Research Article

Removal of contaminant in electroplating wastewater and its toxic effect using biosynthesized silver nanoparticles

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Abstract
This research is designed to remove contaminant in electroplating wastewater, using biosynthesize silver nanoparticles (SNPs) and to determine its in-vivo toxic effect. Silver nanoparticles (SNPs: 1,2,3 and 4) synthesized at different conditions and characterised, yielded spherical shapes of irregular sizes comprising of – OH, – C=C, – C=O, – C–H and – NO functional groups. The electroplating wastewater treated with the synthesized SNPs, were subjected to physicochemical analysis which revealed the ability of the SNPs to remove pollutants, with SNP4 displaying a higher affinity. The haematological investigation disclosed no significant impact on haemoglobin, packed cell volume, mean corpuscular haemoglobin concentration, red blood cell, neutrophils and lymphocytes compared to the control group. Although, the liver tissues revealed toxic effects of the treated wastewater. The study validates that the biosynthesized SNPs contained stabilizing and reducing agent and also has the ability to eliminate pollutant in electroplating wastewater.

Article highlights

- Spherical shaped SNPs exhibits loosely bound properties and aggregation.
- SNPs contained functional groups acting as stabilizing and reducing agent.
- The SNPs treated wastewater had no significant impact on haemoglobin, packed cell volume and red blood cell in rats.
- The synthesized SNPs had the ability to remove contaminant from the electroplating wastewater.

Keywords Green synthesis · Wastewater treatment · Silver nanoparticles · Heamatology · Histopathology · Electroplating wastewater

1 Introduction

Water is undeniably essential for the sustenance of life. Global population growth and extended drought, engenders difficulties in accessing clean water [1]. Electroplating industries are significantly involved in generating liquid waste. In fact, these wastes are concentrated with intolerable levels of heavy metal ions and organic molecules discharged into water bodies without adequate treatment and provoking global concern. These effluents maybe consumed by unsuspecting persons leading to serious health complications and possibly loss of lives [2, 3]. The deposition of contaminants into water bodies are dependent on the kind of technological processes involved [4]. The over-exposure of

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living system to metals and organic compounds discharged from industrial effluents have been reported to exhibit neurological, dermatitis impairment, delay in the physical, also mental development of children [5, 6]. This pollution, has equally been attributed to the death of over 500 children in Zamfara state of Nigeria [7, 8]. The field of Nanotechnology offers the application of metals, metal oxides and polymers at nano sizes in various field, due to their attractive roles to sorb and bind with different types of surfaces and contaminants in wastewater [9, 10]. Amongst all the nanoparticles, silver nanoparticles are at the pull of research because of their novel physical and chemical characteristics contrasted with their large scaled peers [11]. SNPs ingested, inhaled or injected have beneficial or detrimental effect on body organs. They are transported through the blood into tissues where they interact exclusively in the cells without altering their physical and chemical properties [12]. In fact, exposures to SNPs may lead to toxicological effects which can be evaluated through haematology or histopathology. Animals exposed to SNPs have been reported to exhibit injuries to the liver, kidney lungs and reproductive organs [13, 14]. SNPs display wide range of bactericidal and fungicidal activities that has made them prominent in different scope such as plastics, cleansers, glues, nourishment etc. [15–17].

Piliostigma thonningii is a leguminous plant that belong to the Caesalpinioideae family. This plant is well known for its medicinal uses in many African countries which includes anti-inflammatory, anti-bacterial and antipyretic activities [18]. Shittu and Ihebunna [19], reported the ability of biosynthesized silver nanoparticles from *P. thonningii* leaves employed in the purification of laboratory stimulated waste. The diverse nature of bioactive compounds found in plants makes them good bio-reducing and stabilizing agents in the synthesis of nanoparticles [20]. The cost and toxicity associated with chemical method has encouraged the use of biological method (plants, bacteria and algae) as some of the utilized resources in the synthesis of nanoparticle [21, 22]. Consequently, this study is aimed at investigating the ability of the synthesised silver nanoparticle to extract contaminant in electroplating waste water as well as its toxic effect on experimental rats.

Fig. 1 *Piliostigma thonningii*

In the next section, the research materials and methods are described (Sect. 2). Section 3 provides the results of the study, with accompanying figures and tables displayed. In addition, the discussions are presented with emphasis on the observations and possible interpretation. In Sect. 4, the conclusion, the importance of the research is reinstated and future work.

