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Journal of Natural and Applied Sciences Pakistan

Journal homepage: http://jnasp.kinnaird.edu.pk/

REVIEW ON COPPER NANOPARTICLES: GREEN SYNTHESIS AND APPLICATION FOR WATER TREATMENT

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Abstract

The wastewater from industries and households contain microorganisms that are hazardous for the health of organisms and environment. Therefore, the discharge from domestic and industrial facilities must be treated before final disposal to meet environment safety standards. The advancement in the science and technology have led to the invention of many purification systems and techniques for the treatment of water and wastewater. Nanotechnology is an emerging non-conventional technology that has a promising future with regards to the purification of water. Among nanoparticles, metallic copper nano particles are receiving much attention due to their unique properties such as high surface to volume ratio, small size, high melting point, eco-friendliness and cost effectiveness that makes them appropriate for a variety of applications. This review presents an overview of green synthesis of CuNPs from bacteria, fungi and plant extracts with special reference to their application for water treatment.

Keywords
Copper nanoparticles, Green synthesis, Biosynthesis, Water treatment.

1. Introduction

The increased global industrialization and development due to the exponential growth in human population has led to deterioration of the environment mainly by exploitation of natural resources either through direct or indirect release of waste and wastewater into the environment. Factories and industries are the major contributors of environmental pollution. The waste coming from petrochemical, pharmaceutical, chemicals, tanneries and textile industries contain many chemicals and other toxic compounds that destroy the quality of waterbodies and soil on which they are discharged. So, the discharge from domestic and industrial facilities must be treated before disposal to meet environment safety standards. Many processes are used for the treatment of surface water and industrial wastewater but their efficiency limits to some extent when comes to purification of water from all the pollutants due to presence of carcinogenic, persistent, highly toxic compounds in them (Que *et al*, 2018).

Nowadays, reuse of wastewater after treatment is one of the most appropriate alternatives available to meet the clean water demands. However; health effects of pathogens and hazardous chemicals found in wastewater make its treatment difficult to meet required hygiene and health standards.

2. Nanotechnology for Water Purification:

The advances in the science have led to the invention of many purification systems and techniques for the treatment of water and wastewater such as oxidation, chlorination, sedimentation, boiling, and filtration. With the advancement, nanotechnology is emerging as a non-conventional technology that has a promising future with regards to the purification of water and wastewater (Lu *et al*, 2016).

In contrast to the conventional water purification techniques, nanotechnology is more efficient due to the use of atoms on nanoscale. Many physical, biological and chemical contaminants are removed by nano membranes. Moreover, these membranes are also used for water softening. In many developed countries, nano technology is used on commercial scale for water treatment as it helps in water filtration, purification and desalination. The characteristics that make this technique effective than conventional techniques include:

- Small volume
- Ability of materials to change chemical, biological and physical properties on nano scale
- More surface area due to extremely small size
- Stronger, durable and more stable particles
- Easier biological and chemical reactions (Picraux, 2018; Voisin *et al*, 2017).

2.1.Nano-photo catalysts

The term photocatalysis is derived from two Greek words, photo meaning light and catalysis meaning decomposition. So photocatalysis means the process that decomposes the compound in the presence of light. This process activates and stimulates the substance by using UV/Sunlight/visible light and without any involvement it chemically transforms the compound. Nano-photocatalysts are those nanoparticles that use light to decompose the compound. Thus, helping in water purification or treatment (Yaqoob *et al*, 2020).

The nano-photocatalysis occur in two different states, homogeneously or heterogeneously. The latter is the more extensively used due to its efficiency of water decontamination and application related to environment. In heterogeneous photocatalysis, the process takes place by the interference of Solid photocatalysts and Liquid photocatalysts (Yaqoob *et al*, 2020).

3. Copper Nanoparticles:

The copper-based particles between the size of 1-100 nm are called copper nanoparticles. Like other nanoparticles, the production of copper nanoparticles may be either through chemical synthesis or natural processes. Due to their application as colouring agents in history and biomedical services, they are of special interest these days.

