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“Biosynthesis and Characterization of silver nanoparticles as sustainable materials for remediation of contaminated water samples”

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ABSTRACT:
New challenges await the current and the forthcoming generations, with the water bodies deteriorating beyond repair and potable water becoming a bare necessity to an expensive entity. In this publication, we lay focus on our contribution to this ever-growing problem through novel engineered nano-sized sustainable materials—the remediation of contaminated water samples through crosslinking and degradation of various dyestuffs taken in different concentrations. The results justify our choice of materials for remediation and their efficacy.

Keywords: Nano-sized, Remediation, Dyestuffs, Potable Water, Contamination, Nanoparticles.

I. INTRODUCTION:

Water, called the elixir of life, is an essential source for all living beings and a vital part of our natural resources [1]. Water is critical in maintaining various biological processes, both directly and indirectly. However, water has been significantly impacted by anthropogenic activities, such as urbanisation, agricultural practices, and industrialisation, leading to alterations in water quantity and quality alterations within ecosystems and adversely affecting the environment [2].

The scarcity of safe drinking water and sanitation is a significant global challenge. According to the World Health Organization (WHO), approximately 1.1 billion people lack access to safe drinking water. In comparison, a staggering 2.4 billion people lack proper sanitation facilities, translating to about one-sixth of the world's population facing freshwater unavailability [3]. This scarcity results from various factors, including contamination caused by geological and anthropogenic activities.

Water contamination has become a pressing global issue, with contaminants originating from both natural and human activities. While water contaminants are difficult to destroy biologically, they can be transformed from highly toxic forms to less harmful ones [4]. The primary causes of water pollution include crude oil contamination, waste oils, urbanisation, domestic sewage, population growth, heavy metals, plastics, polythene, chemical industry waste, radioactive waste, global warming, atmospheric depositing, toxic waste disposal, industrial waste, municipal waste, animal wastes, and excessive pesticide applications in agriculture [5, 6]. Furthermore, using chemicals in food preservation, mineral processing, and agricultural practices contributes to the contamination of water resources and renders water toxic and unsuitable for irrigation [7].

The contamination of water sources is a significant problem worldwide, leading to serious health issues and waterborne diseases [8, 9]. Heavy metals, such as cadmium, chromium, arsenic, magnesium, silver, copper, lead, and nickel, pose significant risks to human health [10]. Lead exposure can cause high blood pressure, kidney damage, and neurologicaldisorders [11]**.** Long-term exposure to cadmium increases the riskof cancers, such as prostate and lung cancers [12]. Ingestion of high levelsof chromium can increase the risk of developing various types of cancers, including lung,nasal, and sinus [13].Excessive exposure to manganese has beenassociated with neurological disorders, including Parkinson’s disease-like symptoms such astremors, difficulty with movement and coordination, and cognitive impairments [14].

Various approaches, including traditional and modern methods, address these issues and remove water contaminants. Natural processes, such as leaching, hydrolysis, precipitation, oxidation, and reduction, occurring on the Earth's crust contribute to the natural treatment of contaminated water [15]. However, providing safe water to all remains a challenging task. Currently, several technologies are available for the systematic and organised removal ofheavy metals from wastewater. Some of them are ion exchange, chemical precipitation,reverse osmosis, etc [16].

Water contaminants and their detrimental effects can be categorised into several categories, including inorganic contaminants (naturally occurring or from industrial and domestic discharges, oil and gas production, mining, or farming), organic contaminants (pesticides, household waste, volatile organic compounds), radioactive contaminants (naturally occurring or resulting from oil and gas production and mining activities), microbial contaminants (viruses and bacteria from sewage treatment plants, septic systems, agricultural livestock operations, and wildlife), and pesticides and herbicides (resulting from various sources such as agriculture, urban stormwater runoff, and residential uses).

Given the significance of preserving this precious resource, treating contaminated water sources and protecting existing ones is crucial. Water treatment processes should aim to minimisethe introduction toxic and harmful chemicals into water bodies. Developing nanotechnology, biotechnology (genetic engineering), ecological engineering, renewable energy, improved sanitation, wastewater treatment technologies, recycling, groundwater resource mapping, and sustainable extraction practices can address these challenges [17].

