Indian Journal of Science, Technology & Environment (IJSTE)
A Peer Reviewed, Refereed, Quarterly Research journal of Science, Technology & Environment

ISSN : 3108-2017(Online)
3108-1304(Print)
Vol.-1; Issue-1 (July-Sept.) 2025
Page No.- 41-48

https://ijste.gyanvividha.com

Author's :

1. Kinjal Bhardwaj
Research Scholar, Department of Chemistry, Janardan Rai Nagar Rajasthan Vidyapeeth (Deemed To Be University), Udaipur, India.

2. Dr. Mangal Shree Dulawat
Assistant Professor, Department of Chemistry, Janardan Rai Nagar Rajasthan Vidyapeeth (Deemed To Be University), Udaipur, India.

Corresponding Author :

Kinjal Bhardwaj
Research Scholar, Department of Chemistry, Janardan Rai Nagar Rajasthan Vidyapeeth (Deemed To Be University), Udaipur, India.

GREEN NANOTECHNOLOGY FOR METAL NANOPARTICLES : SYNTHESIS, PROPERTIES, AND APPLICATIONS -A REVIEW

Abstract : Research on nanotechnology has grown rapidly over the last decade due to its numerous applications in various sectors, including food safety, transportation, sustainable energy, environmental science, catalysis, and medicine. Materials developed, modified, and used at the nanometre size scale (1 to 100 nm) are collectively referred to as nanotechnology. For the production of NPs, various physical and chemical techniques are used. However, the majority of these procedures are expensive and could potentially be harmful to the environment and the creatures that live in it. Green synthesis techniques are particularly suitable for producing nanoparticles because they eliminate the need for hazardous substances, hazardous operating conditions (such as high temperature and pressure), and the need for external stabilising or capping agents. Several species of microbes and plants are being tested in an effort to develop a process that is safe for the surroundings, affordable, and organic. This review offers a comprehensive examination of the parameters affecting the synthesis, the characterisation of synthesised NPs, and the green synthesis of metallic NPs utilising microorganisms and plants. Metal nanoparticles' potential uses in a variety of fields have also been highlighted, as have the primary challenges in terms of toxicity and applied research.

Keywords : Metal Nanoparticles, Green synthesis, stabilizing agent.

1. Introduction : Nanotechnology has become one of the most exciting areas of contemporary research, providing novel approaches to environmental cleanup, energy, medicine, and catalysis. The distinctive physicochemical characteristics of metal nanoparticles (MNPs), which include high surface area, adjustable optical and catalytic activity, and phenomenal antibacterial potential, have drawn a lot of attention among the many nanomaterials. These include silver, gold, copper, zinc, and iron.

Traditionally, physical and chemical processes are used to create these nanoparticles. These technologies are effective, but they frequently use dangerous chemicals, consume a lot of energy, and produce toxic byproducts, which raises severe concerns about both human safety and the sustainability of the environment. Green nanotechnology has become more popular in recent years as a sustainable substitute for traditional techniques.

