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Green Synthesis, Characterization, Thermogravimetric and Antibacterial Studies of Fe^{2+} and Mn^{2+} Complexes of Salicylidene-3-Amino Benzoic Acid

*[1]Ama, S.O., [2]Wuana, R.A., [2]Sha'Ato, R. and [2]Eneji, I.S.

[1]Department of Chemical Sciences, Federal University, Wukari, Taraba State, Nigeria

[2]Department of Chemistry, Joseph Sarwuan Tarka University, Makurdi, Nigeria

*Corresponding Author: shadrackama@gmail.com

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ABSTRACT

Over the past three decades, efforts were made to design novel compounds to confront new strains of resistance micro-organisms. Metal complexes have been found to have antimicrobial properties and could be effective against diseases. The study of salicylaldehyde metal complexes is increasingly becoming important particularly in drug design. The Schiff base ligand, Salicylidene-3-amino benzoic acid (SAB), was prepared by reacting salicylaldehyde with 3-amino benzoic acid. Its Fe^{2+} and Mn^{2+} complexes were prepared by reacting ethanolic solutions of SAB with magnetically stirred solution of metal salts in distilled water using microwave-assisted heating for 30 min. The ligand and complexes were characterized on the basis of physical properties, FT-IR, UV-Vis, magnetic susceptibility, XRD and TGA/DTA. All the complexes were coloured. It was observed that the metal complexes melted within the range of 278-340 ˚C which shows that the complexes are relatively stable. The TGA/DGA data revealed that the complexes are stable to heat. The FT-IR spectra revealed the presence of -C=N, -C=O, M-O, M-N, -OH and NO_3 functional groups and this showed that the ligands coordinated to metal via N and O donor. The magnetic moment and electronic data are consistent with proposed octahedral and tetrahedral geometries for the complexes. The complexes were evaluated for their antibacterial activity against human pathogens like *Staphylococcus aureus*, *Methicillin resistant Streptococcus aureus*, *Escherichia coli* and *Pseudomonas aeruginosa* strains. The results of bacterial screening showed that the ligands and complexes had moderate antibacterial activities and the metal complexes showed higher activity than their corresponding ligands.

Keywords: Coordination, green synthesis, ligands, salicylaldehyde, schiff base

INTRODUCTION

Coordination chemistry is one of the most active research areas in inorganic chemistry [1]. Thousands of coordination complexes have been synthesized and investigated during the past

few decades [2]. It has been reported that coordination compounds of iron and manganese have wide application in food industry, dye industry, analytical chemistry, catalysis, fungicidal, agrochemical and biological activities [3]. The escalating prevalence of bacterial infections and the concurrent rise in antibacterial drug resistance have emerged as pressing global concerns in recent years. Consequently, the severity of these infections, which often result in high mortality rates, underscores the necessity of the discovery of novel, effective antibacterial agents with minimal toxicity [4].

Since the importance of coordination phenomenon in biological processes was realized, a lot of iron and manganese containing macromolecules have been synthesized and studied to understand the mechanisms of complex biological reactions. Some complexes of iron and manganese have been found to have antimicrobial properties and could be effective against diseases [5]. This has led to investigations on metal-drug interactions and more studies on complexes of iron and manganese with the aim of discovering more effective therapeutic agents to fight diseases caused by the resistant strains. [4-5].

Thermogravimetric analysis of Schiff base ligands and metal complexes are useful tools as it provides information about the thermal stability and indicates whether the water molecules (if found) are inside or outside the inner coordination sphere of the central metal ion, and also suggests the general scheme for the thermal decomposition of metal complexes [6].

Though many Schiff bases derived from salicylaldehyde or substituted salicylaldehyde with amines have been reported [7], literature work on iron and manganese complexes formed from the condensation reaction between salicylaldehyde and 3-amino benzoic acid are scanty [8]. Here, the green synthesis, characterization, thermogravimetric and antibacterial studies of Fe^{2+} and Mn^{2+} complexes of Salicylidene-3-amino benzoic acid are reported.

MATERIALS AND METHODS

Reagents and equipment

All the chemicals used were of analytical grade and purchased from Sigma-Aldrich Ltd and BDH. They were used without further purification. The infrared spectra of the ligand and complexes was carried out using DGH-9101-ISA PEC model and analyzed using KBr disc in the range of 4500-450 cm^{-1}on a Shimadzu infrared spectrophotometer. X-ray diffraction studies of

the synthesized complexes were carried out using X-ray Diffractometer Thermo Scientific Model ARL X TRA X-ray 197492086.