3.1.Copper Nanoparticles Synthesis:

Copper has potential for oxidation in air which makes synthesis of CuNPs difficult as compared to other noble metals. In contrast to other noble metals (Ag, Au and Pt), metallic CuNPs are receiving much attention due to their unique properties such as high surface to volume ratio, small size, tendency to improve shape, size and oxidation resistance, etc. Since, Cu oxidizes in air; the production of copper nanoparticles is carried out in an inert environment. While in some cases, surfactants and protective polymers are used to inhibit oxidation (Tamilvanan *et al*, 2014; Gracia-Pinilla *et al*, 2010; Mishra *et al*, 2011).

Copper nanoparticles can be produced by using various techniques typically classified as

- bottom-up or chemical methods
- top-down or physical methods

In bottom up or chemical method, the copper nanoparticles obtain the structure of atoms or clustered molecules on a nano scale through chemical modification. Some of these methods include supercritical fluid synthesis, spinning, use of templates, green synthesis, sol-processes and sol-gel process, laser pyrolysis, aerosol-based process, atomic or molecular condensation, chemical vapour deposition (CVD) and plasma or flame spraying synthesis. In top-down or physical method, cutting, sputtering, laser abrasion and milling or grinding techniques are used to obtain the nanoscale dimension from a bulk piece (Tamilvanan *et al*, 2014; Bali *et al*, 2006; Iravani *et al, 2011)*.

Other important methods reported for the synthesis of CuNPs (Table 1) include thermal reduction (Ong *et al*, 2014; Yallappa *et al,* 2013), metal vapor synthesis (Venkatakrishnan *et al,* 2014; Al-thabaiti *et al*, 2015; Hayashi *et al,* 2006), microemulsion route (Rajeshkumar *et al*, 2018; Shikha *et al*, 2015), hydrothermal synthesis (Seku *et al,* 2018), continuous flow techniques (Morioka *et al*, 2016) and biological synthesis (Hasan *et al*, *2015*; Nasrollahzadeh *et al,* 2017)

Table: 1 Important Methods for Copper Nanoparticles Synthesis

Methods	**Reference No.**
Thermal reduction	11, 12
Metal vapor Synthesis	13, 14, 15
Microemulsion route	16. 17
Hydrothermal Synthesis	18
Continuous Flow Techniques	19
Biological Synthesis	20-36

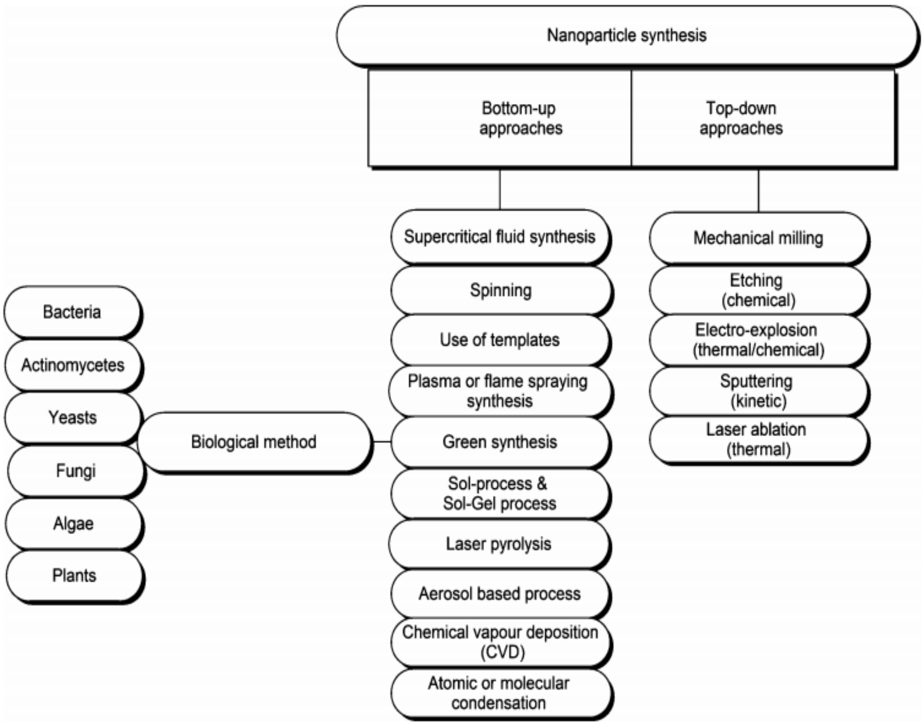

Figure 1: Manufacturing methods for nanoparticles synthesis (Iravani *et al,* 2011)

