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REVIEW ARTICLE

Nanofabrication of Biochar from Cellulosic Waste for Bio-Sensing Application of Waste Water Treatment: Process, Challenges and Future Update

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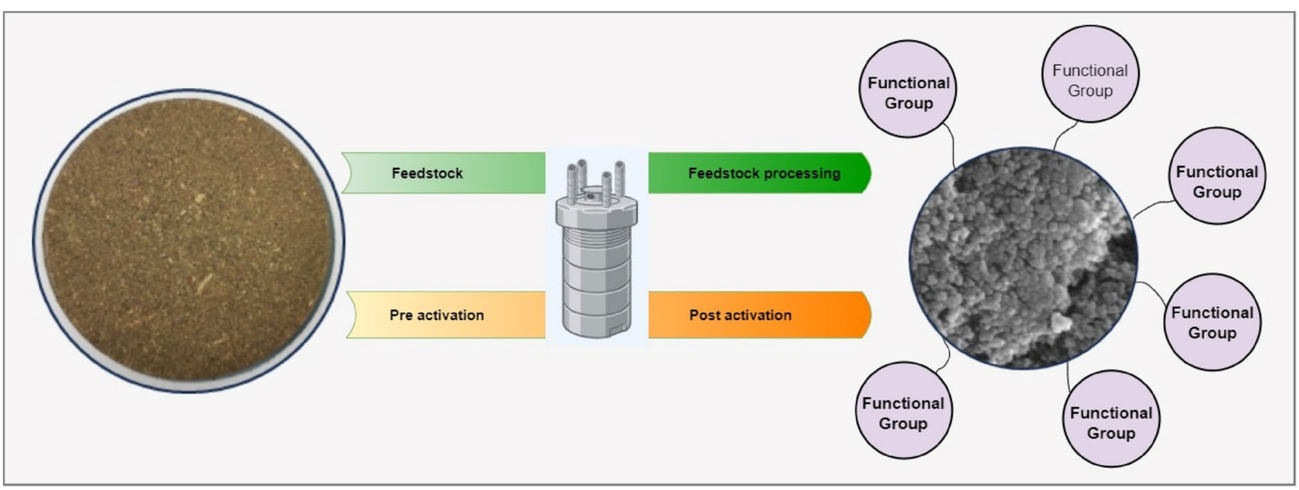
Abstract
Waste water pollution is one of the most prominent concerns across the globe due to its severe impact on human health and environment which affects the ecosystem directly. Therefore, for sustainable and consistence environment, waste water treatment is the primary and mandatory agenda of agencies involve worldwide to rectify this issue. Additionally, among various sustainable trail based strategies for waste water treatment, biochar catalyst utilization is very potential and impactful whereas, use of nanoform of biochar which is also known as nanobiochar is more impactful in waste water pollution remediation. Therefore, the present review represents the sustainable fabrication of nanobiochar from organic waste biomass and process strategy for its reduction from bulk form to nano form using different sustainability procedures. Type and mode of action of different biomass, types, fabrication, methods and functional properties along with their functional efficacy have been highlighted and discussed in the review. Existing challenges and sustainable possibilities to overcome them have also discussed as future prospects for sustainable and promising application of nanobiochar as potential sensor foreco-friendly remediation of waste water pollution.

Graphical Abstract
The figure present general overview to fabricate nanobiochar from waste biomass biomass for environmental application



Keywords Biochar · Nanobiochar · Waste biomass · Waste water · Biosensor · Sustainable fabrication