Preparation of salicylidene-3-amino benzoic acid

The ligand was prepared using a method described by Shamly *et al.* [9]. Salicylidene-3-amino benzoic acid was prepared by condensation of 0.01 mol (24.5 g) 3-amino benzoic acid in 10 mL of water and 0.01 mol (9 mL) of salicylaldehyde. The mixture was stirred at room temperature for 10 min. The crystals formed were filtered, washed with distilled water and dried in a desiccator.

The chemistry of reaction leading to the synthesis of the ligand is as presented in Equation (1)

$$C_7H_6O_2 + C_7H_7O_2N \rightarrow C_{14}H_{11}O_3N + H_2O \quad (1)$$

Synthesis of complexes

The complexes were prepared using a procedure described by Iorungwa *et al.* [10] with slight modifications. Salicylidene-3-amino benzoic acid (23.2 g; 0.01 mol) was dissolved in 10 mL ethanol. The metal nitrates (Fe(II) and Mn(II)) (0.01 mol) were dissolved in 10 mL of distilled water and the salicylidene-3-amino benzoic acid solution was then poured gently into the Fe(II) solution or Mn(II) solution placed on a magnetic stirrer with constant stirring for 10 min. The mixture was then placed in microwave oven for 30 min. The crystals obtained were filtered, washed with distilled water and dried in a desiccator and weighed. The synthesis of the complexes was done according to Equations 2 and 3.

$$Fe(NO_3)_2.6H_2O + SAB \rightarrow [Fe(SAB)(H_2O)_2NO_3]NO_3 + 4H_2O \quad (2)$$

$$Mn(NO_3)_2.6H_2O + SAB \rightarrow [Mn(SAB)(H_2O)_2NO_3]NO_3 + 4H_2O \quad (3)$$

RESULTS AND DISCUSSION

Physicochemical characteristics

The physicochemical characteristics of the ligand and complexes are presented in Table 1. The prepared compounds were crystalline, colored, have high yields and the sharp melting point shows the purity of the complexes as presented in Table 1.

Table 1: Physicochemical data of ligand and complexes

Compound M.P(°C)	Colour	Yield	Nature of compound
SAB 174	Yellow	66	Powdery
Fe-SAB 340	Brown	79	Crystalline
Mn-SAB 278	Light Green	77	Crystalline

Electronic spectra and magnetic moment

The electronic spectral studies of the ligand SAB, and its metal complexes were recorded in methanol in the range of 190 to 1100 nm as presented in Table 2. In the SAB ligand, a band was observed at 325 nm corresponding to π-π* which undergoes a red shift to the longer wavelength indicating complexation. The electronic spectrum of Fe-SAB shows two bands at 300 and 415 nm which can be attributed to π-π* and $d \rightarrow d$ transitions respectively, proper for a tetrahedral geometry. In the UV/Visible spectrum of Mn-SAB, a peak at 325 nm was attributed to π-π* transition.

In the complexes, there were notable changes in both frequencies and intensities in the characteristic bands of the complexes compared to free ligands. The blue shifts and hypsochromic shifts observed in the absorption bands during complex formation indicate coordination of the ligands to the metal ion. These observations are in complete agreement with those of previous works [11].

Magnetic susceptibility was recorded at ambient temperature by suspending the powdered samples from a string using a plastic cap that was epoxy-bonded to the string [12]. The Fe(II) complex has a magnetic moment of 4.89 B.M. which corresponds to a tetrahedral arrangement for Fe-SAB [1,6]. Magnetic moment of 5.37 B.M. was recorded for Mn-SAB indicating a tetrahedral structure [1,6].The electronic spectra and magnetic data of the ligand and complexes is presented in Table 2.

Table 2: Electronic spectra/ magnetic moment data for ligand and complexes

Compound	λ_{max}(nm)	Assignment	M.M (B.M)
SAB	325	π-π*	-
Fe-SAB	300	π-π*	4.92
	415	$dxy \rightarrow dx^2\text{-}y^2$	
Mn-SAB	325	π-π*	5.37

Infrared studies

The infrared spectra of the ligand and complexes were recorded in the range of 4000-400 cm^{-1} using KBr pellets which revealed the nature of the functional groups present. The comparison of the infrared spectral of the ligand and complexes shows the binding mode of the ligand to the metal ion. The free ligand exhibited a strong band at 1573 cm^{-1} which was assigned to ν(C=N). This band shifts to higher region in the complexes. It suggests bonding through the azomethine nitrogen [13]. Another strong band was observed at 1678 cm^{-1} assignable to ν(C=O). The band position of ν(C=O) has shifted to lower frequency in the complexes on coordination of metal ions indicating the involvement of the carbonyl group in bonding to metal [14].