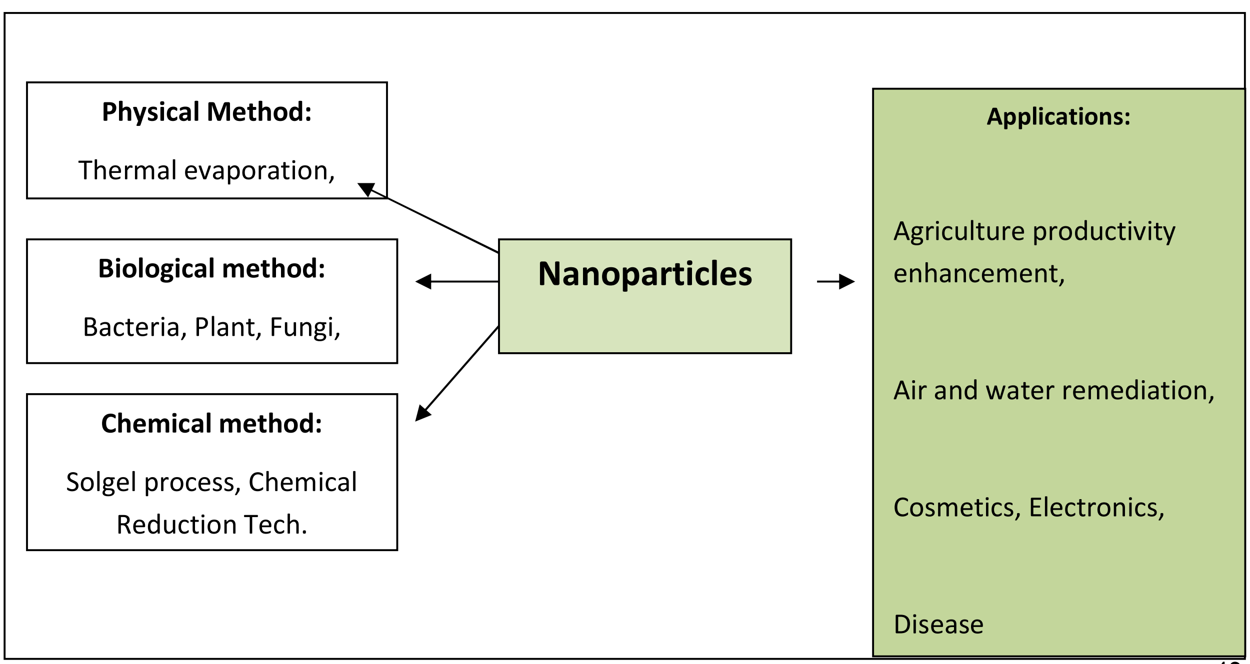
There are two categories of NPs: inorganic and organic. They are the most often used of all the synthesised NPs, with over 25% of them found in household items. AgNPs' primary use is as antiviral, antifungal, and antibacterial agents.

According to the bottom-up method, atoms, molecules, and smaller particles or monomers are used to create nanoparticles. Both methods include identifying the resulting nanoparticles using different methods to determine characteristics like size distribution, shape, surface area, and particle size. Additionally, three separate approaches are used for the production of NPs[2].

The chemical and biological methods for the synthesis of NPs follow a bottom-up approach, whereas the physical methods generally fall under the top-down approach category. The most popular physical techniques used to make NPs are pyrolysis, electrolysis, diffusion, evaporation-condensation, and laser ablation. However, these techniques' most significant drawbacks are their high energy consumption, costly procedures, and limited production rate.

Thus, the physicochemical synthesis methods are attractively replaced by the biological synthesis methods. To effectively target medication delivery to the desired place, a metal Nps that responds to various parameters can be synthesised.

Figure1:



Since the Nps are made from organic components, they can break down the pollutant without harming the ecosystem, making them useful for bioremediation in addition to pharmaceutical delivery applications. The primary focus of this study is on innovative and advanced green synthesis techniques for metal Nps that are sensitive to a wide range of factors. These techniques produce prominent and affordable Nps that can be utilised for a variety of purposes, as well as their capacity to decay into biomass[3].

2. Nanoparticle synthesis from biological materials : A wide range of resources, including bacteria, viruses, yeast, fungi, algae, and plants and plant products, can be used to carry out the biological synthesis of NPs. Mixing biological materials with precursors of high-quality metal salts initiates the creation of NPs.The creation of metal nanoparticles using environmentally friendly methods is based on the reduction of metal complexes in solutions that are diluted.

The goal of the procedure is to create metal colloidal dispersions. Natural or green sources like microbial and plant extracts have drawn a lot of attention because they contain specific compounds. Additionally, the green method for nanoparticle creation covers the synthesised NPs or even serves as in situ capping in addition to using materials derived from plants, algae, fungi, or microorganisms as reducing agents.

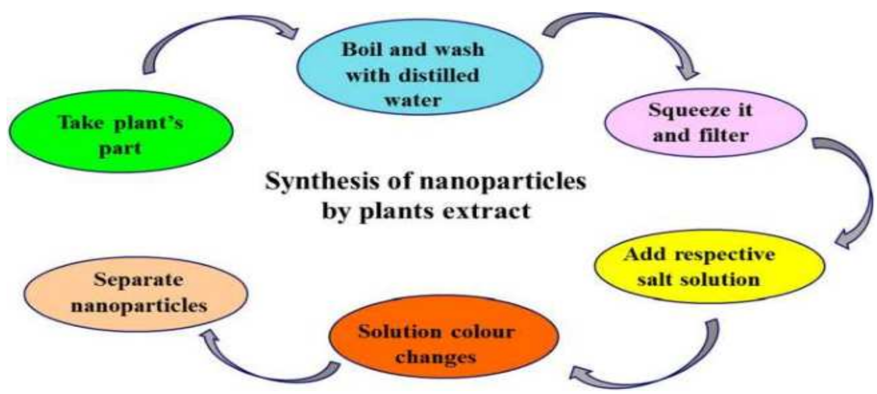


Figure 2: Green Method of synthesising of Metal Nanoparticles

It is essential to remember that the benefits and drawbacks of green synthesis might change based on the particular process and result. The goal of current sector is to overcome these obstacles and improve methods[4].