2 Materials and methods

2.1 Collection and preparation of *P. thonningii* leaves extract

Table 1 Levels of factors considered in the factorial experimental design for green synthesis

Factors	Conc. of $AgNO_3$ (ml)	Conc. of leaf extract (ml)	Temperature (°C)	pH	Time (min)
Upper	1.25	7.5	75	7.5	60
Lower	1	5	65	6.5	50

Fresh leaves of *P. thonningii* (Fig. 1) were collected from the military barracks Minna Nigeria, (9º 32′ 59.2″ N to 6º 34′ 02.5″ E). The plant leaf was identified at the Department of Plant Biology, Federal University of Technology Minna Nigeria, with the voucher number FUT/PLB/FAB/001. The leaves were rinsed with distilled water, and air dried at room temperature to prevent the destruction of thermo labile constituent of the plant by direct sun rays. The dried leaves were then milled into powder. The method Twenty-five (25 g) of the powdered leaves of *P. thonningii* was weighed and transferred into a 1000 ml conical flask containing 500 ml distilled water. It was mixed properly and boiled at 100 ºC for 25 min. The extract was filtered through a muslin cloth and Whatman filter paper No.1 [23]. The filtrate was used for further studies.

2.2 Biosynthesis and characterization of silver nanoparticles

For the biosynthesis of silver nanoparticles (SNP1, SNP2, SNP3 and SNP4), the experimental design in Table 1 was utilized. 5 ml of each extract concentration was measured into 4 different Erlenmeyer flask containing 95 ml of its equivalent concentration of aqueous 1.25 mM Ag NO_3. The solutions were heated at varying temperature, pH and

time. To improve the optimization and reproducibility of the synthesis, the central components Design of Experiments "one factor- at-a time" (Tables 1 and 2) was used in this research. The formed nanoparticles were collected and characterized using UV-1800 Shimadzu spectrophotometer within a wavelength range of 300 to 700 nm. Zetasizer 3000 (Malvern Instruments, UK) was used to determine the diameter of the SNPs by dynamic light scattering (DLS) at 450 nm. Transmission Electron Microscope (TEM) was used to assess the shape and size of the SNPs. The functional group of reducing agent was assessed by Fourier transform infrared spectroscopy (FTIR).

2.3 Wastewater collection

Wastewater was obtained from Electroplating section of scientific equipment development institute (SEDI) Minna, Niger state, Nigeria, (9° 33′ 4.4″ N, 6° 34′ 54.6″ E). The wastewater was diluted 10 ml to 1L of distilled water to make 1:100 dilution factor. One gram of the functionalized silver nanoparticles and polyethylene glycol (PEG) was added to 15 ml of the diluted wastewater and shake at 200 rpm for 60 min and then filtered with filter paper.

2.3.1 Wastewater analysis

The electroplating wastewater was analysed by the method described by American Public Health Association (APHA) [24]. Total dissolved solid (TDS), conductivity, dissolved oxygen (DO), pH, chloride, sulphate, total alkalinity, nitrate, nitrite, ammonium, cyanide, phosphate, calcium, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total bacteria count were determined.

2.4 Experimental animals

Twenty-four male and female albino rats weighing between (150–165) g were purchased from Ahmadu Bello University Zaria. The rats were bred in the animal house, department of biochemistry Federal University of Technology Minna and used for the experiment. The animals were housed in cages under twelve hours of dark/light cycle. They were allowed to acclimatize for 2 weeks at 26 ± 2°C room temperature with free access to feed and water ad libitum.

Table 2 Experimental design for biosynthesis of SNPs

Factors	Conc. of $AgNO_3$ (mM)	Conc. of leaf extract (ml)	Temperature (°C)	pH	Time (min)
SNP1	1.00	7.5	75	6.5	60
SNP2	1.00	7.5	65	7.0	60
SNP3	1.13	9.22	70	7.5	55
SNP4	1.00	7.5	65	6.5	50

2.4.1 Ethical statement

All the experiments were performed in strict accordance with standard guidelines internationally, and the ethical approval was obtained from the ethical committee of the Federal University of Technology Minna (000,022), for the care and use of laboratory animals.

2.4.2 Determination of LD_{50}

The lethal dose (LD_{50}) of the silver nanoparticles (SNP1, SNP2, SNP3 and SNP4), were determined by the method described by Lorke [25]. The following doses were administered orally to the experimental rats (3 per group) 100, 1000, 1600, 2900 and 5000 mg/kg body weight.

2.4.3 Determination of sub chronic toxicity

Twenty-four male and female albino rats were divided into 6 groups of four (4) rats each. The treatment groups are described below.

Group 1: served as the normal control group and received distilled water.
Group 2: served as the vehicle control group and received PEG in distilled water.
Group 3: received oral 300 mg/kg body weight of SNP1 treated wastewater.
Group 4: received oral 300 mg/kg body weight of SNP2 treated wastewater.
Group 5: received oral 300 mg/kg body weight of SNP3 treated wastewater.
Group 6: received oral 300 mg/kg body weight of SNP4 treated wastewater.

2.4.4 Blood and liver collection

On the 29th day, 24 h after the last administration, all the rats were fasted overnight and anesthetized by ether and sacrificed. Blood was collected from the left ventricle into heparinzed tubes for haematological evaluation. While, the liver organs were also collected and fixed in 10% formalin for histopathology study.