The broad band absorptions in the region 3360-3410 cm^{-1} in the complexes are ascribed to phenolic hydroxyl group [15]. In the IR spectra of complexes, a very intense band appears at 1307 cm^{-1} which indicates the existence of free nitrate group in the coordination sphere [16]. The absence of these bands in the ligands further confirms that coordination has taken place. In the region 567-513 cm^{-1} range, bands associated to ν(M-N) and ν(M-O) have been assigned and are in good agreement with data found in the literature [17]. The changes observed in the infrared spectra on complexation are attributed to several changes in the ligand. These changes are observed in the electronic structure, the state of energy or symmetry of the ligand. These changes affect the vibrations of the ligand and this in turn will cause a change in its vibrational spectrum compared to that of the free ligand. The infrared spectra of the ligand and complexes are presented in Table 3.

Table 3: FT-IR bands of ligands and their complexes

Compound	ν(C=N)	ν(C=O)	ν(M-O)	ν(M-N)	ν(OH)	ν(NO_3)
SAB	1573	1678	-	-	-	-
Fe-SAB	1573	1678	443	513	3360	1307
Mn-SAB	1574	1624	567	567	3410	1307

X-ray diffraction (XRD) studies

The X-ray diffraction studies was carried out to determine the type of crystal system lattice parameters and the cell volume as presented in Tables 4-6 and their spectral patterns are in Figures 1 and 2 for the complexes.

The XRD pattern indicated a crystalline nature for the metal complexes. Indexing of the diffraction pattern was performed with the aid of the trial and error method. The Miller indices (*h,k,l*) along with observed and calculated 2θ angles, the observed and calculated d values are shown in Tables 5 and 6. From the data, it was found that the ligand and its complexes have orthorhombic structure. The crystal structures of similar type of samples were reported as orthorhombic [18]. Again, using the diffraction data, the mean crystallite sizes of the ligands and complexes D was determined. The average crystallites sizes of all the samples were found to be (7.03 nm) as presented in Tables 4-6.

Table 4: Unit cell parameters for ligand and complexes

Compound	Unit Cell Parameters			Volume	Crystallite Size	Crystal Structure
	a(Å)	b(Å)	c(Å)			
SAB		5.97	5.43	6.13	198.72	2.11 Orthorhombic
Fe-SAB	3.97	3.12	2.53		31.34	14.59 Orthorhombic
Mn-SAB	2.60	2.35	2.04		12.46	4.40 Orthorhombic

Table 5: X-Ray diffraction data of Fe-SAB

	d-Spacing (Å)		2θ values		Δ2θ	h,k,l
	Observed	Calculated	Observed	Calculated		
1	3.9743	3.9732	11.1755	11.1688	0.0067	100
2	3.1254	3.1237	14.2685	14.2646	0.0039	010
3	2.8245	2.8236	15.826	15.8190	0.007	110
4	2.3633	23627	19.0225	19.0140	0.085	111
5	1.7905	1.7899	25.4805	25.4676	0.0129	002

Table 6: X-Ray Diffraction data of Mn-SAB

	d-Spacing (Å)		2θ values		Δ2θ	h,k,l
	Observed	Calculated	Observed	Calculated		
1	17.222	17.2115	2.602	2.6005	0.0095	100
2	19.1405	19.1353	2.3483	2.3483	0.0052	010
3	22.213	22.2037	2.0375	2.0210	0.0093	001
4	32.385	32.3710	1.4382	1.4376	0.014	111

