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

**Introduction**

In 2015 the world population was more than 7.3 billion people. That is more than seven billion three hundred million bodies that need to be fed, clothed, kept warm and ideally, nurtured and educated. More than 7.3 billion individuals, while busy consuming resources are also producing vast quantities of waste and our numbers continue to grow. The United Nations estimates that the world population will reach 9.2 billion by 2050.

It's no surprise 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 lead to detrimental impacts on the ecosystem. The next global challenge towards a sustainable future will be wastewater treatment serving multiple treatments and recovery of water, nutrient, and energy resources.

Furthermore, due to the excessive population growth, producing enough food with only organic plant nutrients has become impossible. Therefore, the need for mineral fertilizers is a fact. Thus, many urban areas have dedicated wastewater treatment plants to remove the nuisance of human waste. But, it is becoming evident that future changes, particularly those associated with urbanization and population growth-related increases in the volume of wastewater, add more stress to the wastewater system performance.

Pharmaceutical and personal care products (PPCPs) comprise various 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 neutral, anionic, cationic, or zwitterionic molecules depending on the environmental conditions and octanol/water partition coefficient (Kow) values [2].

Antibiotics in wastewater have gained worldwide attention, thereby considering emerging pollutants that require adequate attention. Newer methods are to be developed for the efficient removal of antibiotics in the wastewater, looking at the possible threats it poses to the oceans' biotic flora and reducing the chemical oxygen demand before being discharged in 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 in treatments with multiple drugs. As a result, many tertiary and quaternary classes of drugs are also found to increase concentration in the wastewater. The percolation of antibiotics in the environment, especially water bodies, leads to increasing antibiotic resistance in the microbial flora, which ultimately finds their way to humans and animals via the food chain as potential threats to the health care sector in the 21st century. Besides, treating livestock with antibiotics in the feed has also added to the water's antibiotic pollution. It persists in the environment through a complex vicious cycle of transformation and bioaccumulation. 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. Antibiotics (β-lactams, sulfonamides, tetracycline), steroidal and nonsteroidal anti-inflammatories, and nutrient supplements are widely used. Management of animal reproductive systems employs hormones and estrogens such as oxytocin, steroids, ergonovine, HCG, GnRH, progesterone, prostaglandins, and FSH. Parasites have been controlled using insecticides and dewormers.[4] Animal antibiotic consumption far exceeds human consumption. Environmental loading of pharmaceuticals from animal husbandry can be more problematic because often human waste is treated while animal waste is not. As a result of which it’s essential to develop newer methods for efficient treatment of the water bodies.

In the past three decades, pharmaceutical residues have been discovered in almost all environmental matrices on every continent, including surface water (lakes, rivers, streams, estuaries, and seawater), groundwater, wastewater treatment plant (WWTP) effluent and influents, and sludge.[5]

Many pharmaceutically active compounds have been detected in water since the first discovery of such contaminants in aquatic systems in the 1980s. Bush[6] grouped these therapeutic compounds as (i) *anti-inflammatories and analgesics* (ibuprofen, paracetamol, diclofenac); (ii) *antibiotics* (sulfonamides, tetracyclines, penicillins, β-lactams, macrolides, fluoroquinolones, imidazoles); (iii) *antiepileptics* (carbamazepine); (iv) *antidepressants* (benzodiazepines); (v) *lipid-lowering agents* (fibrates); (vi) *antihistamines* (famotidine, ranitidine); (vii) *β-blockers* (metoprolol, atenolol, propranolol); and (viii) *other substances* (barbiturates, narcotics, antiseptics, and contrast media).[6] Antibiotics are the most frequently detected compounds, followed by analgesics.

**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. Three mechanisms, including inhibition of protein synthesis, nucleic acid (DNA/RNA) synthesis, or cell envelope synthesis, play essential roles. These compounds are designed to treat bacterial infections in livestock and humans. Thus, these compounds are intended to limit or avoid affecting mammalian cells. There are cases wherein it has been observed that antibiotics can also interact with similar receptors present on other organisms present in the ecosystem.[4]

 A large number of organisms of lower phyla possess receptors similar to those in upper phyla. Nontherapeutic exposure to these compounds is assumed to more adversely affect environmental microbes versus aquatic vertebrates, such as fish.[6,7] hence, pharmaceutically active compounds in the environment can exert toxic effects on numerous organisms in the environment.

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 all been observed. [7,8] Oxytetracycline and trimethoprim antibiotics induce toxic effects in *Daphnia Magna*, the green alga *Pseudokirchneriellasubcapitata*, and the cyanobacteria *Anabaena Flos-aque*.[8,9] The well-known decline of vulture populations in South East Asia is linked to the pharmaceutical Diclofenac.[9,10]

Different 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, 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 LanasynGray | 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). Biochars have 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, 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 the antibiotics 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 pollutions are industrialization, population growth, domestic sewage, pesticides, fertilizers, urbanization, and weak management system [30]

Deeplydeveloped 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 the 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 litters, 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.

Stormwater 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 the industrial, medical, 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, radiological contaminants [41]. The major source of water contaminants are pesticides, domestic waste, and industrial wastes [41]. Biological contaminants include living organisms, such as algae, bacteria, protozoans, or viruses [41]. Radiological contaminants includes radioactive elements [41].

Chemical pollution, oxygen-depletion pollution, microbiological pollution, nutrient pollution, groundwater pollution, and surface water pollution are the different types of water pollutions. 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 micropollutants, 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 phosphorous 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 to the ecosystem that causes temporary or permeant pollution. Chemicals are harmful to the ecosystem. Organic pollutants are not indigenous to the ecosystem except. 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 amount of the suspended particles that are responsible for water pollutions. Organic pollutants discharge into freshwater generally originate from domestic sewage, urban runoff, industrial (trade) effluents, and farm wastes. Discharge of organic pollutants in freshwater 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 the wastewater [47, 48].

Uncontrolled and unaccountable discharge of micropollutants (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 significant concern for the ecosystem as well as human health [54-56]

Phenolic compounds, polycyclic aromatic hydrocarbons (PAHs) and agricultural chemicals as organic pollutants in the freshwater is responsible for critical health problems to the human being as well as to ecosystem also [57, 58]

Organic pollutants are generally placed into three general categories as i) organometallic compounds, ii) hydrocarbons, iii) oxygen, nitrogen, and phosphorus compounds.

Discharges from motor vehicles on to road come into the water as a pollutant due to stormwater. 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, production sites are also responsible for the discharge of organic pollutants in water. Organic pollutants, including petroleum, surfactants, pesticides, humic substances, dye, phenolic compounds, and pharmaceuticals, are important pollutants in wastewaters.

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 afresh 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 the important starting materials of many industries like fine chemicals, polymers, pharmaceuticals, pesticides, and paints. Because of their more significant production and uses all these industries becomes the primary source of organic pollutant in water.

Agrochemicals are the various chemicals which use 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 results in the contamination of water. Agrochemicals through water pollution affect the 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 polyaromatic hydrocarbons (PAHs).

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