2.4.5 Haematological studies

Haemoglobin (Hb) count, packed cell volume (PCV), mean cell volume (MCV), Mean corpuscular haemoglobin (MCH), Mean corpuscular haemoglobin concentration (MCHC), red blood cells (RBC), platelet count (PLCx102), total white blood cells (TWBC), neutrophils, lymphocytes and eosinophils were determined using an automated haematologic analyzer (D&H 600 model).

2.4.6 Histopathological examination

The tissue sections for histological examination were prepared by standard embedding and hematoxylin and eosin stain (H–E staining) [26]. The photomicrographs were captured at 100 × and viewed to detect possible damages.

2.5 Statistical analysis

The analysis was carried out using statistical package for social sciences (SPSS) (version 21). The obtained data were subjected to one-way analysis of variance (ANOVA) to determine the level of significance. Data are expressed as mean ± standard error of mean and values different at $p < 0.05$ were considered significant.

3 Results and discussion

3.1 Biosynthesis and characterization of silver nanoparticles

In this study, the successful biosynthesis of SNPs using *P. thonningii* leaf extract was confirmed by the development of brown colour. The observed colour change proposed that the interactions of silver ions with *P. thonningii* leaf extract led to its reduction and formation of SNPs [27]. This explains the origin of the surface plasmon resonance absorption in the particles which was confirmed by UV–Vis absorption spectroscopy previously reported by Shittu and Ihebunna [19]. Some of the phytochemicals confirmed in *P. thonningii* leaf extract are flavonoids, phenols and terpenoids, which have been considered as likely bio-reducing and stabilizing agents for the synthesis of SNPs [19, 28].

3.1.1 Particle size of the synthesized silver nanoparticles

The biosynthesized silver nanoparticles sizes for various conditions are shown in Fig. 2. The conditions gave different particle size range of 59.64 to 114.20 dnm. Whereas, the most intense particle size is 114.20 dnm. Concentrations of metal salts, reaction time, solution temperature and reducing agent have been reported to influences the size of particle synthesized [29].

3.1.2 Transmission electron microscopy (TEM)

In this study, the shapes and sizes of the biosynthesized SNPs were analysed using TEM (Fig. 3). The micrographs displayed at 50 nm magnification suggests that all SNPs were spherical shaped. SNP1, SNP2 and SNP3 were smaller sized and showed properties of aggregation with the exception of SNP 4 which were of various sizes and loosely bound. The properties of nanoparticles depend on their size, shapes, interaction with stabilizers, surrounding media and preparation methods [30, 31].

3.1.3 Functional group composition of 200 biosynthesized silver nanoparticle

The FTIR spectra for SNP1, SNP2, SNP3 and SNP4 are shown in Fig. 4. They indicate the presences of different functional groups in *P. thonningii* leaf extract that act as stabilizing and reducing agent during the synthesis of SNPs. The FTIR spectra identified the major strong peaks at range 2882 to 2893 and 3457 to 3493 cm^{-1}; the minor peaks at range 1468 to 1480 and 1653 to1662 cm^{-1}. The peak at range 3457 to 3493 cm^{-1}corresponds to –O–H stretch which can be assigned to H-bonded –O–H stretch and hydroxyl groups. These peaks maybe attributed to presences of polyphenolic groups. In addition, the peaks at range 1468 to 1480 and 1653 to 1662 cm^{-1} indicates the