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Introduction

In developing sustainable environment, preservation of water and its quality contributed major role. Due to human activities and tremendous industrialization, water pollution is one of the main environmental issues. Release of pollutants and contaminants generate waste water which severally hampered the ecosystem of the earth [1]. Water pollution caused by industrial dyes is one of the rigid causes of environmental pollution. Dyes are complex organic compounds which can be produce by adopting both natural and synthetic pathways [2]. Compared to synthetic dyes, naturally produced dyes more toxic and needs immediate remediation. However, their consumption and production both are in high range and generally, these dyes are classified into different classes and they have severe health complications. Skin, respiratory and eyes related diseases are the common and frequently occurred health issues due to which immediate remediation of these dyes are mandatory [3]. The available conventional chemical and physical methods for the treatment of these dyes are time and cost consuming whiles the biologically treatment methods for the effective removal of these dyes are sustainable, low cost and eco-friendly. In biological methods, removal of dyes from waste water using biochar like catalyst is gaining attention due to its low cost and sustainable treatment application [4]. Biochar is a carbon rich catalyst obtained through pyrolysis process under strict anaerobic conditions and controlled environment. High specific surface area, porosity and high pore volume are the qualities of the biochar along with low cost, sustainable fabrication and eco-friendly reactions. Different process and methods have been identified to fabricate the biochar [5]. Additionally, for improving the reaction efficiency of the catalyst, pre-activation and post activation have been performed with biochar. Fabrication of the biochar from biomass seems to be a very promising approach to develop functionally efficient biochar. Lignocellulosic biomass (LCB) especially waste biomass is the potential source of biochar fabrication due to abundant quantity of carbon present in biomass structure, ample and lower cost availability. Additionally, the majority selective process to for these LCB transformation and value addition are sustainable [6].

Further, with the science of using applied nanotechnology, it is possible to further reduce the size and shape of the particle at nanorange and improving its activity. By applying nanotechnology, the size of biochar can be further reduced at nano level and it improves functional ability of the biochar along with surface area and porosity. Moreover, mechanical and thermal stability of the biochar can be further enhanced by adopting its nanoform. Further, in form of nanobiochar the functional immobilization capacity of the catalyst further enhanced due to better adsorption capacity [7]. Due to its high adsorption capacity, it can effectively adsorb dyes and pollutants. Additionally, it has also found significant application as biosensor in waste water treatment and photocatalytic degradation. However, the nanochar catalytic properties and fabrication mode are more intense research and exposure for its further and frequent use [8] (Table 1).

Therefore, the objective of the present review is to present sustainable fabrication of nanobiochar from waste biomass and its use indeveloping biosensor for sustainable waste water treatment. The reviews expose and discuss the fabrication process using different biomass to prepare biochar and nanobiochar for their effective sensing application. Emphasis of the review is also provided on function and activity of the nanobiochar based sensors in waste water treatment and their effective removal. Further, the current existing research advancement and research gap have also been discussed in this review.

Fabrication of Nano-BC from Waste Biomass

For sustainable biochar and nanobiochar production from biomass, structural and compositional biomass play basic role to develop efficient catalyst. Amount of total carbon present in LCB is vary based on different variety of biomass while the chemical bonding of the biomass are nearly same. Additionally, the growing variety of biomass is also one of the impotant points of consideration while selecting the biomass for biochar fabrication. Carbonization of biomass in oxygen starvation is mandatory condition to develop char which is rich in carbon. For transformation of bulk to nanoform needs size range from < 100 nm for biochar nanoparticles and thermochemical process are selective for this process [16]. Along with oxygen deficit condition, the varying temperature range for thermochemical process is between 200–700 °C exclusively using biomass. Pyrolysis is the main process known for fabrication of biomass in which smooth thermochemical process can process in absence of oxygen. For conversion of bulk to nano form, may supportive methods such as ball milling, centrifugation, sonication, microwave pyrolysis, prior and post heating along with pre and post activation has been applied to increase the functional efficiency of nanochar [17]. Cutting and grinding are the basic pretreatment step which can be adopted as very first step. Additionally, from industrial scale point of view, grinding and ball milling are the preferable procedure to reduce the particle size especially in case of biomass. However, the total functional efficiency of formed catalyst is depended on other biomass parameters like total carbon content, lignin content, crystallinity index, degree of polymerization, surface area, thermal stability, and particle

Table 1 Presents different nanobiochar fabrication using different biomass in different biosensing applications in waste water treatment