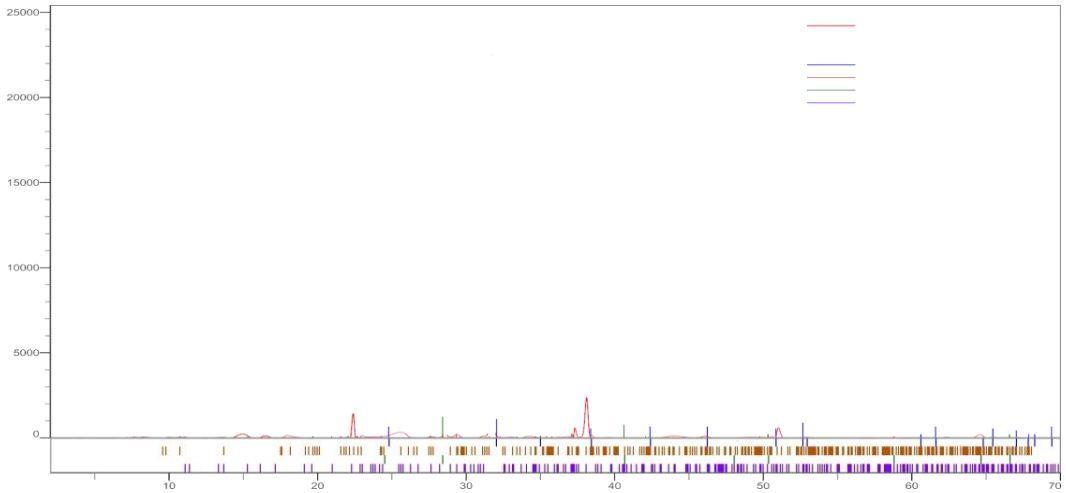

Figure 1: XRD spectrum of Fe-SAB

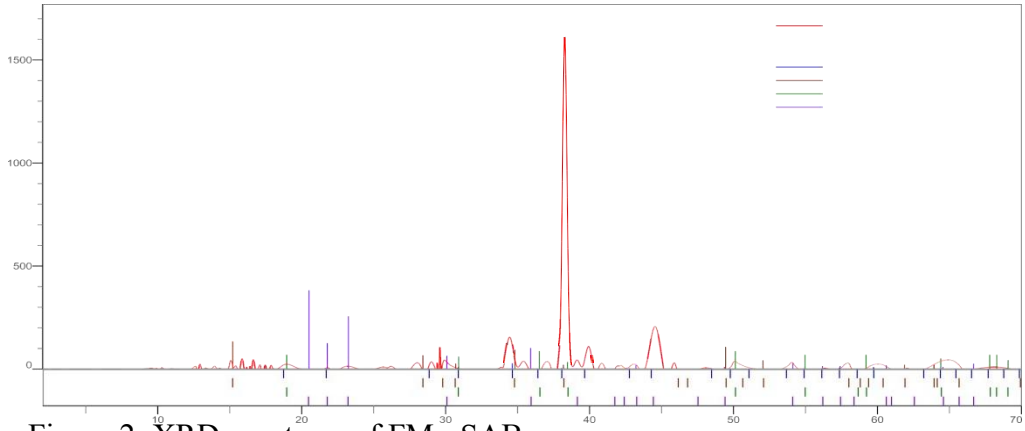

Figure 2: XRD spectrum of FMn-SAB

Thermo-gravimetric analysis

The Thermo-gravimetric analysis (TGA) was carried out on the complexes to determine their thermal stability. The thermal behaviors of all the complexes were studied in the temperature range of 30-950 ˚C. Thermal analysis plays an important role in studying the stability, melting point, structure and decomposition properties of the metal complexes. The thermo gravimetric analysis of the metal complexes has been studied to establish different decomposition process and confirm the proposed stoichiometry [19]. It also provides information about thermal stability of the complexes and decides whether the water molecules are inside or outside the inner coordination sphere of the central metal ion. The results of the thermal behavior of the synthesized metal complexes are presented in Table 7. The result indicated a reasonable correlation between the calculated and found weight loss values.

The Fe-SAB complex indicateS a total weight loss of 2.0% (cal. 2.3%) observed in the temperature range of 30-195 ^{o}C with the DTA value of 80 ^{o}C which is attributed to the loss of 2 molecules of water. The second stage of the decomposition suffers the loss of C_6H_5ON with the total weight loss of 40.0% (cal. 38.7%) in the range of 196-495 ^{o}C. The third stage of decomposition occurred at 436-535 ^{o}C representing a loss of C_8H_5O. The FeO residue decomposed at a temperature above 536 ^{o}C with the total weight loss of 3.83% (cal. 4.1%) which agrees with the theoretical value.