4. Green Synthesis:

With the advancement in science and technology, new methods and techniques have been found that are used as alternatives to the chemical synthesis. Green synthesis, also referred to as biosynthesis, is the latest technology used for the nanoparticles production. Biosynthesis is a process that utilizes living organisms for the formation of complex compounds. Biosynthesis of Nanoparticles uses microorganisms either prokaryotes or eukaryotes to synthesize metallic nanoparticles that include iron, silver, copper, gold, platinum, cadmium, metal oxide, zirconium etc. and the microorganisms used for this process includes bacteria, fungi, algae and plant extracts. Leaves of many trees and plants are also used for this purpose (Hasan *et al, 2015).*

4.1.Components of Green Synthesis:

The synthesis of nanoparticles requires many chemicals such as stabilizers, toxic reductants, high intensity radiations etc. that pose serious hazards to terrestrial and marine ecosystem. In contrast, green nanoparticles are eco-friendly, cost-efficient and their reactions are easy to initiate (Siddiqi *et al,* 2016; Singh *et al,* 2018).

4.1.1. Fungi

Biosynthesis of Nanoparticles using fungi is also one of the prominent methods used as green and eco-friendly technique. Many microorganisms like *Fusarium oxysporum, Phanerochaete chrysosporium, Pleurotus sajor-caju, Coriolus versicolor,* and *Schizophyllum commune*, white-rot fungi have been used for the biosynthesis of metal nanoparticles. They also proved to have better antimicrobial activity as compared to nanoparticles synthesized chemically (Gupta *et al,* 2013).

The *P. aurantiogriseum, P. citrinum, P. waksmanii, and F. oxysporum* have also been used to synthesis copper nanoparticles but they showed no-large polydispersity in pH 5-9. Copper nanoparticles prepared by using these microorganisms are fairly uniform and have spherical shape. They are proved to be environment friendly as they are cheaper, smaller, efficient, require less energy yield and require less raw material to manufacture (Cuevas *et al,* 2015). Biosynthesis of metal nanoparticles can be done by using white rot fungi S. *hirsutum.* The extracellular protien is responsible for the production of copper nanoparticles (Siddiqi *et al,* 2016; Honary *et al, 2012).*

4.1.2. Microbes

Microbes can also be used for the synthesis of nanoparticles due to their short generation time, easy culture, easy downstream process and mild experimental conditions such as pressure and pH. They work either intracellularly or extracellularly for the synthesis of nanoparticles. Microbes have an ability to transform the toxic metal into non-toxic metal such as in oxides and sulfide form when kept in harsh conditions. Therefore, they can be used for the synthesis of nanoparticles. Bacteria produce nanoparticles extracellularly and have high tolerance and easy to culture (Siddiqi *et al,* 2016; Shantkriti *et al,* 2014).

Copper nanoparticles can also be produced by using bacteria. *Pseudomonas Fluorescence* is most commonly used bacteria for the biosynthesis of copper nanoparticles. The size of biosynthesized copper nanoparticles by using *Pseudomonas Fluorescence* ranged from 20-80 nm and shape was spherical and hexagonal under neutral pH in 90 minutes incubation (Subhankari *et al,* 2013).

4.1.3. Plant extracts

Plants extracts are widely been used for the biosynthesis of nanoparticles. Copper nanoparticles are been made also used by using leaf and plant extracts of *Henna, Ginkgo biloba L, Azadiarachta indica, Plantago asiatica, Magnolia Kobus* leaf. This green method involves wide range of application depending upon the morphology and is used to reduce the problems related to chemical and physical processes i.e. high cost and use of hazardous chemical substances. The clove extracts are also used for the green/bio synthesis of copper nanoparticles by reducing Copper sulphate with aqueous solution of clove extracts. The copper particles formed are ranged in size of 5-40 nanometer. The aqueous solution of copper particles prevents the oxidation and have good stability. This type of biosynthesis does not involve any toxic or hazardous chemical and considered environmentally friendly (Shobha *et al,* 2014).