SL. No	Nanobiochar name	Waste biomass precursor	Properties	Application in biosensing	References
1	Electroreduced nano biochar (ErNBC)	Tea residue	–	Development of an electrochemical sensor combined with machine learning for selective detection of Pb^{2+} in actual water samples with a satisfactory recovery rate	Su et al. [9]
2	MgO modified biochar	Tea wastes	Surface area, porous structure, surface functional groups and surface charge of biochar enhanced after the modification	*o*-chlorophenol removal from industrial wastewater with maximum adsorption capacity of *o*-chlorophenol 128.7 mg/g	Chu et al. [10]
3	Biochar-based magnesium oxide composite (MTBC)	Prepared using Traditional Chinese Medicine residues and $MgCl_2$ solution,	Work as an effective adsorbent for the remediation of agricultural effluents containing TDF and DIN	Applied for the removal of triadimefon (TDF) and/or dinotefuran (DIN) in water	Chen et al. [11]
4	Biochar-based iron oxide composite (FeYBC)	Synthesized using pomelo peel and ferric chloride solution	–	Use as an efficient adsorbent for the remediation of industrial effluents containing Cr(VI) and phenol	Dong et al. [12]
5	Amino-functionalized magnetic biochar	Wasted peanut hull	–	Adsorption properties for Cr(VI)	Cai et al. [13]
6	Ca and Fe modified biochars	–	–	Removal of arsenic As(V) and chromium Cr(VI) from aqueous solutions	Agrafioti et al. [14]
7	Iron oxide amended rice husk char	–	–	Arsenate removal	Cope et al. [15]
8	Biochar and nanobiochar of water hyacinth and black tea waste	–		Effective role in metal removal from aqueous solutions	[1]

size. Further, this pretreatment step also reduces the overall cost of nanochar fabrication [18]. Additionally, the cost of overall process will also be reducing further via use of acid or alkali pretreatment methods. Based on the intense research on synthesis process it is established that grinding, sieving, dipping in aqueous suspension are the most reliable and effective method even at industrial scale [19]. Additionally, membrane filtration and centrifugation are the known separation methods of biochar in which second one is more preferable due to fast and relatively fine separation. Moreover, post membrane filtration is also recommended for better size option of nanochar. However, the cost of the membrane can be an issue in the industrial scale fabrication [20]. Therefore, the proposed sustainable methods need to be more investigated independently for more the fabrication methods development and its industrial scale sustainability to obtain more define shape and size of the newly prepared nanobiochar (Figs. 1, 2).

Further, based on the type of fabrication process, different types of nanobiochar have been known as potentially identified. For example, the nanobiochar which can be prepared using the conventional process only like ball milling,