2.1 Plant-based green synthesis of metal nanoparticles : One of the most popular techniques for creating nanoparticles is plant-based synthesis because of its simplicity of use, affordability, and flexibility.

Flavonoids, phenols, alkaloids, and terpenoids are among the many bioactive substances found in these extracts that support the reduction of metal ions to nanoparticles while also stabilising their surface. Plant extract and a metal precursor solution are typically combined in this process, which is conducted under carefully regulated temperature, pH, and stirring conditions[5]. Harsh chemicals that endanger the environment and users are no longer necessary with this way of creating nanoparticles.

Furthermore, by extracting the bioactive compounds with simply hot water, high-energy-consuming procedures are removed. Most of the produced nanoparticles can be used in biomedical applications due to the absence of harsh reagents [6].Citations in Table 1 indicate that the most abundant kind of nanoparticles made from plant material are silver nanoparticles.

Table 1: Silver nanoparticles made from plant extracts.

Metal Nanoparticles	Species	Active Molecule	Application	Part Used	Reference
Silver	*Acadia rigidula*	Phenolic compound	Antimicrobial	Leaf, Bark	[7]
	Argemone mexicana	Sanguinarine and Flavonoids	Antioxidant, Antimicrobial, Anticancer	Leaf, Seed	[8]
	Morinda citrifolia L.	Anthraquinones, Flavonoids, Polysaccharides	Antimicrobial, Antitumor, Anti-inflammatory	Leaf, Fruit	[9]
	Carica papaya	Vitamins, Phenols, Proteolytic enzymes	Antimicrobial properties	Leaf, Fruit	[10]
	Moringa oleifera	Flavonoids, Phenolic acids	**Antimicrobial and Anticancer activities.**	Leaf	[11]
	Euphorbia helioscopia	Propargylamines	Antiarthritic, Antiviral	Leaf	[12]
	Datura metel	Flavonoids & Phenolics	Anticholinergic agents	Leaf	[13]
	Saraca indica	Flavonoids, Tannins & Polyphenols	Analgesic, Anti-inflammatory	Leaf	[14]
	Gardenia Jasminoides Ellis	Terpenoids, Phenolic compounds	Anti-depression, Antigastritis, Anti-diabetics	Leaf	[15]

In addition to silver, reports of nanoparticle production have also been reported for copper, gold, and selenium. Various plant materials can be used to synthesise silver nanoparticles if their extracts contain reducing, stabilising, and capping agents. In addition to leaves, the biosynthesis of various NPs uses additional plant parts such as roots, fruit, flowers, petal, seeds, peels, bark, etc.

2.2. Antimicrobial Synthesis of Metal Nanoparticles : A number of microbes, including bacteria, fungi, actinomycetes, and viruses, have been reported to synthesise different metal nanoparticles in addition to plant-mediated synthesis. Numerous biological processes, including biomineralisation, bioremediation, bioleaching, and biocorrosion, have previously benefited from the interaction between metals and microbes. Furthermore, because of its benefits over various methods, microbial synthesis of NPs has lately become a promising field of study.

The type of microbe determines whether the NPs are produced extracellularly or intracellularly. Microorganisms' extracellular and intercellular components are essential for the synthesis of AuNPs. AuNP reduction is supported by extracellular substances like exopolysaccharides and intercellular elements, such as reducing sugar, fatty acids, and enzymes[16]. Apart from bacteria, fungi have also drawn more attention due to their NP synthesis because of their many benefits, including easy downstream processing and scale-up, economic viability, and higher surface area because of mycelia.

2.3 Factors Influencing the Synthesis of NPs : The functionality of metal nanoparticles for a variety of applications is further improved by adjusting their size and shape. By adjusting a number of experimental factors. one can control the morphological properties of NPs[17]. When optimising metal nanoparticle manufacturing by the biological approach, accurate control of these factors can be crucial. By altering the medium's pH, NPs' size and shape can be adjusted; however, large-sized NPs are formed when the pH is too acidic.