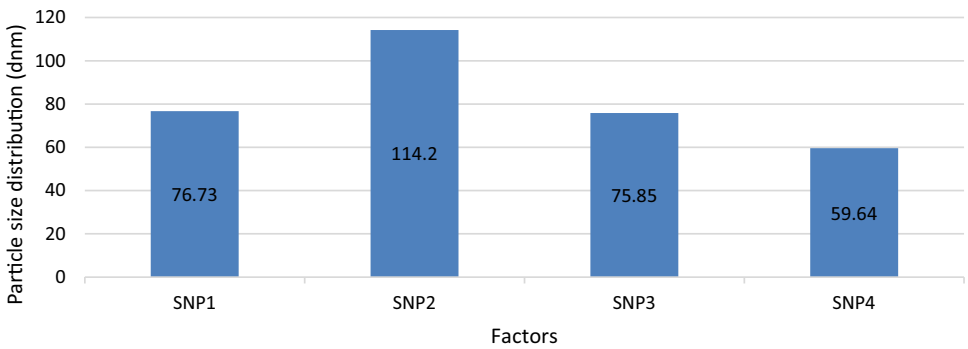

Fig. 2 Particle size diameter of the biosynthesized silver nanoparticle

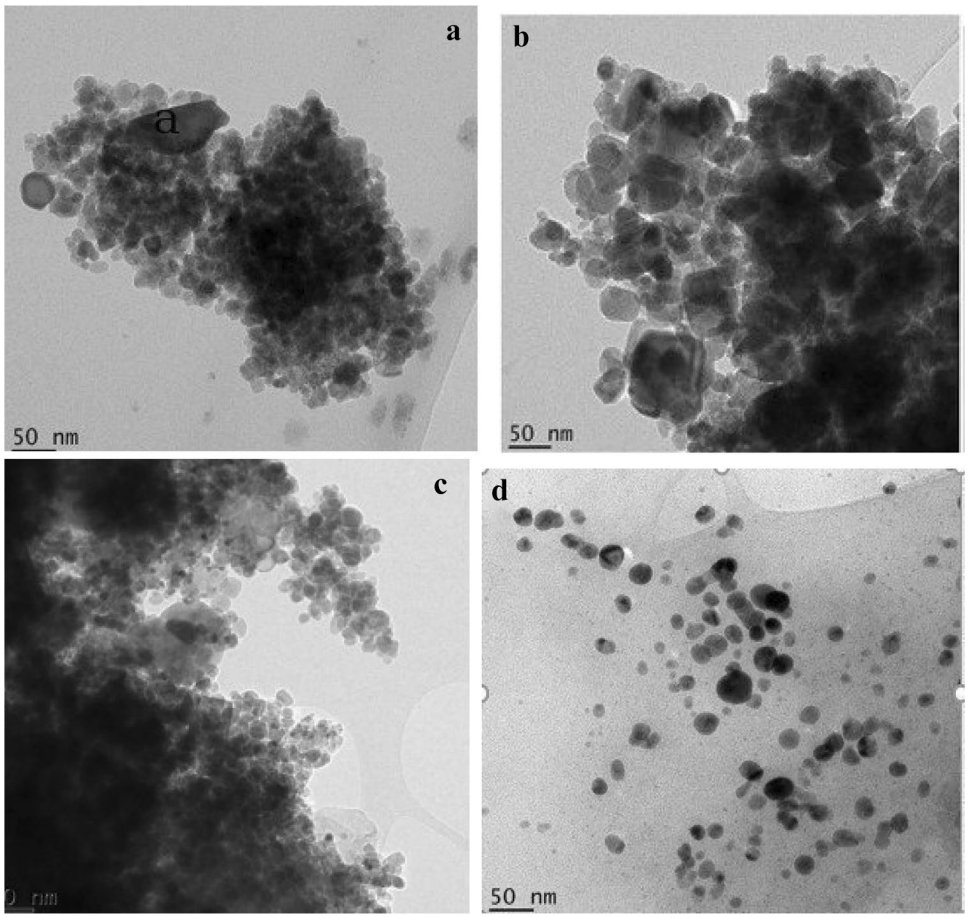

Fig. 3 TEM of bio-synthesized silver nanoparticle: **a** (SNP1); **b** (SNP2); **c** (SNP3); **d** (SNP4)

existence of –C=C or –C=O stretching vibration (alkenes) and –NO asymmetric stretch (nitro compounds). While the peak at 2882 to 2893 cm^{-1} may be attributed to the C-H alkane functional group. The FTIR results verified the participation of the plant phytochemicals (polyphenols, alkene, carboxyl) on the surface of the SNPs through the -OH, C-H, C-O functional groups [32].

3.2 Water analysis

3.2.1 Untreated and treated wastewater profile

Figure 5a and b shows the electroplating wastewater before and after treatment. The result of the water analysis serves as an indicator of water quality (Table 3). The SNPs showed high percentage removal of heavy metals from the electroplating wastewater. There was significant reduction in the total dissolved solid (TDS) concentration, increase in the pH range, dissolved oxygen and total alkalinity after the treatment with SNPs. TDS are the entire quantity of salts, minerals, charged ions or metals dissolved in a given volume of water, it is directly associated with quality of the purification systems [1]. The initial concentration for TDS in the wastewater was 191,500. However, the treatment of the wastewater with the SNPs effectiveness improved the cleansing with SNP4 having a significantly 95.91% reduction. The conductivity of water is dependent on its TDS, the concentration of dissolved ions in the water as the purer the water the weaker its conductivity [1]. This result explains the correlation between the TDS and conductivity result for SNP4. High concentration of chloride was observed in the untreated wastewater. When chlorine is introduced into the water, the quantity of electrolytes in the water upsurges and in turn raises the conductivity of the water which can be harmful to aquatic life [33].

pH is a chemical constituent of wastewater having a direct influence on toxicity and solubility of compounds and survival of marine organisms. During the wastewater treatment with SNPs, the pH increased from 0.83 to 5.98. This may possibly be as a result of the exposure and reactivity of the functional groups on the surface of the SNPs with the wastewater [34, 35]. Variations of pH can stimulate aggregation of particles by altering their surface charge properties and under acidic conditions, accumulation and sedimentation do not occur [36].