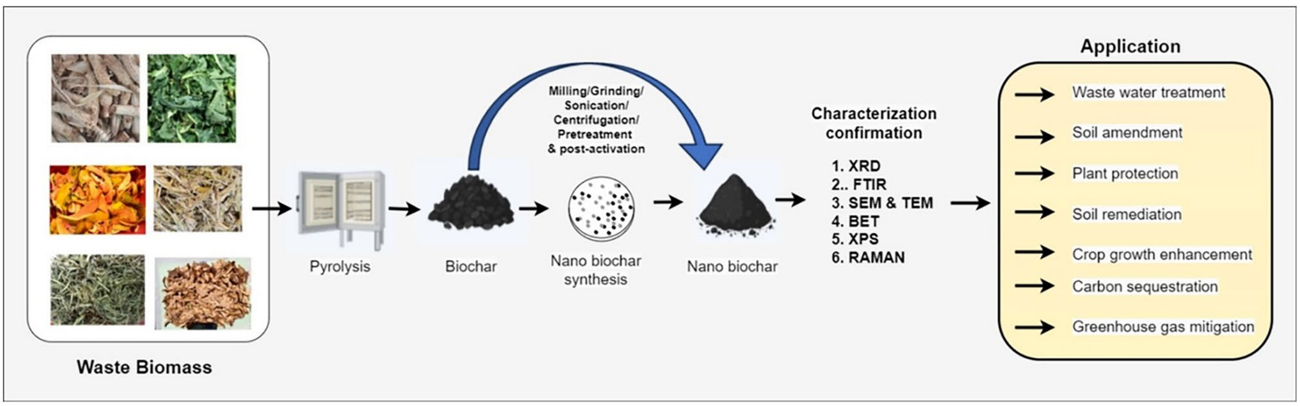
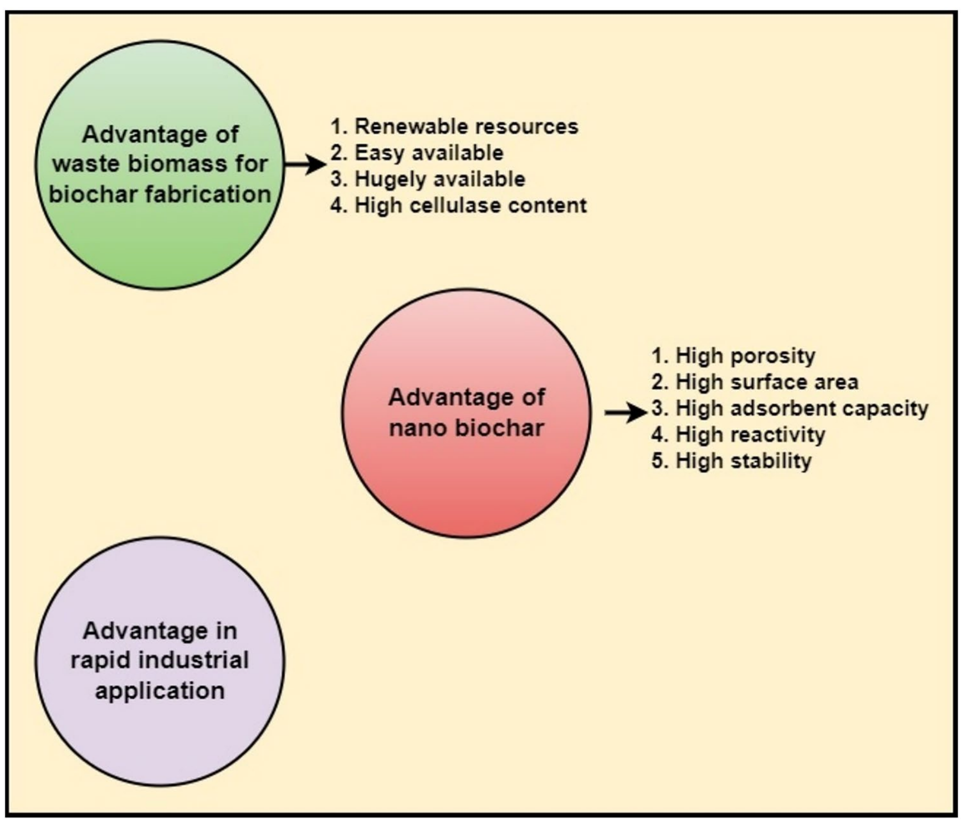


Fig. 1 Process overview of nanobiochar fabrication from waste biomass

Fig. 2 advantages of waste biomass and nanobiochar for industrial application



sonication, centrifugation, pretreatment, hydrothermal treatment [21]. These are the most commonly used convention technique for nanobiochar fabrication. Ball milling process is generally known for enhancing surface area, reduced the particle size mechanically, reducing oxygen availability and enhancing the functional stability of the fabricated nanobiochar. Additionally, in this process, kinetic energy needed to break the chemical bond of the large molecules and reduces the glycosidic linkages. Metallic ball in the milling chamber facilitate the nano form via collision process. One of the biggest advantages of ball milling process is that it does not use any toxic chemicals. One the other hand, process of wet milling involves higher dispersion of smaller particles for enhancing the surface area and improving the particle size reduction [22]. Moreover, when compared, both milling process showed same surface area but structural properties of the nanochar can be different. Similarly, physical change in the structural barrier can be shown in the process of sonication nanochar fabrication [23]. The process of sonication is make the biomass structure more flexible due to breakage of the bonds present in biomass using ultrasound irradiation and for achieving the desirable size of the particle this process should be repeated many times using high energy wave. The dispersed biochar has been located in the solvent while the larger particle size settled by gravity whereas,the high wave range increases the porosity of the prepared biochar. The process recommended high quality of nanbiochar with smooth surface area when repeats many time with higher frequency for longer duration [24].