Industries should also focus on developing chemicals with minimal environmental degradation, as the mixture of heavy metals and organic compounds contributes to water contamination and its subsequent toxic effects on health. Adsorption is one of the most effective processes in wastewater treatment technologies, with activated carbon being the most widely used adsorbent [18]. Additionally, decentralised wastewater treatment systems should be preferred over high-cost centralised systems to reuse water and nutrients locally [19].

Several techniques, such as thermal treatment, pump-and-treat, chemical oxidation, and nano remediation, have been developed for remediation purposes. Nanotechnology, particularly nano remediation, has emerged as a promising and sustainable technology for environmental contamination. Nanomaterials possess unique properties, including nano size, large surface area, high reactivity, and strong solution mobility, making them effective in treating contaminated water [20]. Advanced developments in nanomaterials, such as nanophotocatalysts, nanomotors, nanomembranes, and nanosorbents, hold the potential for treating contaminated water [21].

Nanotechnology is referred to as the term for fabrication, characterisation, manipulation and application of structure by controlling shape and size at the nanoscale. Nanoparticles, characterised by their small size, exhibit distinct properties and behaviour compared to their bulk counterparts. They offer remarkable optical, physical, and chemical capabilities due to their ability to retain electrons and create quantum effects. However, the environmental fate, transport, and toxicity of nanomaterials still require further research [22]. The synthesis and utilisation of nanoparticles in the treatment of contaminated water provide efficient and cost-effective remediation solutions. Nanotechnology offers an eco-friendly approach, allowing for the mitigation of pollutants such as chlorinated solvents, pesticides, and heavy metals [23].

Addressing water contamination and pollution is of utmost importance to ensure the availability of safe water resources. Using eco-friendly techniques, such as nano remediation, holds promise in treating water contaminants effectively and efficiently. Continued research and development in this field are necessary to overcome the challenges associated with water pollution and preserve this invaluable resource for future generations.

II. MATERIALS AND METHODOLOGY:

Purified sodium hydroxide pellets, silver nitrate, methylene blue, rhodamine B, and chromium nitrate, all of which were of AR grade and required no further purification. The fresh wheatgrass leaves were washed using distilled water for several times to remove the dust particles and shade dried for four-five days. The dried wheatgrass material was ground and sieved to form a powder.

UV–Vis spectra of silver nanoparticles (AgNPs) in cross-linked wheatgrass in alginate solution were acquired using ElicoUV–Vis spectrophotometer operating in the transmission mode. A solution containing cross-linked wheatgrass in sodium alginate was used as a blank. Fourier Transform Infrared Spectroscopy (FTIR) was recorded on a spectrometer by the KBr tablet method, and the spectra were scanned in the range of 400-4000 cm^{-1} at a resolution of 4 cm^{-1}

Deionized water was employed to prepare all solutions, while all glassware was meticulously cleaned and oven-dried before use. Instruments utilized during the experiments included a UV-Visible Elico spectrophotometer, a microwave, and a magnetic stirrer equipped with magnetic beads for efficient mixing.

Synthesis of Silver Nanoparticles

30 g of powdered wheatgrass leaves were taken and boiled in 300 mL distilled water for five minutes and filtered. Post centrifugation for 15 minutes, the supernatant was collected and stored at 4^0C. 1.5 g of sodium alginate was dissolved in 100 mL distilled water using a heating magnetic stirrer after complete dissolution, the pH of the solution was adjusted to 10. Equal volumes of silver nitrate (3 mM), sodium alginate, and wheatgrasswere stirred for three hours using magnetic stirring. The constituents were microwaved for two cycles of thirty seconds each. The reduction of Ag(+1) to elemental silver caused the colour change from colourless to brown upon microwave heating. After a span of 24 hours incubation period, silver nanoparticles were observed collected at the bottom of the beaker.