The TGA curve of Mn-SAB complex follows a four-stage decomposition process. The first stage decomposition is obtained in the temperature range of 30-210 ^{o}C with the percentage

weight of 5.0% (cal. 6.08%) which correspond to the dehydration of 1 mole of water. The second stage decomposition corresponds to the loss of C_6H_5ON with the total weight loss of 83.2% (cal. 76.0%). The third stage decomposition range is obtained at 441-475 ^oC with the total mass loss 6.0% (cal. 5.5%) attributed to the loss of C_8H_5O. The MnO decomposed in the fourth stage in the temperature range above 476 ^oC. The total weight loss corresponding to this decomposition is 5.0% (cal. 5.2%).

The percentage weight loss in all the complexes is in agreement with the calculated values. The nature of the thermographs and percentage weight loss in all the complexes correspond to [ML].$2H_2O$, [ML].H_2O for Fe-SAB and Mn-SAB respectively. These observations are in agreement with previous works [20]. The percentage loss in all the complexes is in agreement with all the calculated values. Similar findings were reported by Kavitha *et al.* [21]. The absence of weight loss at higher temperatures indicated that there is no hydrated water molecule in the crystalline solid. The thermo-gravimetric curves for the complexes are presented in Figures 3 and 4.

Table 7: Thermo analytical results for Fe-SAB and Mn-SAB

Compound	TGA (˚C)	DTA (˚C)	Stage	Mass loss Found	Cal	Assignment
Fe-SAB	30-195	80	I	2.0	2.3	Dehydration of 2 moles of water
	196-495	310	II	40.0	38.7	C_6H_5ON
	496-535	440	III	40.0	41.0	C_8H_5ON
	>536	630	IV	3.83	4.1	FeO Residue
Mn-SAB	30-210	150	I	7.0	7.2	Dehydration of 1 mole of water
	211-440	350	II	35.5	35.0	C_6H_5ON
	441-475	440	III	38.5	37.3	C_8H_5O
	>476	550	IV	20.8	20.5	Mn Residue