Low levels of dissolved oxygen present in water, is an indicator of pollution. It is one of the significant factors in determining water quality, contamination control,

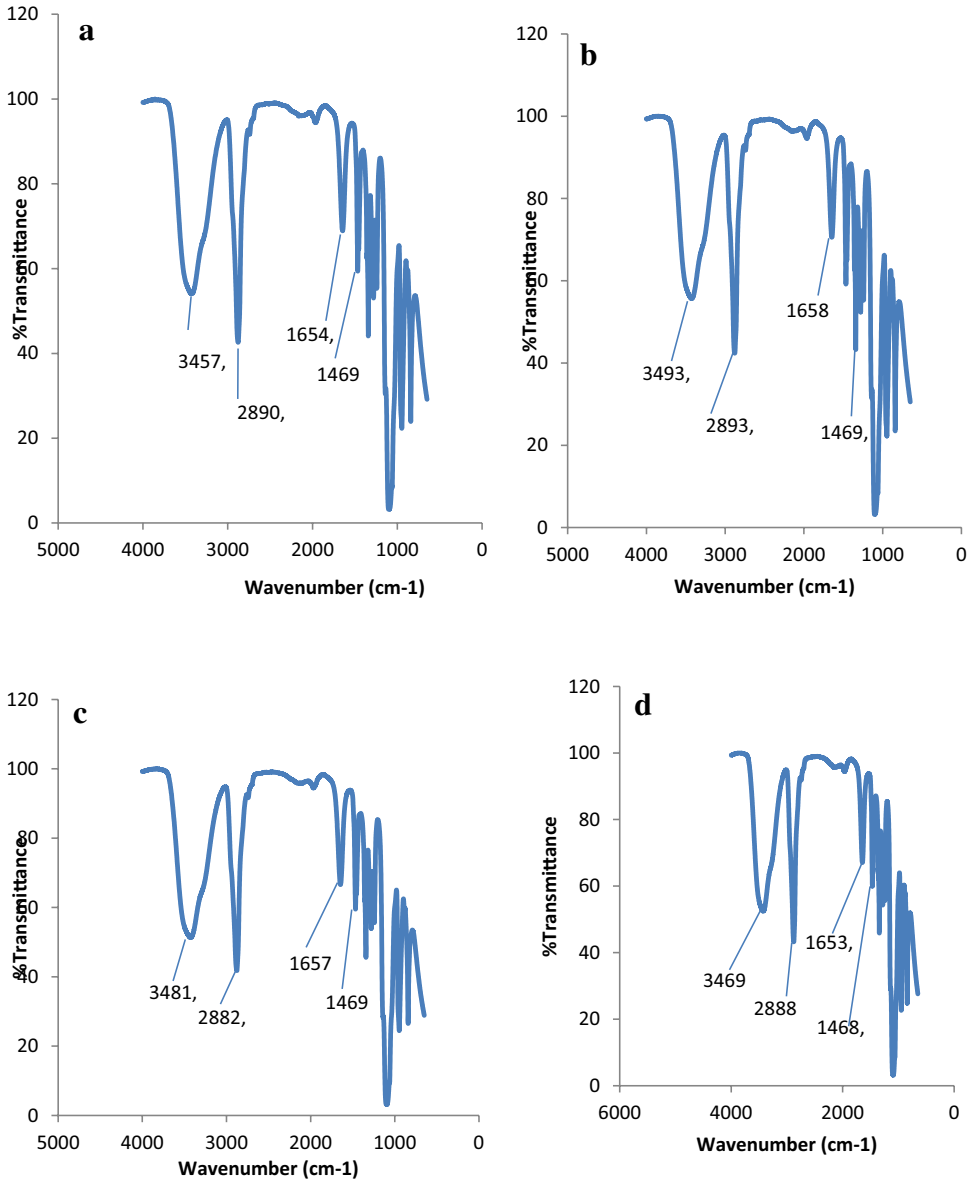

Fig. 4 FTIR spectral of biosynthesized **a** (SNP1); **b** (SNP2), **c** (SNP3); **d** (SNP4)

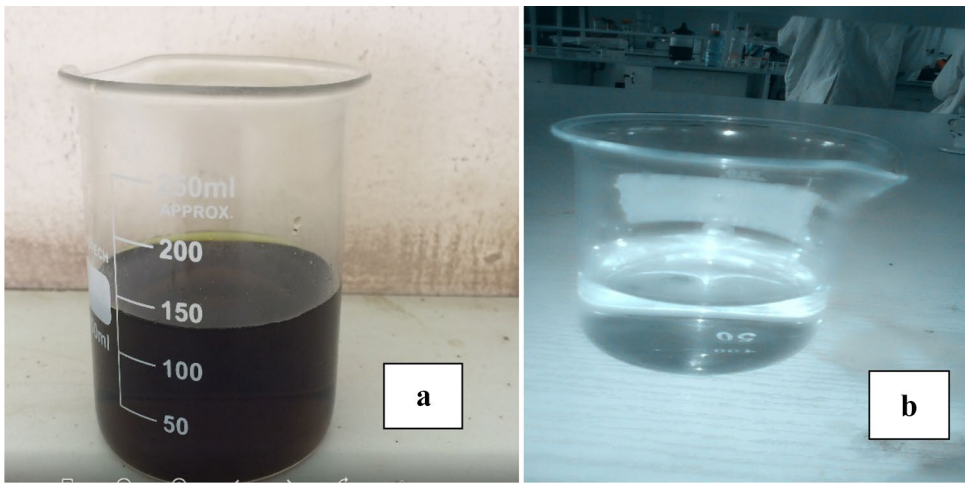

Fig. 5 **a** Electroplating waste water, **b** treated electroplating wastewater

Table 3 Wastewater and treated electroplating wastewater using green synthesized silver nanoparticle