III. RESULT AND DISCUSSION

Mechanistic details for forming silver nanoparticles and related results:

The nanomaterials employed were engineered using simple laboratory heating and microwave induction techniques. Nanoparticles that have a size scale in the range of 1 to 100 nm show various unique characteristics that are not seen in their bulk forms. The importance of nanoparticles in any field is attributed to the high surface area available for chemical reactivity, which is absent in bulk [24]. The wheatgrass extract and Sodium alginate was used to perform a dual role: as a reducing agent and as a stabilising agent during/after the formation of Metal NPs. The dried residue was then collected and tested for potency. Using a UV-visible spectrophotometer, it was tested based on the absorbance spectrum observed after the reaction with the dyestuffs and chromium nitrate. A diluted, well-dispersed solution in distilled water was used for the absorption study at each step of the nanomaterial engineering process. A change in optical absorbance was observed at each step of the procedure.

These metal cluster surfaces are likely to be anchored through a strong association between the Metal NPs surface and the "O" atom of the functional groups ($–COO^-$ and –OH) of cross-linked wheat grass and sodium alginate. The overall product after the synthetic procedure is presented in **Fig. 1**.

Fig. 1: AgNp (After Microwave)

Characterisation by FTIR for the formation of silver nanoparticles

Spectroscopic analysis of synthesised silver nanoparticles was carried out at varied time intervals within the range of 300 -700 nm. The maximum absorbance was observed at 417 nm. **Fig. 2** shows the FTIR spectra of Wheat-sodium alginate-Ag NPs. In the case of sodium alginate, the peaks centeredat around 3435 cm^{-1} can be attributed to the stretching vibration of the hydroxyl group; the strong height noted at 1609 cm^{-1} is due to the stretching vibration of CO_2^- (carboxylate ion) group; the band at around 1414 cm^{-1} is ascribed to the hydroxyl group deformation vibration; the absorption band at 1083 cm^{-1}corresponds to C–O–C stretching mode from the glycosidic units. In the case of Wheat- sodium alginate-AgNPs, the band of CO_2 is shifted to 1585 cm^{-1} and the peaks of 3435 and 1414 cm^{-1} shift to 3300 and 1400 cm^{-1} indicating that carboxyl groups and the hydroxyl group are involved in the synthesis and stabilization of NPs. The variations of the hydroxyl and carboxylate groups have been reported in the previous study on the synthesis of AgNPs with another polysaccharide.

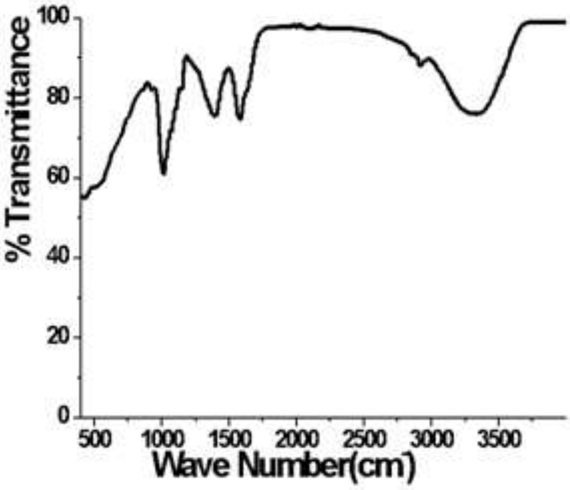

Fig. 2: FTIR Analysis of the Synthesized Nanoparticles

UV-Vis spectroscopic results for synthesized nanoparticles:

UV-Vis spectroscopy is a simple and sensitive technique for the characterization of Ag NPs due to the excitation of surface plasmon resonance (SPR) in the AgNPs. The general trend is that the SPR absorption band shows a red shift with increasing particle size. After microwave irradiation, the sodium alginate and wheat grass solutions containing silver nitrate changed from colourless to brown; the appearance of brown color in the reaction mixtures supports the formation of AgNPs.

The spectra exhibita unique SPR absorption band at approximately 417 nm for Silver NPs, which is associated with the formation of nanoparticles. The increase in SPR band intensity could be attributed to forming more nanoparticles. The possible reason is that the increased number of carboxyl groups and hydroxyl groups facilitates the complexation of metal ions to the molecular matrix. Meanwhile, more hydroxyl groups benefit the reduction of metal ions.