Along with all existing process and steps of nanobiochar, centrifugation is the common step to refine the nanobiochar. For separation of nanobiochar, centrifugation is mandatory step which is dependent on solvent and time. Additionally, along with these all associated techniques, hydrothermal is a process which is influenced by acid or alkali treatment applications for improved properties applications [25]. However, the primary stage trials of hydrothermal techniques are available to synthesize nanobiochar which is dependent of optimization conditions. Presently, acid biochar technique is more successful over other associate hydrothermal techniques and due to this reason, the area needs more in depth investigation and establishment of process studies for sustainable industrial applications (Fig. 3).

In one of the study by Zhang et al. [26], acidic deep eutectic solvent (DEC) solvent technique has been used under mild condition to prepared biochar via pyrolysis of LCB waste and used for removal chromium [Cr(VI)] in the process of waste water treatment. Additionally, maximum adsorption capability of the newly fabricated biochar has been recorded 270.27 mg/g at 30 °C. In the research investigation of Burachevskaya et al. [27], biochar fabrication has been attempted using different types of lignocellulosic waste wood, and agricultural residues (sunflower and rice husks) under pyrolysis conditions while authors recommended general characterization techniques for the identification of this fabricated biochar. Further, Li et al. [28], N-doped biochar has been fabricated using LCB of *Medulla tetrapanacis* under pyrolysis of 700 °C with modification urea and $NaHCO_3$ and showed significant adsorption capacity. In the study of Muigai et al. [29], a comparative investigation has been conducted using different LCB name yellow oleander and sugarcane bagasse at two different temperature 350 and 550 °C. It was concluded in the result of this study based on characterization techniques that biochar fabricated from sugarcane bagasse at 550 °C has better properties over biochar fabricated from yellow oleander.

Biosensing Activity of Nanobiochar for Wastewater Treatment

Water contamination and pollution has been become a global threat for aquatic ecosystem which is resultant of overloaded contaminants generation due to continuous industrialization and human activities. To restore clean water conservation and elimination of pollutants from water, sustainable waste water goal has been set to achieve [30]. Nano-biochar has become most promising sensing catalyst based adsorbent to remediate pollutants from water and contributed heavily in waste water treatment. However, based on structure and properties of nano-biochar, functional efficacy of this catalyst may vary from type of pollutant present in contaminated water body [31]. Thus, it is needed to be exploring the pollutant specific catalyst nano-biochar or it can be multifunctional nanobiochar which can be effectively remediating more than one type of pollutants. Additionally, single or multifunctional pollutants removal efficacy in single and multipollutants removal has need to be investigated based on catalyst fabrication status and its efficiency. Moreover, with the advancement of nanotechnology, different and unique functional efficacy embedded nanobiochar can be potentially design for waste water treatment [32]. Most of the nanobiochar has improved surface area, pore size, active sites, catalytic degradation and separation efficiency.. One of the unique functional propertys of nanobiochar is that it can improve the basic functional efficiency after combining with pollutants and reduces the waste water pollution load. Based on the rigorous research studies, it has been now proven that nanobiochar has been confirmed as the potential catalyst for waste water treatment to remove all types of organic and inorganic impurities. Additionally these developed nanobiochar can be effective in both type of catalytic and photocatalytic performance for waste water treatment and reducing the pollution load [33]. The results of pollutants removal can be calculated on adsorption efficacy of the functional nanobiochar catalyst. Generally, it has