Parameter	Wastewater before treatment	PEG	SNP1	SNP2	SNP3	SNP4
TDS (mg/l)	191,500	16,744	11,736	9376	8520	7825.6
Conductivity (µS/cm)	286,000	25,000	17,520	14,000	12,720	11,680
Dissolved Oxygen (mg/l)	4.0	4.18	4.27	4.40	4.45	4.60
pH	0.83	3.39	4.97	5.46	5.67	5.98
Chloride (mg/l)	5,500	1079.2	818.4	1227.2	780.8	1004.0
Sulphate (mg/l)	18,000	1900	1030	900	790	730
Total Alkalinity (mg/l)	100	1050	1000	1000	1000	480
Nitrate (mg/l)	89,100	2180	1730	1470	1200	990
Nitrite (mg/l)	5.7	2.96	2.72	3.20	1.60	1.84
Ammonium (mg/l)	1500	40	10	7	5	4
Cyanide (mg/l)	180	18.0	14.0	11.0	9.50	8.00
Phosphate (mg/l)	278	83.9	59.1	50.3	48.1	40.4
Calcium (mg/l)		528	1232	1372.8	1056	950.4
Biochemical oxygen demand (mg/l)	4.0	19.6	18.5	18.9	14.4	1.00
Chemical oxygen demand (mg/l)	109,400	12,260	11,600	11,870	9010	120
Total bacteria count (cfu/1 mL)	0	0	0	0	0	0

TDS total dissolved solid

treatment process and the key life sustaining component for aquatic organisms. The quantity of dissolved oxygen in the SNPs treated water improved compared to the untreated wastewater. The SNPs may have enhanced the process of oxidation in the wastewater through adsorption of oxygen on the large specific area of the SNPs influenced by the agitation of wastewater during treatment [37, 38].

Biochemical oxygen demand is the volume of oxygen essential for the biodegradation of organic matter. The observed biochemical oxygen demand is as a result of high level of organic contamination of water. The loosely bound nature of SNP4, increased its available surface area and capacity to adsorb organic matter compared to the aggregated nature (SNPs 1, 2 and 3) which may have reduced the surface area given that the particles will be interacting with each other leading to a decreased adsorption efficiency. SNPs possess adsorbent properties for which decreased size produces increased surface area in relation to its shape. [39, 40].

Chemical oxygen demand is the quantity of the organic matter susceptible to oxidation by strong chemical oxidant into carbon dioxide and water. This may help to determine the impact of organic pollution in water and estimate the effectiveness of the treatment process [37, 41].

Nitrogen is significant in the generation and control of water contamination. Nitrogen in the process of conversion of ammonia to nitrite and nitrite to nitrate leads to oxygen and alkalinity consumption [42]. High concentrations of ammonia are poisonous to fishes, and the content of ammonia in the wastewater reduced to a range of 4-10 mg/l from 1500 after treatment. Nitrate and nitrite in the wastewater were (89, 100 and 5.7) mg/l and decreased to (990 and 1.60) mg/l respectively after treatment with SNP3 having the least nitrite concentration. The presence of nitrate in the wastewater samples may be due to its usage as a corrosion inhibitor in industrial process water [33].

Furthermore, phosphorus is present in the form of phosphate and pH dependent in polluted waters. They exist either bound to soluble organic matters or to particulate organic materials in wastewater and essential for the growth of microbes and a high concentration in water bodies can lead to eutrophication [42]. Phosphate was significantly reduced in all SNPs treated water compared to the untreated wastewater.

The cyanide content in the wastewater was reduced after treatment from 180 to 8.00 mg/l which still falls below the required limit. Industrial electroplating involves process which produces effluents with high levels of heavy metals, cyanides (5–20) % and sulphate complexes [43]. The concentration of sulfate was reduced significantly in the untreated effluent to a range of 730–1030 mg/l in the SNPs treated groups. However, these values were still over the WHO permissive limit of 250 mg/l [44].

3.2.2 LD_{50} study of the SNPs

No mortality was recorded following the oral administration of SNPs (1, 2, 3 and 4) at 5000 mg/kg bodyweight dose to rats (Table 3). This result revealed that the LD_{50} of the SNPs is above 5000 mg/kg bodyweight.