5. Mechanism of Green Synthesis:

Green synthesis of nanoparticles from different biological species includes several steps such as extraction, analysis, characterization, modification, purification and then finally their application. Figure 5 gives a brief description of the steps involved in green synthesis of nanoparticles.

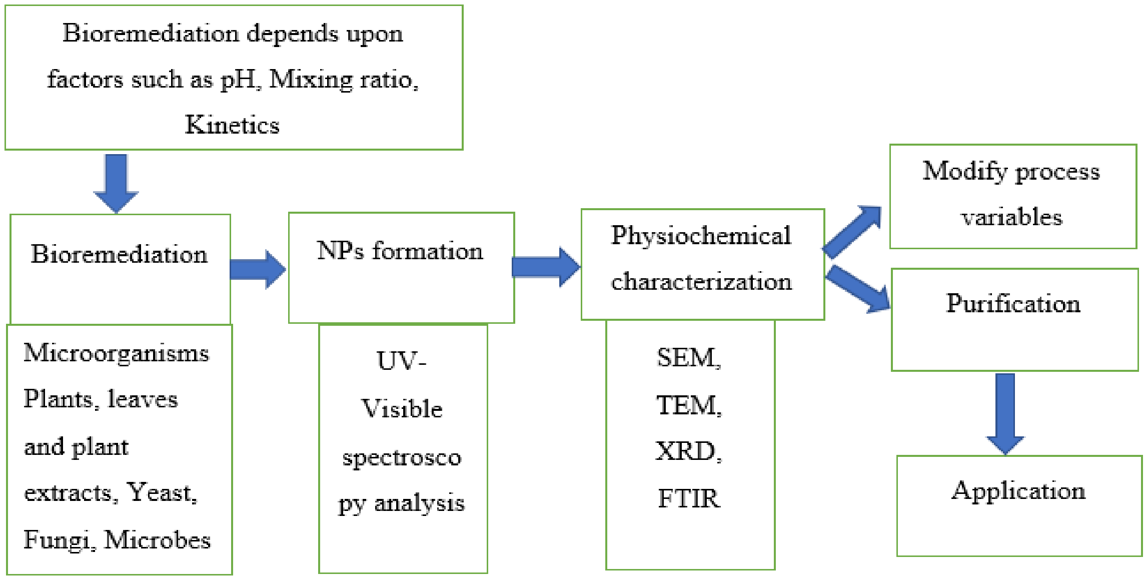

Figure 2: Process flow of Biosynthesis of Nanoparticles

5.1.Microorganism based mechanism:

The formation of nanoparticles utilizes different synthesis mechanism depending upon microorganisms. These microbes absorb the metal ions from the environment on their surface or inside their cells. The ions are reduced by electrostatic interaction between the ion and the negatively charges ion and cell wall into nanoparticles by the cellular activity in the presence of enzymes (Siddiqi *et al,* 2016; Jha, *et al,* 2009). The nanoparticles can be biosynthesized by using following living organisms. The bacteria take longer time to reduce metal ions to nanoparticles as they require longer incubation time. Various studies describe the mechanisms of microorganism assisted nanoparticles formation however bio-reduction mechanism is yet unexplored for the metal salt ions and their resulting nanoparticles (Mittal *et al,* 2013).

5.2.Plant leaf extract-based mechanism:

In this synthesis mechanism, plant leaf extract, at different reaction conditions, is mixed with metal solution. The rate of nanoparticle formation, their stability and yield is controlled by parameters determining the plant leaf extract conditions such as pH, temperature, metal salt concentration etc. These extracts act as both reducing and stabilizing agents, hence, play a dual role in nanoparticles synthesis. Different phytochemicals present in plant leaf extracts such as ketones, aldehydes, terpenoids, amides, carboxylic acids and sugars also govern the synthesis mechanism as they are responsible for the bio reduction of nanoparticles (Siddiqi *et al,* 2016; Mittal *et al,* 2013; Li *et al,* 2011).