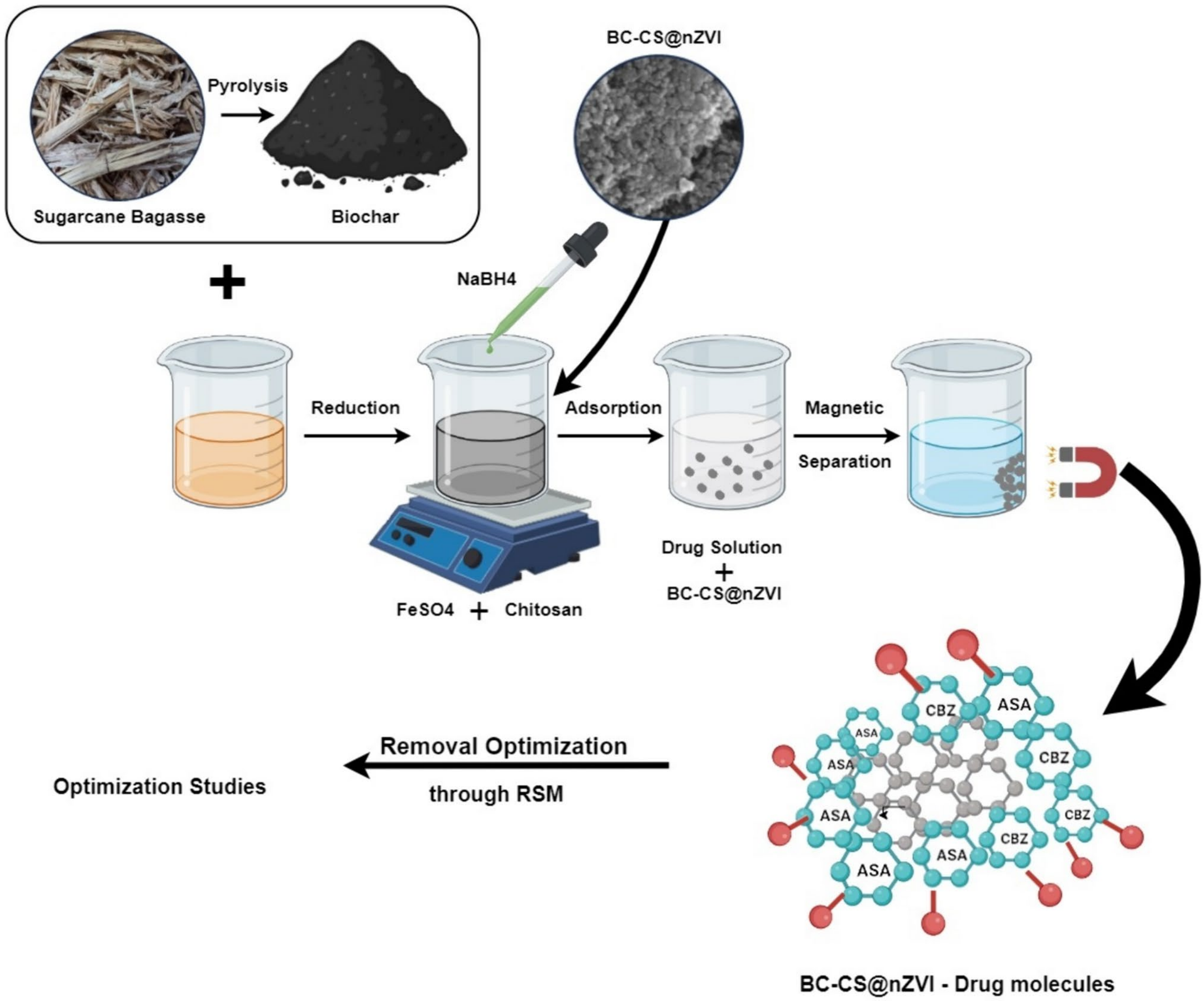


Fig. 3 General fabrication process of nano-biochar using waste biomass

been observed that nanobiochar allied composites are the better performer to remove water contaminants and other impurities. Moreover, nearly all types of contaminants can be effectively removed by using nanobiochar composites. Pyrolyzed nanocomposite nano cerium oxide-functionalized maize straw biochar (Ce-MSB), hydroxyapatite-biochar nanocomposite are potentially known nanobiochar adsorbent for waste water treatment. The removal of impurities generally sticks on the surface of nanobiochar catalyst in fast reaction mode [34]. Thus, additions of nanotechnology in char formation and used as sensing catalyst is the area which is growing rapidly for detection and quantification [35]. These catalysts are used as marker to targeting the pollutants points and act as detection and quantification tools. Both in developing nanobiochar and used it as sensor they key improving points are lies in developing and improving the structural properties which influence the remediation of waste water generated pollutants [36]. Thus, this area is also recommended on improving the structural and functional properties of the nanobiochar using new developed. In the study of Aziz et al. [37], nanobiochar has been prepared from pyrolysis technique at 600 °C upto 2 h and characterized through different characterization techniques. Biochar preparation was firstly adopted via pyrolysis method and thereafter the nanoform reduction has been occurred with centrifugation and sonication and maximum 91.7%, dye removal has been observed via this nanobiochar. Further, in the study of Elbehiry et al. [1], metals removal investigation has been found very effective using nanobiochar which was fabricated from water hyacinth and tea waste and maximum 99.8% metal removal has been observed using this fabricated nanobiochar. Similarly in the research investigation of

Dhasmana et al. [38], nanobiochar has been prepared from pineapple waste and used in waste water treatment whereas, significant reduction has been observed in TDS (total dissolve solid), pH and conductivity upto 27.3 mg/l, 7.11 and 53 µS/m, respectively.

Limitations and Future Scope

High surface area, porosity and functional efficiency are the potential properties of nanobiochar due to which it is known as potential catalyst. Enhancement of these properties may speed up the waste water remediation. Based on these properties the remarkable remediations of waste water contaminants are possible and thus, it is highly expected to improvement in these properties to enhance the stability and immobilization of