3.2.3 Haematological studies

The haematological parameters of the rats administered SNPs treated water is showed in Table 4. Haematological profile reveals valuable information on cellular elements, extent of damage to the blood and therapeutic responses to treatment [45, 46]. The SNPs treated water had no observable influence on Hb, PCV, MCHC, RBC, neutrophils and lymphocytes compared to the control group. This outcome suggests that the SNPs may have not repressed blood osmoregulation, plasma osmolarity, synthesis of blood cells and as well not affected the immune response of the animals [45, 47]. RBCs accounts for majority of the blood cells and any intrusion initiates either an increased or decreased packed cell volume. Hb and PCV are involved in the transport of nutrients and oxygen to tissues to enhance energy release for the body [48]. While, granulocytes are the innate immune system cells that have the ability to generate antibodies, fight microbial infections, respiratory complications and allergies [49, 50].

MCV, MCH, MCHC are valuable parameters used in diagnosing different types off anaemia and monitoring toxicity that may alter blood or health status of an animal [46]. The MCH result obtained suggests that the SNP1 and SNP2 treated water may have slightly transformed the oxygen carrying capacity of haemoglobin in the red blood cells to the tissues [51].

Blood platelets are known to play a major role in blood clotting. The factors involved in the synthesis of SNP4 may have influenced its high platelet concentration proposing that in an event of injury, the process of blood clotting may be shortened and excessive blood loss avoided [46].

3.2.4 Histopathological studies

The histopathological examination of the effect of SNPs treated water on rat liver is displayed in Fig. 6. The sections of the control group showed that the architectural preservation of the hepatocyte (Fig. 4a). Although, the SNPs treated water triggered slight inflammation of the hepatic blood vessels, it also stiffened the thrombosed central vein (Fig. 4b–e). This is in contrast to the account by Shittu et al. [49], who reported the unscathed nature of the hepatocytes after wound healing activity of silver nanoparticles. The PEG treated water groups revealed thrombosed and recanalized blood vessels and focal areas

Table 4 Haematological profile of oral administration of silver nanoparticle treated water after 28 days

GRP	Hb (g/dL)	PCV (%)	MCV (Fi)	MCH (pg)	MCHC (g/dl)	R BC × (10)%	PLC × (10)%	TWBC	Neutrophils (N)	Lymp (L)	Eos (E)
C	10.26 ± 0.55^{a}	31.3 ± 1.45^{ab}	52.3 ± 0.33^{bc}	17.0 ± 0.00^{b}	32.3 ± 0.33^{abc}	6.30 ± 0.11^{ab}	147.0 ± 15.58^{a}	5.00 ± 0.63^{cd}	9.50 ± 4.33^{ab}	65.67 ± 9.82^{ab}	24.33 ± 5.48^{abc}
SNP1	9.30 ± 3.05^{a}	29.6 ± 9.52^{ab}	49.3 ± 0.33^{bc}	15.0 ± 0.00^{a}	31.0 ± 0.57^{ab}	6.26 ± 1.81^{ab}	321.0 ± 135.7^{abc}	2.20 ± 0.64^{a}	8.40 ± 2.94^{a}	65.33 ± 8.37^{ab}	25.66 ± 5.48^{abc}
SNP2	7.70 ± 0.40^{a}	25.0 ± 0.00^{a}	51.0 ± 0.57^{abc}	16.00 ± 0.57^{a}	30.6 ± 1.45^{ab}	4.90 ± 0.05^{a}	284.0 ± 82.92^{ab}	5.73 ± 0.37^{cd}	10.53 ± 4.64^{ab}	73.66 ± 6.64^{b}	15.66 ± 2.02^{a}
SNP3	9.13 ± 1.36 a	27.3 ± 3.75 ab	48.33 ± 0.88 a	16.66 ± 0.33 b	33.3 ± 0.33 bc	5.73 ± 0.78 ab	206.0 ± 69.85 a	4.63 ± 0.60 abc	13.00 ± 5.77 ab	56.67 ± 8.56 ab	28.33 ± 2.60 bc
SNP4	11.63 ± 1.84 a	34.0 ± 5.77 ab	49.0 ± 0.00 ab	16.6 ± 0.33 b	34.3 ± 0.33 c	6.86 ± 1.18 ab	505.0 ± 2.08 c	7.30 ± 1.27 d	12.33 ± 3.76 ab	69.33 ± 4.09 b	17.33 ± 0.33 a
PEG	13.00 ± 0.75 a	42.66 ± 2.60 b	54.0 ± 2.88 c	16.66 ± 0.88 b	30.33 ± 0.33 a	8.10 ± 0.00 b	473.6 ± 26.84 bc	5.86 ± 0.69 cd	3.33 ± 0.33 a	78.66 ± 2.33 b	17.66 ± 2.02 ab

Each value is of three determinations ± SEM Values are significantly different in comparison with control ($p < 0.05$).