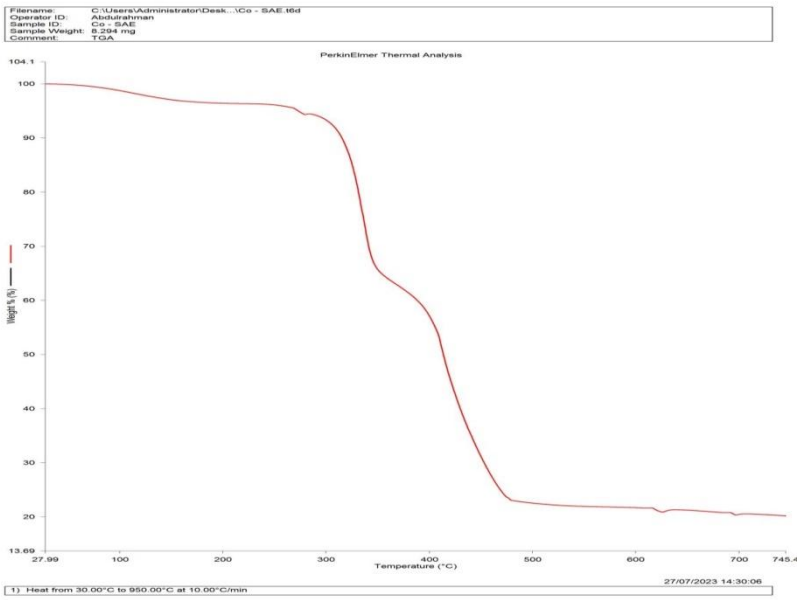

Figure 3: Thermogravimetric curve for Fe-SAB complex

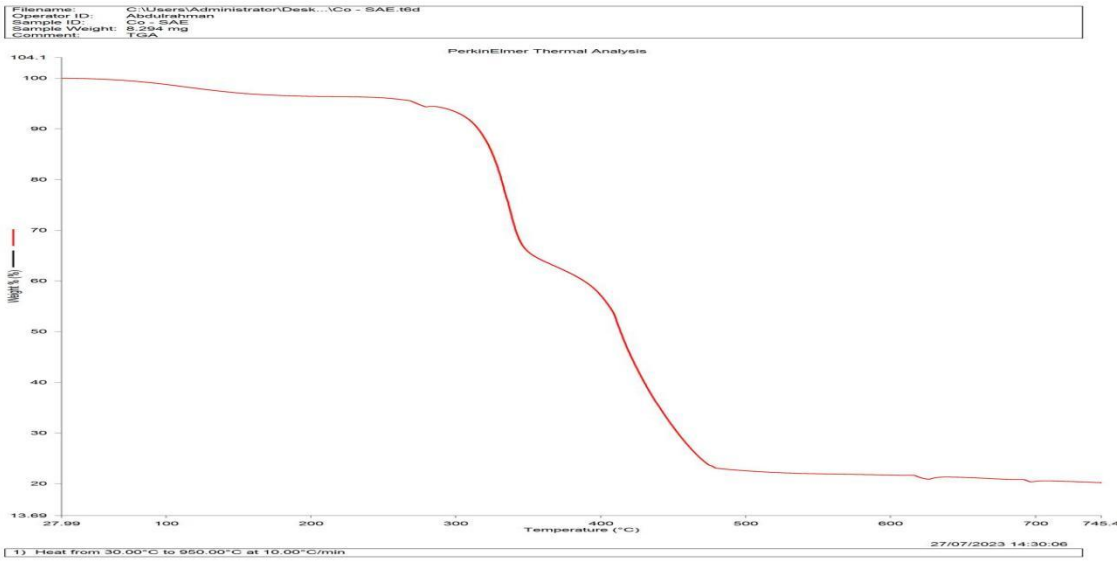

Figure 4: Thermogravimetric curve for Mn-SAB complex

Antibacterial studies

The results of the antibacterial studies of the ligand and its metal complexes are presented in Tables 8 and 9. The ligand and metal complexes were tested for antibacterial activities against *Staphylococcus aureus*, *Methicillin resistant Streptococcus aureus*, *Escherichia coli* and *Pseudomonas aeruginosa* strains using Mueller Hinton agar. It was observed that the standard

drugs, sparfloxacin and ciprofloxacin, were more potent than the ligand and metal complexes. All the metal complexes have higher antibacterial activities compared to the ligand.

Table 8: Antibacterial screening of ligand and complexes

Complex	MRSA	*S. aureus*	*E. coli*	*P. aeruginosa*
SAB	21	22	24	0
Fe-SAB	24	25	0	28
Mn-SAB	23	25	0	24

Table 9: Zones of inhibition of bacteria in the presence of ligand and complexes

Complex	Zone of inhibition (mm)			
	MRSA	*S. aureus*	*E. coli*	*P. aeruginosa*
SAB	21	22	24	0
Fe-SAB	24	25	0	28
Mn-SAB	23	25	0	24

The results showed that the ligand is active against all the tested bacteria except *P. aeruginosa*. The complexes were also active against all the bacteria strains except *E. coli*. Hence, the result of these studies showed that all the metal complexes are more effective antibacterial than the ligand against the tested species. It was observed that metal chelation has affected significantly the antimicrobial or bioactive behaviour of the ligand. The increased activity upon complexation can be attributed to the blocking of the metal binding sites in enzymes or microorganisms, thereby deactivating various cellular enzymes crucial for metabolic pathways [1,16,22]. The results indicate that the ligand and the complexes have antibacterial activity against the tested microorganisms.

This research work has limitations. It was limited to synthesis, characterization and testing the antibacterial activity of the ligands salicylidene-aniline, salicylidene-ethylenediamine and salicylidene-3-amino benzoic acid and their complexes with Cu^{2+}, Co^{2+}, Fe^{2+}, Ni^{2+}, Mn^{2+} and Zn^{2+} only. It is recommended that antifungal, antimalarial and nematicidal studies should also be carried out on these complexes.

CONCLUSION

The synthesis of complexes of azomethine linkages have been extensively studied, and it is an area of research with great potentials in new drug design. The present work described the green synthesis of Fe^{2+} and Mn^{2+} Schiff base complexes derived from the condensation reaction of 3-amino benzoic acid with salicyaldehyde. The green synthesis involved the use of microwave assisted synthesis which reduces reduces the amount of solvents used. It also reduces the energy requirement and there is no or minimum pollution/waste. The physical (molar conductance, magnetic susceptibility measurement and thermal gravimetric analysis, spectral (uv-vis, FTIR, XRD) data for the complexes provided evidence that the Schiff base is coordinated to the metal ion through the azomethine linkage. The thermo-gravimetric analysis affirmed the stability of the complexes and the position of the water molecule in the coordination sphere of the complexes. The antibacterial study showed that the ligand and complexes have moderate activities and the complexes are more active than the ligand.

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