Using Azadirachta indica leaf extract, a shift in silver NP particle size was seen in the 10–35 nm range when the reaction period was extended from 30 minutes to 4 hours. The shape, size, and yield of NPs are also determined by the reaction temperature, which is another important variable in the biological synthesis of NPs. Using citrus sinensis (sweet orange) peel extract, the average size of silver nanoparticles (NPs) dropped from 35 to 10 nm as the reaction temperature increased from 25 to 60 °C[18].

3. Working with nanoparticles in the field of

3.1. Food Industry : Raw food ingredients are transformed into a pleasant form with a long shelf life through food processing, which also guarantees effective marketing and distribution strategies for the business. Combining NPs with other technologies can result in significant advancements in food product manufacturing, packaging, storage, and transportation.

The primary factor influencing the delivery rate of bioactives to their target sites is particle size, since certain cell lines are unable to absorb microparticles. A variety of methods have been devised by researchers for packing these bioactives utilising nano-sized particles or nano-emulsions, which increases their surface to volume ratio and increases their bioavailability.

3.2. Pharmaceuticals and Medicines : They are a great way to target specific spots and quickly penetrate inside cells or sick sites because of their structural features[20].

Based on therapeutic necessity, different types of NPs were found, depending on their origin and application. Iron oxide, polymeric protein, metal-based, and liposomal NPs have become the best. Our discussion in this review is primarily concerned with the utilisation of metal nanoparticles. Over the past ten years, medications based on nanotechnology have drawn a lot of interest. NPs are one of the most researched and investigated topics because of their unique properties, which include their small size and ability to flow through veins, connections, barriers, and fine blood capillaries[21].

3.3 Process of Treating Wastewater : The aquatic environment has been affected by wastewater released into the ecosystem as a result of industrialisation, an increase in population, and excessive chemical use. Because it contains inorganic (fluoride, arsenic, copper, mercury, etc)[22].

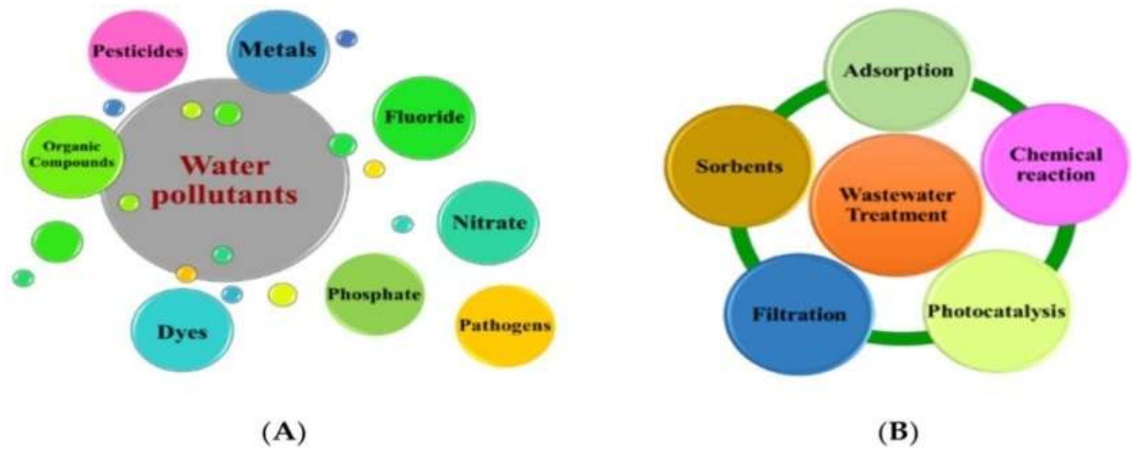


Figure 3: A) Common pollutants in water, B) Methods for treating wastewater that use nanoparticles.

The process of gaseous or liquid molecules adhering to a solid surface and forming a coating or film of molecules is known as adsorption. This process primarily occurs on the adsorbent surface where the adsorbate builds up. Depending on whether the adsorbent and adsorbate are bound by van der Waals forces, covalent bonds, or electrostatic attraction, the adsorption process may be physisorption or chemisorption. Because it is inexpensive, simple to use, and does not produce secondary pollutants, adsorption is the most widely used method for removing toxins from water[23]**.**

The photoexcitation of the catalysts' electrons is the process underlying photocatalysis. Green synthesised Ag, Au, Pt, and Pd NPs have been shown in numerous studies to have photocatalytic activity in the degradation of various dyes[24].