Fig. 3: Uv-Vis spectra of AgNP using cross-linked wheat extract and sodium alginate

Degradation of different dyes and Chromium salt using silver nanoparticles (AgNP):

Choice of silver nanoparticles over rest of metal Nanoparticle is that Silver is one of the most commonly preferred bactericides in fouling reduction. Membranes infused with silver nanoparticles have been reported to be highly effective against two bacterial strains, Waze, P. Mendocino KR1 and E. coli K 12, which are generally present in wastewater. We have studied the reactivity of synthesisedAgNP using the greener approach with the prepared solutions Methylene blue, Rhodamine, and chromium nitrate (2 mM). The difference in absorbance of pure and treated samples over 250-700 nm was visualised using a UV-visible spectrophotometer (Fig.4, 5, 6).

The shift in the absorbance spectrum of the dyestuffs (methylene blue, rhodamine-b) and chromium nitrate solution (**Fig. 4, 5, 6**) after reaction with the prepared AgNP shows that the prepared nanomaterial is efficient in arresting the activity of the heavy metals in the solution mixture, thereby degrading the concerned dyestuffs and chromium nitrate solution. The same AgNP can be used to treat contaminated water samples containing heavy metals, called nano remediation.

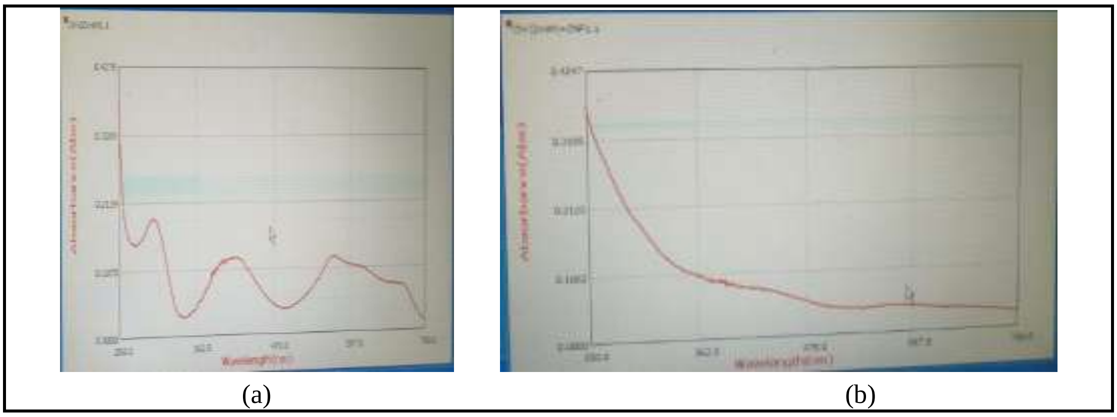
(a) (b)

Fig.4: UV-Vis spectra of (a) Pure chromium nitrate solution, 2 mM

Degradation of chromium nitrate solution 2 mM by AgNP
(b) Degradation of CR (2 mM) by CF