5.2.1. Synthesis of CuNPs by Henna leaves

The green synthesis of copper nanoparticles was reported using henna (Lawsonia *inermis*) leaves. The henna leaves contain gallic acid, fats, resins and the active compound hennotannic acid (2-hydroxy-1,4-naphthoquinone, C10H6O3, red color) in it and for this reason they are widely used in making medicine and cosmetics throughout the world. The results of UV-Visible spectrum for the nano-bio composite of the henna leaves extract showed that the reddish-brown copper nanoparticles were formed at the maximum absorbance of 570 nm at pH of 11 (Cheirmadurai *et al*, 2014).

5.2.2. Synthesis of CuNPs by using *Ginkgo biloba L.*

The copper nanoparticles were also reported to be prepared by using Ginkgo biloba L. leaf extract. Ginkgo biloba Linn is found mostly in Himalayan mountains and belongs to world's oldest tree family used mainly for herbal medicines. They are also considered living fossils. Under surfactant free conditions, they were made as reducing and stabilizing agents. The formation of copper nanoparticles was observed with the help of UV-Visible absorption spectra, TEM, EDS and the results indicated that the copper nanoparticles were quite stable even after a month. This significantly indicated the stability of copper nanoparticles. They proved to have high catalytic activity for Huisgen [3+2] due to high metal surface area as compared to azides and alkynes at room temperature. Without any loss of catalytic activity, they can be re-used and recovered. The results of TEM showed that they ranged from 15-20 nm in size. This technique showed high efficiency and yield, CuNPs could be made easily without toxic agents and have high tolerance for wide range of pollutants (Nasrollahzadeh *et al*, 2015).

5.2.3. Synthesis of CuNPs by using *Azadiarachta indica*.

Copper nanoparticles can be synthesized by using leaf broth of *Azadiarachta indica*. Under the optimum condition of leaf broth 20 %, temperature 85 degree centigrade and pH 6.6, the copper ions were reduced into copper nanoparticles by the plant biomolecules that acted as the stabilizing and reducing agents. During the synthesis, the UV-Visible spectra was used to monitor the formation of the copper nanoparticles. The characterization of copper nanoparticles formed showed that they were highly stable, cubical, crystalline with the average size of 48 nanometers that are stable for 2 months at 4 degree centigrade due to high zeta potential. The technique was easy, novel, cost effective and does not involve any toxic or harmful chemicals (Nagar *et al*, 2018).

5.2.4. Synthesis of CuNPs by using *Plantago asiatica*.

The synthesis of copper nanoparticles by the *Plantago asiatica* leaf extract is also included in the methods of green synthesis of nanoparticles. This method proved to be a simple, easy and ecofriendly method for the preparation of copper nanoparticles. Without using any stabilizer of reducing agent, the extracts of *Plantago asiatica* leaf reduced the copper ions into Cu (0) within 5 minutes of reaction. The results indicated that the copper nanoparticles were highly stable and pure, with higher yield, non-toxic with short react ion time (Nasrollahzadeh *et al*, 2017).

5.2.5. Synthesis of CuNPs by using *Magnolia Kobus* leaf.

The Magnolia Kobus leaf extracts were also used for the green synthesis of copper nanoparticles. The stable copper nanoparticles were produced by using CuSO4·5H2O and *Magnolia Kobus* leaf extract. The copper nanoparticles characterized by using ICP, EDS, XPS, HR-TEM indicated that the size ranged from 37-110 nanometers. The anti-bacterial efficiency of copper nanoparticles analyzed by counting viable E. coli after 24 hours indicated that the untreated foams with biologically synthesized copper nanoparticles have higher antibacterial activity as compared to the treated foams with chemically synthesized copper nanoparticles (Lee *et al*, 2013).

