides, domestic waste, and industrial waste [41]. Biological contaminants include living organisms, such as algae, bacteria, protozoans, or viruses [41].Radiological contaminants include radioactive elements [41].

Chemical pollution, oxygen-depletion pollution, microbiological pollution, nutrient pollution, groundwater pollution, and surface water pollution are the different types of water pollution. Generally, water pollutants are classified as organic pollutants, nutrients and agriculture pollutants, thermal, radioactive, inorganic pollutants, pathogens, suspended solids, and other pollutants.

Organic and inorganic pollutants are discharged into the water bodies through industrial effluents and sewage. Chemical water pollution is mainly due to the infiltration of chemicals into underground water and surface water. Chemical water pollutants usually are of two types: macro pollutants and micro pollutants, depending upon their concentration in the water [42].

Agriculture waste, biological compounds, oils, and gasoline are the primary sources of micropollutants [43-45]. Inorganic pollutants mainly include heavy metals (e.g., Cr, Ni, Cu, Zn, Cd, Pb, Hg, U, Pu) and metalloids (e.g., Se, As).Agricultural pollutants mainly include nutrients, salts, sediments, pesticides, fertilizers, pathogens, and heavy metals. Nutrients mostly contain nitrogen and phosphorus present in organic fertilizers. Some of the pesticides include herbicides, insecticides, fungicides, and DDT.

Substances for which no regulations are currently established but are released into the environment are called Emerging pollutants (EPs); they have also been termed contaminants of emerging concern (CECs). Emerging pollutants mainly include hormones, surfactants, flame retardants, wood preservatives, food additives, and disinfectants.

**Organic pollutant:**

The organic pollutant is defined as the organic chemicals released into the ecosystem that causes temporary or permanent pollution. Chemicals are harmful to the ecosystem. Organic pollutants are not indigenous to the ecosystem. Chemicals released into the ecosystem when excess to the natural concentration become a pollutant to the ecosystem.

Increasing organic pollutants in the water bodies is a serious threat to the aquatic ecosystem and human health. Organic pollutants in water produce toxic chemicals during the disinfection process. Organic effluent contains a large number of suspended particles that are responsible for water pollution. Organic pollutants discharge into freshwater generally originate from domestic sewage, urban runoff, industrial (trade) effluents, and farm wastes. Discharge of organic pollutants in freshwater is responsible for eliminating the activity of microorganisms

Environmental friendly, renewable, and Cost-effective techniques are the need of the hour for wastewater treatment before discharging into natural water bodies [34]. Large amounts of chemical, pharmaceutical, and agricultural industries are the primary source of organic pollutants in wastewater [47, 48]. Uncontrolled and unaccountable discharge of micro pollutants (trace level concentration) is also harmful to the aquatic ecosystem and human health [49- 53]. The concentration of organic pollutants in sewage is low, but the volume largely makes them a primary source of organic pollutants in water.

Toxic nature, semi-volatile nature, high bioaccumulation, non-biodegradability, and lower water solubility of organic pollutants make them a more signi cant concern for the ecosystem as well as human health [54-56]

Phenol compounds, polycyclic aromatic hydrocarbons (PAHs), and agricultural chemicals as organic pollutants in the freshwater is responsible for critical health problems for human being as well as for the ecosystem also [57, 58]. Organic pollutants are generally placed into three general categories i) organometallic compounds, ii) hydrocarbons, iii) oxygen, nitrogen, and phosphorus compounds.

Discharges from motor vehicles onto the road come into the water as a pollutant due to storm water. Motor vehicles are the primary source of hydrocarbons, dioxins, and polycyclic aromatic hydrocarbons (PAHs) pollutants in water. These compounds contain elements like hydrogen and carbon, with some containing chlorine and oxygen as well. Synthetic organic chemicals, unit process operations, and production sites are also responsible for the discharge of organic pollutants into water. Organic pollutants, including petroleum, surfactants, pesticides, humic substances, dye, phenol compounds, and pharmaceuticals, are important pollutants in wastewater.

The dramatic increase of synthesized chemicals like pesticides, plastics, hydrocarbon fuels, soaps, detergents, and other valuable substances in the last century has increased the levels of organic pollutants in water to a great extent. Organic pollutants are centered on a few chemical families (PCBs, HCHs, DDT, PAHs, etc.),

Waste of fresh synthetic industrial compounds and industrial release is the prominent source of organic pollutants in the water. They are potentially dangerous to human health and the ecosystem [59-62]. Organic chemicals are important starting materials for many industries like ne chemicals, polymers, pharmaceuticals, pesticides, and paints. Because of their more significant production and use, all these industries become the primary source of organic pollutants in water.

Agrochemicals are the various chemicals that are used in the agriculture sector. This includes pesticides, fungicides, insecticides, herbicides, nematicides, synthetic fertilizers, hormones, and other chemical growth regulators. Some examples of agrochemicals used widely are Aldrin, Chlordane, DDT, Dieldrin, Endrin, Furans, Heptachlor, Hexachlorobenzene, Mirex Polychlorinated Biphenyls (PCBs), and Toxaphene. Agriculture activities are the major source of water pollutants that release into the environment resulting in the contamination of water. Agrochemicals through water pollution affect aquatic life as well as a human being by largely affecting the endocrine system [63, 64]

Due to bioaccumulation, fat solubility, and environmental persistence, some organic chemicals posed more significant problems to the ecosystem and human health. These pollutants are commonly referred to as Persistent Organic Pollutants (POPs). POPs compounds commonly include DDT, PCBs, and dioxins. POPs have a significant effect on the endocrine system even at low concentrations [65-68].

POSs are long-lived in environments, lipophilic, semi-volatile, and toxic [69, 70] Industrial, agricultural, and other anthropogenic activities have led to the increase of POPs in water. Some of the POPs include polychlorinated biphenyls (PCBs), γ-hexachlorocyclohexane (γ-HCH), polychlorinated dibenzo-p-dioxins (PCDDs), and dibenzofurans (PCDFs) as well as the poly aromatic hydrocarbons (PAHs).

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