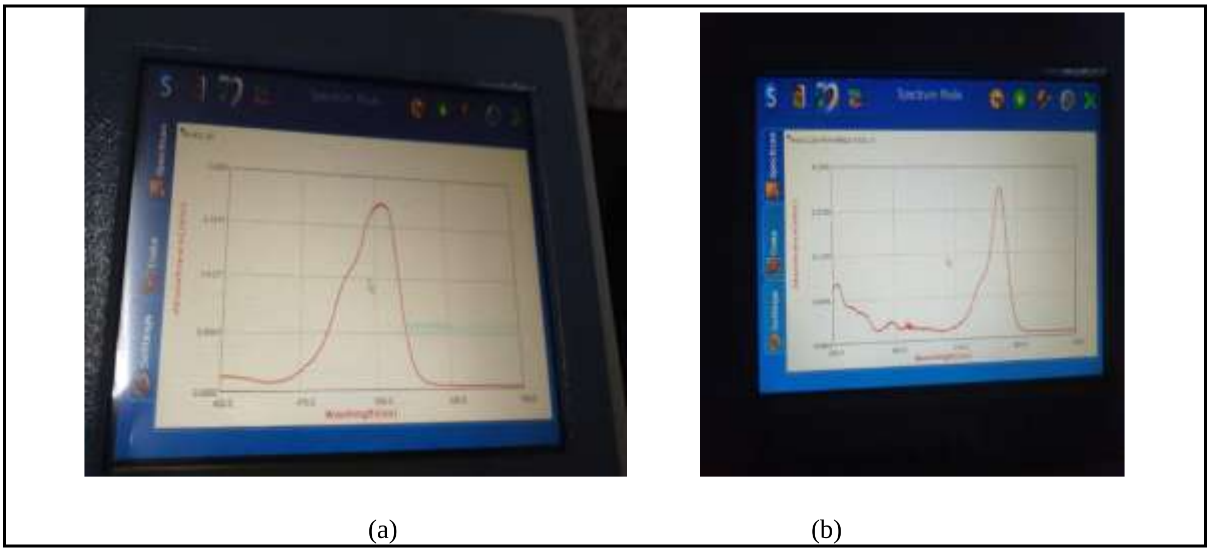
(a) (b)

Fig. 5: UV-Vis spectra of (a) Pure rhodamine dye solution, 2 mM
(b) Degradation of rhodamine dye solution 2 mM by AgNP

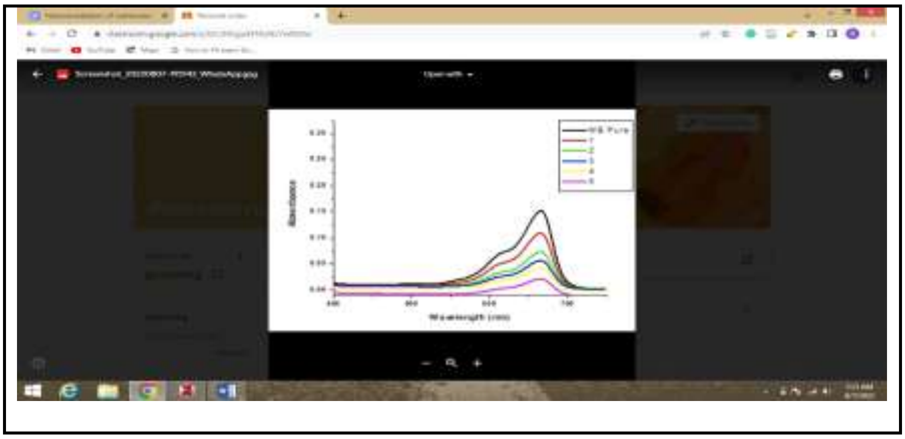

Fig. 6: UV-Vis spectra of (a) Pure methylene blue dye solution, 2 mM
(b) Degradation of methylene blue dye solution 2 mM by AgNP at different time intervals

Silver nanoparticles exhibit new optical properties, which are not observed neither in molecules nor in bulk metals [25]. The use of such cost-effective and sustainable nanomaterials ensures the degradability of heavy metals present in contaminated water, thereby providing a facile solution to a challenging problem like wastewater remediation.

IV. CONCLUSION

Nano remediation is an innovative approach to solving the issues around the availability of potable water around the globe effectively and cost-efficiently. Out of all the structurally engineered nanomaterials, ‘silver nitrate infused with wheatgrass crossed with sodium alginate’ proved to be the most efficient in degrading the heavy metal component of the dyestuffs (Methylene Blue, Rhodamine B) and Chromium Nitrate solution under observation at varied concentrations. The nanoparticles synthesised from silver nitrate, sodium alginate, and wheatgrass, employing microwave radiation, were employed to degrade sequentially diluted dyestuffs like methylene blue, rhodamine B and chromium nitrate and were analysedspectrophotometrically. The basic degradation of dyestuff in various concentrations presents a promising primary premise for the remediation process.

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