4. Major Obstacles and Prospects : Numerous studies have documented the environmentally friendly production of metallic nanoparticles (NPs) from a variety of biological sources, including yeast, bacteria, fungi, and plants. Nonetheless, a number of obstacles still exist that restrict its widespread manufacturing and the ensuing uses.

By overcoming these obstacles, green synthesis techniques may become affordable and on level with traditional techniques for producing NPs on a big scale.

5. References :

1. Dikshit, P. K., Kumar, J., Das, A. K., Sadhu, S., Sharma, S., Singh, S., Gupta, P. K., & Kim, B. S. (2021). Green Synthesis of Metallic Nanoparticles: Applications and Limitations. *Catalysts*, *11*(8), 902. https://doi.org/10.3390/catal11080902

2. Shah, M., Fawcett, D., Sharma, S., Tripathy, S. K., & Poinern, G. E. J. (2015). Green Synthesis of Metallic Nanoparticles via Biological Entities. *Materials*, *8*(11), 7278-7308. https://doi.org/10.3390/ma8115377
3. Samuel, M. S., Ravikumar, M., John J., A., Selvarajan, E., Patel, H., Chander, P. S., Soundarya, J., Vuppala, S., Balaji, R., & Chandrasekar, N. (2022). A Review on Green Synthesis of Nanoparticles and Their Diverse Biomedical and Environmental Applications. *Catalysts*, *12*(5), 459. https://doi.org/10.3390/catal12050459
4. Radulescu, D.-M., Surdu, V.-A., Ficai, A., Ficai, D., Grumezescu, A.-M., & Andronescu, E. (2023). Green Synthesis of Metal and Metal Oxide Nanoparticles: A Review of the Principles and Biomedical Applications. *International Journal of Molecular Sciences*, *24*(20), 15397. https://doi.org/10.3390/ijms242015397
5. Singaravelu, S., Motsoene, F., Abrahamse, H., & Dhilip Kumar, S. S. (2025). Green-synthesized metal nanoparticles: a promising approach for accelerated wound healing. *Frontiers in bioengineering and biotechnology*, *13*, 1637589. https://doi.org/10.3389/fbioe.2025.1637589
6. Huston, M., DeBella, M., DiBella, M., & Gupta, A. (2021). Green Synthesis of Nanomaterials. *Nanomaterials*, *11*(8), 2130. https://doi.org/10.3390/nano11082130
7. Escárcega-González, C. E., Garza-Cervantes, J., Vázquez-Rodríguez, A., Montelongo-Peralta, L. Z., Treviño-González, M., Díaz Barriga Castro, E., & Morones-Ramírez, J. R. (2018). In vivo antimicrobial activity of silver nanoparticles produced via a green chemistry synthesis using *Acacia rigidula* as a reducing and capping agent. *International Journal of Nanomedicine, 13,* 2349–2363. https://doi.org/10.2147/IJN.S1 60605
8. Mustapha, T., Misni, N., Ithnin, N. R., Daskum, A. M., & Unyah, N. Z. (2022). A Review on Plants and Microorganisms Mediated Synthesis of Silver Nanoparticles, Role of Plants Metabolites and Applications. *International Journal of Environmental Research and Public Health*, *19*(2), 674. https://doi.org/10.3390/ijerph19020674
9. Sathishkumar, G., Gobinath, C., Karpagam, K., Hemamalini, V., Premkumar, K., & Sivaramakrishnan, S. (2012). Phyto-synthesis of silver nanoscale particles using *Morinda citrifolia* L. and its inhibitory activity against human pathogens. *Colloids and Surfaces B: Biointerfaces, 95,* 235–240. https://doi.org/10.1016/j.colsurfb.2012.03.001
10. Banala, R. R., Nagati, V. B., & Karnati, P. R. (2015). Green synthesis and characterization of *Carica papaya* leaf extract coated silver nanoparticles through X-ray diffraction, electron microscopy and evaluation of bactericidal properties. *Saudi Journal of Biological Sciences, 22*(5), 637–644. https://doi.org/10.1016/j.sjbs.2015.01.007
11. Nayak, D., Pradhan, S., Ashe, S., Rauta, P. R., & Nayak, B. (2015). Biologically synthesised silver nanoparticles from three diverse family of plant extracts and their anticancer activity against epidermoid A431 carcinoma. *Journal of Colloid and Interface Science, 457,* 329–338. https://doi.org/10.1016/j.jcis.2015.07.012
12. Nasrollahzadeh, M., Sajadi, S. M., Babaei, F., & Maham, M. (2015). *Euphorbia helioscopia* Linn as a green source for synthesis of silver nanoparticles and their optical and catalytic properties. *Journal of Colloid and Interface Science, 450,* 374–380. https://doi.org/10.1016/j.jcis.2015.03.033
13. Murugan, K., Dinesh, D., Kumar, P. J., et al. (2015). *Datura metel*-synthesized silver nanoparticles magnify predation of dragonfly nymphs against the malaria vector