Table 2: Synthesis of CuNPs from Various biological species

Sr. No.	Species	Size	Reference No.
Fungi			
1.	*Stereum hirsutum* (white-rot fungus)	5-20nm	13
2.	Penicillium citrinum	91-225nm	14
3.	Penicillium waksmanii	80-179nm	14
4.	Penicillium aurantiogriseum	91-102nm	14
Bacteria			
5.	*Pseudomonas Fluorescence*	20-80nm	15
Plant leaf Extract			
6.	*Syzygium aromaticum* (Cloves)	5-40nm	16
7.	Lawsonia *inermis* (Henna)	22-38nm	21
8.	*Ginkgo biloba Linn*	15-20nm	22
9.	*Azadirachta indica*	48nm	23
10.	*Plantago asiatica*	7-35nm	24
11.	*Magnolia Kobus*	37-110nm	25

Table 2 represents summary of synthesis of copper nanoparticles from various biological species mentioned in this paper.

6. Applications:

CuNPs have wide range of applications due to their physiochemical properties such as small size, magnetism, light absorption, heat transfer and high melting point. They may be used as antimicrobial and anti-infective agents, fuel additives for diesel engine, biosensors and in heat transfer systems, catalysts and high strength materials (Xuan *et al,* 2000; Dankovich *et al,* 2014).

6.1.Copper Nanoparticles for the treatment and Purification of Water

Copper and copper compounds have been demonstrated to eliminate a wide variety of microorganisms, including Vibrio cholerae, Shigella, E. coli, Salmonella, fungi, viruses, and other types. In hospitals, the metallic copper surfaces are used for the prevention of bacterial growth. The antimicrobial and the catalytic activity of copper nanoparticles can be enhanced by incorporating the fibrous material into it that also act as a long-lasting reservoirs of copper ions. The applications of copper nanoparticles to cellulosic materials have also been demonstrated by many researchers. However, Copper nanoparticle membranes can also be used as antibacterial drinking water purifiers (Mousa *et al*, 2015).

6.1.1. Removal Efficiency of Pollutants by Bioflocculant (CuNP):

The phosphorus and Sulphur in coal mine water have been removed by using CuNPs. Dlamini *et al.* conducted a study whose results showed that chemical flocculants can be replaced by copper nanoparticles. They are more environmentally friendly and have degradability than other chemical flocculants. The high concentration of P and S in wastewater do not support aquatic life and result in algal bloom and eutrophication that destroys the water quality therefore their removal is necessary. The CuNPs showed the ability to remove COD by 93% and BOD by 96% from wastewater that is more than removal efficiency of polyamine flocculant that removed 89% of COD from dye water (Dlamini *et al*, 2019).

Table 3: Pollutant removal efficiency of CuNPs for different types of wastewater (Dlamini *et al*, 2019)

Flocculant	Types of Wastewater	Types of Pollutants in Water	Water Quality before Treatment (mg/L)	Water Quality after Treatment (mg/L)	Removal Efficiency (%)
CuNPs	Coal mine water	Phosphate	2.00	0.3	85
		Sulphate	0.55	0.13	76
		Chemical oxygen demand (COD)	154	11.2	93
		Biochemical oxygen demand (BOD)	123.2	5.0	96
	Domestic wastewater	Phosphate	7.6	1.5	80
		Total nitrogen	155	17.0	89
		Nitrate	20.6	7.7	63
		Aluminum	0.86	0.33	62
		Sulphate	1.7	0.61	64
		Chemical oxygen demand (COD)	2.313	0.654	72
		Biochemical oxygen demand (BOD)	123.2	4.123	96
	Mzingazi River water	Phosphate	85.7	7.521	92
		Total nitrogen	0.223	0.108	52
		Chemical oxygen demand (COD)	3.300	0.278	92
		Biochemical oxygen demand (BOD)	133	15.0	89

6.1.2. Antibacterial and Antifungal Activity:

The wastewater from industries and households contain a lot of microorganism that are hazardous for the health of human beings, organisms and environment if the wastewater is poorly managed and discharged without treatment. When the microorganisms from wastewater enter the surroundings and human bodies, they may cause serious illness. Therefore, their removal is necessary from the wastewater before its final disposal and reuse (Korzeniewska *et al*, 2011; Ramyadevi *et al*, 2012).