the nanobiochar for frequent environmental applications. Moreover, this functional efficiency was further enhanced by using appropriate fabrication process, suitable feedstock and activation steps are involved. To enhance the overall process suitability of the feedstock is the most crucial point. Type and overall carbon content of the feedstock are the primary step to enhance the process quality and catalyst amount. Further, the appropriate channel processing of the feedstock from which the nanobiochar have been synthesized is need to be discovered, identified and established for better production and frequent application of fabricated biochar. Sustainable and cost effective large scale technologies for nanobiochar fabrication is need to be developed for diverse range of applications. Additionally, the chances of contamination during synthesis of biochar from biomass are need to be identified and fixed for smooth application. Furthermore, cost, sustainability and lignin barrier are needed to be also checked for sustainable fabrication of nanobiochar. Towards making the fabrication process even more sustainable, cost of nanomaterial which are used for functional activation are need to be address and for this reason, nanomaterial generated via green route are need to be used and apply. Inspite of huge benefits of nanobiochar, eco-toxicity of fabrication method as well as the fabricated nanobiochar is need to be checked and optimized for sustainable application at large scale.

Conclusion

Nanobiochar is highly efficient and potential catalyst with number of active functional group to use for different environmental applications. Mode of synthesis and selection of precursor is the main reason to enhance its physicochemical properties and catalytic efficiency. Moreover, the green and flexible fabrication methods applying different waste biomass and alternate sustainable methods options using different waste biomass make the fabrication process more eco-friendly and economical. Additionally, different fabrication method of using biomass is preferable due to number of advantages over the conventional process. The functional and catalytic improvement found in the developing exact fabrication method for specific nanobiochar catalyst and its development. The development of efforts towards developing fixed fabrication methods and functional efficacy using waste biomass can lead improved sensing application for waste water treatment.

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Declarations

Conflict of interest The authors of the manuscript declare that there is no conflict of interest.

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