Anopheles stephensi. *Parasitology Research, 114,* 4645–4654. https://doi.org/10.1007/s00436-015-4710-x

14. Perugu, S., Nagati, V., & Bhanoori, M. (2016). Green synthesis of silver nanoparticles using leaf extract of medicinally potent plant *Saraca indica*: A novel study. *Applied Nanoscience, 6,* 747–753. https://doi.org/10.1007/s13204-015-0486-7
15. Saravanakumar, K., Chelliah, R., Shanmugam, S., Varukattu, N. B., Oh, D.-H., Kathiresan, K., & Wang, M.-H. (2018). Green synthesis and characterization of biologically active nanosilver from seed extract of *Gardenia jasminoides* Ellis. *Journal of Photochemistry and Photobiology B: Biology, 185,* 126–135. https://doi.org/10.1016/j.jphotobiol.2018.05.032
16. Tan, K. B., Sun, D., Huang, J., Odoom-Wubah, T., & Li, Q. (2021). State of arts on the bio-synthesis of noble metal nanoparticles and their biological application. *Chinese Journal of Chemical Engineering, 30,* 272–290. https://doi.org/10.1016/j.cjche.2020. 11.010
17. Gurunathan, S., Han, J., Park, J. H., & Kim, J. H. (2014). A green chemistry approach for synthesizing biocompatible gold nanoparticles. *Nanoscale Research Letters, 9,* 248. https://doi.org/10.1186/1556-276X-9-248
18. Kaviya, S., Santhanalakshmi, J., Viswanathan, B., Muthumary, J., & Srinivasan, K. (2011). Biosynthesis of silver nanoparticles using Citrus sinensis peel extract and its antibacterial activity. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 79*(3), 594–598. https://doi.org/10.1016/j.saa.2011.03.040
19. Ezhilarasi, P. N., Karthik, P., Chhanwal, N., & Anandharamakrishnan, C. (2013). Nanoencapsulation techniques for food bioactive components: A review. *Food and Bioprocess Technology, 6*(3), 628–647. https://doi.org/10.1007/s11947-012-0944-0
20. Sebastian, R. (2017). Nanomedicine – The future of cancer treatment: A review. *Journal of Cancer Prevention & Current Research, 8*(1), 204–208. https://doi.org/10.15406/jcpcr.2017.08.00265
21. Elsaesser, A., & Howard, C. V. (2012). Toxicology of nanoparticles. *Advanced drug delivery reviews*, *64*(2), 129–137. https://doi.org/10.1016/j.addr.2011.09.001
22. Sharma, S., & Bhattacharya, A. (2017). Drinking water contamination and treatment techniques. *Applied Water Science, 7*(3), 1043–1067. https://doi.org/10. 1007/s13201-016-0455-7
23. Usman, M., Farooq, M., Wakeel, A., Nawaz, A., Cheema, S. A., Rehman, H. U., Ashraf, I., & Sanaullah, M. (2020). Nanotechnology in agriculture: Current status, challenges and future opportunities. *The Science of the total environment*, *721*, 137778. https://doi.org/10.1016/j.scitotenv.2020.137778
24. Anjum, M., Al-Makishah, N. H., & Barakat, M. A. (2016). Wastewater sludge stabilization using pre-treatment methods. *Process Safety and Environmental Protection, 102,* 615–632. https://doi.org/10.1016/j.psep.2016.05.022

•