The removal efficiency of biosynthesized copper oxide nanoparticles towards bacterial species of K. pneumoniae, P. aeruginosa, Shigella Salmonella paratyphi s. showed high antibacterial activity as compared to the efficiency showed by chemically prepared copper nanoparticles. The copper nanoparticles by using Magnolia Kobus leaf extracts for the green synthesis ranged from 37-110 nanometers. The anti-bacterial efficiency of copper nanoparticles analyzed by counting viable E. coli after 24 hours indicated that the untreated foams with biologically synthesized copper nanoparticles have higher antibacterial activity as compared to the treated foams with chemically synthesized copper nanoparticles (Siddiqi *et al*, 2016; Lee *et al*, 2013).

The study of Ramyadevi et al. showed the antifungal activity of copper nanoparticles against three fungal strains and antimicrobial activity of copper nanoparticles against five bacterial strains. The human gram-negative pathogenic bacteria of *Micrococcus luteus, Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae,* and *Pseudomonas aeruginosa* showed growth inhibition after using copper nanoparticles. The fungal culture including *Aspergillus flavus*, *Aspergillus niger* and *Candida albicans* also showed similar results. Positive test results were scored when a zone of inhibition was observed around the well after the incubation period (Ramyadevi *et al*, 2012).

The antimicrobial activity of Cu NPs against Micrococcus luteus. S. aureus K. pneumoniae, p. aeruginosa, E. coli and fugus like Aspergillus flavus, Aspergillus niger and Candida albicans showed more inhibitory activity in five bacterial strains than in fungus. Cu NPs showed more zone of inhibition in E.coli (26 mm) than in C. albacians (23 mm) (Ramyadevi *et al*, 2012).

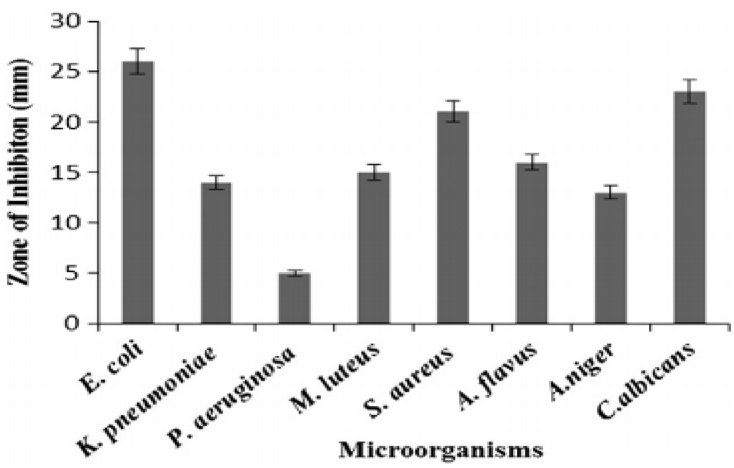

Figure 3: Inhibition activity of CuNPs against microorganisms in wastewater (Ramyadevi *et al*, 2012)

The use of Copper Nanoparticles for antibacterial activity was also reported by Biswas *et. al.* as they concluded that copper nanoparticles are cheaper and have better antibacterial activity as compared to silver nanoparticles. The disinfection of water from E. coli using copper acetate nanoparticles showed zero cell count after 10 minutes of experiment. Where the silver acetate nanoparticles showed 23 minutes of time required for zero cell mount for the E. coli. The copper nanoparticles along with activated carbon were also reported to be used for removal of pollution from the water. This Biswas *et. al* showed great removal of pollutants specially nitrates from the water by using copper with activated carbon. The results indicated that the carbon impregnated with 1.5 % copper-24 hours proved to be having similar efficiency as compared to pure carbon for organic removal. It also increased the nitrate removal efficiency (Biswas *et al*, 2017).