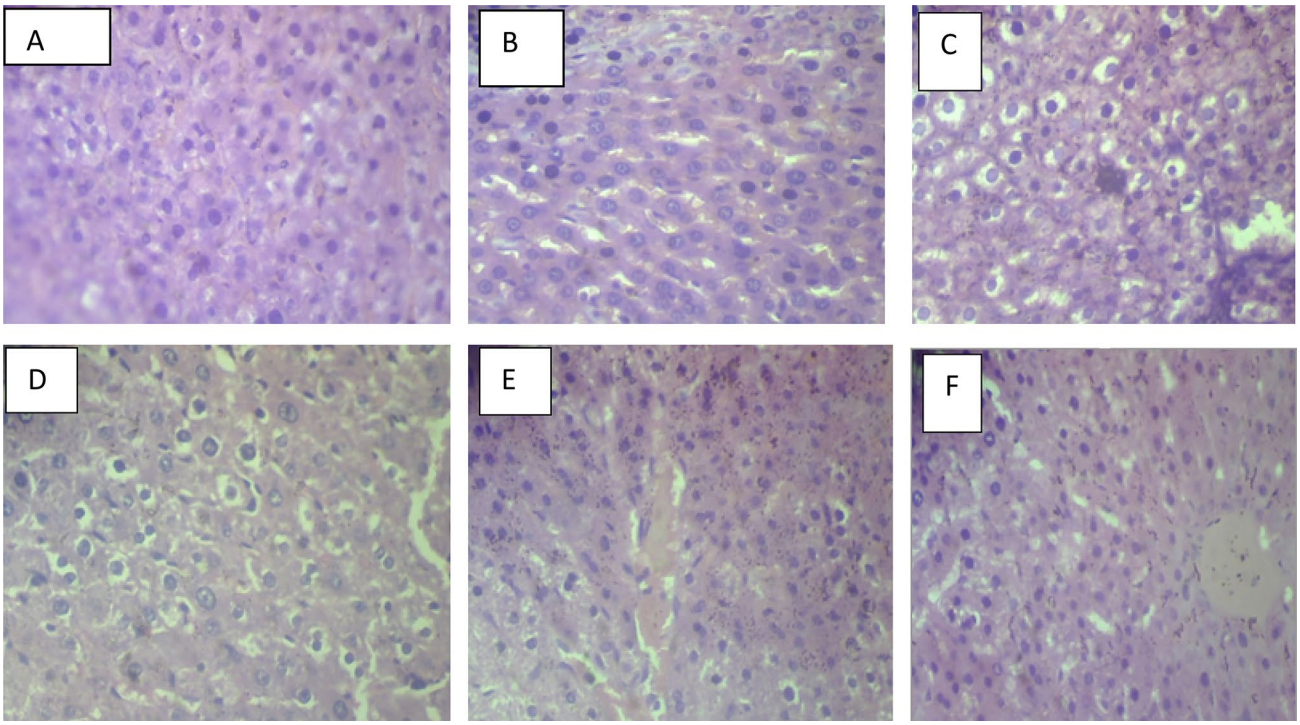

Fig. 6 Effect of SNPs and PEG treated water on histopathological sections of liver in rats. Hematoxylin and eosin stain at × 100 magnification

of necrosis (Fig. 6F). SNPs can accumulate in organs with abundant vascular networks, intensify thrombotic risks, promote procoagulant activation of RBCs and dissolve silver ions (Ag^{+}) in circulating blood, leading to draining from the vessels which induces immune responses and inflammatory reactions [52–54]. Recanalization is part of the physiological process in the veins of thrombus remodelling. Thrombus release inflammatory mediators which together with the process of recanalization may damage venous valves [53]. Necrotic cell death can be triggered by the deposition of SNPs in the liver leading to alterations seen as necrosis [54].

4 Conclusion

This study presents the potential of biosynthesized SNPs from *P. thonningii* under various conditions of concentration, temperature, pH and time to withdraw pollutants from electroplating wastewater, and to determine the level of safety of the treated wastewater in living system. The finding establish that the biosynthesized SNPs were spherical in shape, with asymmetrical particle sizes range from 59.64 to 114.20 dnm. FTIR observations of the SNPs reveal the presence of functional groups; –OH, –C=C, –C=O, –C–H and –NO. The SNPs demonstrated the ability to remove contaminants in the electroplating wastewater with SNP4 displaying a higher affinity. In the sub-chronic toxicity evaluation of the SNPs treated wastewater. The heamatological parameters showed no significant influence on Hb, PCV, MCHC, RBC, neutrophils and lymphocytes. Nonetheless, the histopathological examination revealed toxic effects on the liver sections. Thus, silver nanoparticles may find application in treatment of industrial wastewater. However, there is a need for improved silver nanoparticles that can maintain and preserve the integrity of the organs.

Author contributions Conceptualization, Methodology and Supervision: SOK; Investigation and analysed data: IO; wrote the paper, revised and edited the final manuscript: GTY. All authors read and approved the final manuscript.

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Data availability All data generated or analysed during this study are included in this published article.

Declarations

Conflict of interest The Authors have no competing interests to disclose.

Ethical approval All the experiments were performed in strict accordance with standard guidelines internationally, and the ethical approval was obtained from Ethical committee of the Federal University of Technology Minna (000022), for the care and use of laboratory animals.

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