The copper nanoparticles have demonstrated better antimicrobial activity towards B. subtilis than E.coli and S. aureus strains. The study of Ruparelia et al. revealed that copper nanoparticles have greater affinity to surface active groups of B. subtilis, which may have led to its greater bactericidal effect.. Combination of silver and copper nanoparticles may give rise to more complete bactericidal effect against mixed bacterial population (Ruparelia, *et al*, 2008).

The copper coated Nano fibrillated cellulose are also been used for the treatment of water. Szekeres *et. al* reported that the use of such filters for the purification of water by providing virus retention of at least 5 magnitude (5 log) and help improving the efficiency of filtration process even at three different pH (5.0, 7.5, 9) (Szekeres *et al*, 2018).

6.1.3. Removal of dyes

Organic dyes are one of the major environmental contaminants released by the industries into the water streams. They not only have chemical and visual impact but may also interfere with biological process by altering photosynthesis process. Usually 10-200 mg per litre concentration of dyes is present in wastewater (Ashrafi *et al*, 2017).

CuNPs are strong adsorbing agents therefore they are used for the removal of dyes from wastewater. Copper NPs having a size range of 2µm-5µm were synthesized from *Centella asiatica* (L.) extract. These nanoparticles acted as a catalyst to remove methyl orange dye from water by photocatalytic degradation (Devi *et al*, 2014).

The biosynthesized copper nanoparticles used for the treatment of textile wastewater showed removal efficiency for methylene blue (91.53%), Congo Red (84.89%) and methyl red (73.89%). Under optimum conditions and presence of L-absorbic acid as a reducing agent these nanoparticles give high removal efficiency for the dye removal (Fathima *et al*, 2018).

The copper nanoparticles synthesized by using native bacterial strain Escherichia sp. SINT7 were stable with the size ranging from 22.39–39 nm. They showed great efficiency for azo dye removal from textile wastewater. The efficiencies for removal for Congo red, malachite green, direct blue, reactive black-5 at a dye concentration of 25mg/l after 5-hours of exposure were 97%, 90.55%, 88.42%, 83.61% respectively. The degradation percentage for 100 mg/l of dye for same order are 83.90%, 31.08%, 62.3% and 76.8% respectively (Noman *et al,* 2020).

6.1.4. Removal of Heavy Metals from Wastewater

6.1.4.1. Removal of Chromium:

The copper (II) oxide nanoparticles are used for the removal of chromium from tannery wastewater.. Gupta *et. al.* reported that the average size of 8nm CuO nanoparticles were most effective for the removal of Cr (IV). These CuO are crystalline in nature and exhibit monoclinic phase. The batch adsorption method was used to optimize the influential parameters such as pH, dose, contact time, temperature and initial Cr (IV) ion concentration. The results reported that the CuO nanoparticles were effective non-adsorbent for the removal of Cr (IV) ions from the wastewater. Where the optimized condition for this reaction were pH of 3, Cr (IV) concentration of 20 mg/L and adsorbent dose of 1.6 g/L (Gupta *et al,* 2016).

6.1.4.2. Removal of Lead:

The CuO nanoparticles are also effective for the removal of Pb (II) as reported by Kumar *et. al.* The results indicated that the absorption of lead onto CuO nanoparticles does not follow pseudo-first order kinetics. It proved to be an endothermic process and occurred spontaneous in nature. This also proved to have a promising future of CuO nanoparticles for the removal of lead from the wastewater as it works as an excellent adsorbent (Kumar *et al,* 2014).

7. Conclusion:

Cu NPs have excellent physiochemical properties such as small size, high surface to volume ratio, high melting point, eco-friendliness and cost effectiveness that makes them appropriate for a variety of applications. Green synthesis is efficient, economical and friendly environmental technique for production of nanoparticles especially copper nanoparticles that have shown immense beneficial properties during recent years. Cu NPs exhibit excellent antimicrobial, antifungal and anti-infectant properties that increases their scope in medical field. Moreover, they also have the tendency to be used for water treatment due to their low toxicity and cost effectiveness. Nanoparticle production can be improved by understanding biochemical pathways involved in metal accumulation, detoxification and resistance of plants. The future approach for increased nanoparticle production is utilization of plants in this field by genetically modifying them into species having improved accumulation capacities and metal tolerance.

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