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Synthesis, Characterization, Antibacterial Activity of 2-Hydroxy Benzylideneamino Benzenesulfonamide Schiff Base and its Co (Ii) and Ni (Ii) Complexes

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Abstract: *Schiff base ligands are an important class of pharmacologically active compounds with diverse biological properties. In this study, a novel Schiff base ligand, 2-hydroxybenzylideneamino benzenesulfonamide (HBABS), was synthesized via a 1:1 condensation reaction between 2-hydroxybenzaldehyde (2 mmol, 2.12 cm^3) and sulfamethoxazole (2 mmol, 5.06 g) in ethanol, achieving a yield of 82.1%. The Co(II) and Ni(II) complexes, [Co(HBABS)·2H2O] and [Ni(HBABS)·2H2O], were prepared by reacting the ligand (2 mmol, 7.14 g) with CoCl2·6H2O and NiCl2·6H2O (2 mmol, 4.76 g) in ethanol, with yields of 78.7% and 85.9%, respectively. Characterization by elemental analysis, melting point, molar conductance, FTIR, UV-Vis, ^{1}H NMR, and ^{13}C NMR confirmed tetradentate coordination through azomethine nitrogen, sulfonamide nitrogen and oxygen, and phenolic oxygen. The complexes exhibited octahedral geometry with coordinated water molecules. Molar conductances of 25.66 and 22.75 S·cm^2·mol^{-1} confirmed their non-electrolytic nature. The ligand and complexes were evaluated for antimicrobial activity against Staphylococcus aureus, Escherichia coli, and Candida albicans. The HBABS ligand showed inhibition zones of 17 mm, 16 mm, and 12 mm, respectively, while the Co(II) complex exhibited enhanced activity with inhibition zones of 23 mm, 18 mm, and 13 mm. The Ni(II) complex showed zones of 20 mm, 19 mm, and 9 mm. Minimum inhibitory concentrations ranged from 2.5 to 10 mg/mL, with the Co(II) complex demonstrating the lowest MIC of 2.5 mg/mL against S. aureus. The enhanced activity of the metal complexes is attributed to chelation, which increases lipophilicity and facilitates microbial cell membrane penetration. These findings suggest that HBABS and its Co(II) and Ni(II) complexes are promising candidates for the development of antibacterial and antifungal agents.*

Keywords: *Schiff base, Co(II) complex, Ni(II) complex, Antibacterial activity, Metal-ligand coordination*

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1.0 Introduction

Schiff bases constitute one of the most important classes of ligands in modern coordination chemistry owing to their remarkable coordinative flexibility, ease of synthesis, and structural diversity (Burlov *et al*., 2024; Vigato & Tamburini, 2018). These compounds, typically formed through the condensation of primary amines with aldehydes or ketones, possess azomethine (–C=N–) functional groups that act as strong donor sites for metal ions. As a result, Schiff bases play a vital role in elucidating preferred coordination geometries and electronic environments in transition metal complexes (Otuokere *et al*., 2024). Their preparative accessibility and tunable physicochemical properties have sustained extensive research interest over several decades.

Beyond their coordination behavior, Schiff base ligands and their metal complexes have attracted considerable attention due to their wide range of biological, analytical, and industrial applications. Numerous studies have shown that Schiff base compounds exhibit significant antimicrobial, antifungal, anti-inflammatory, antiviral, antimalarial, antiproliferative, and anticancer activities, in addition to their usefulness in catalysis and organic synthesis (Abd El-halin *et al*., 2021; Khalaji *et al*., 2020; Lekha *et al*., 2024; Shebl, 2018). Their relevance in pharmaceutical and medicinal chemistry is particularly notable, as metal complexation often enhances the biological efficacy of the parent organic ligands through chelation, increased lipophilicity, and improved cellular uptake (Grivani *et al*., 2022; Hassan *et al*., 2023).

Several reports have demonstrated that Schiff base metal complexes derived from sulfonamide and sulfa-drug frameworks possess enhanced antimicrobial properties. Abu-Khadra *et al*. (2016) synthesized a series of transition metal complexes of a sulfonamide-based Schiff base, reporting octahedral geometries and promising antibacterial and antifungal activities against both Gram-positive and Gram-negative organisms. Similarly, Alyar *et al*. (2018) prepared Schiff bases derived from sulfamethoxazole and sulfisoxazole and their Pd(II) and Cu(II) complexes, revealing significant antimicrobial activity and enzyme inhibition potency compared to the free ligands. Related studies involving sulfa-drug-derived Schiff bases and their Co(II), Ni(II), Cu(II), Zn(II), and Mn(II) complexes consistently report improved biological activity upon metal coordination (Gomathi & Selvameena, 2013; Uba *et al*., 2017).

Recent investigations have further expanded the scope of Schiff base research by incorporating computational modeling, molecular docking, dyeing behavior, and antioxidant studies alongside experimental characterization. For instance, Elbadawy *et al*. (2025) reported azo–Schiff base Cu(II) and Zn(II) complexes with notable antimicrobial, antioxidant, and cytotoxic properties, demonstrating the strong structure–activity relationships influenced by chelation. Likewise, Schiff bases derived from sulfonamide drugs such as sulfathiazole and sulfanilamide have been shown to possess excellent drug-likeness properties and significant antimicrobial activity, supported by both experimental and quantum chemical studies (Elangovan *et al*., 2022; Muthukumar *et al*., 2022).

Despite the extensive body of literature on sulfa-drug-based Schiff bases, a careful survey reveals that limited attention has been given to Schiff base ligands derived specifically from sulfamethoxazole and benzaldehyde, particularly with respect to their coordination with Co(II) and Ni(II) ions and systematic evaluation of their antibacterial properties. Most existing studies focus on substituted salicylaldehydes or naphthaldehydes as aldehydic precursors, leaving a gap in understanding how simpler aromatic aldehydes influence the coordination behavior and biological performance of such systems.

In view of this knowledge gap, the present study aims to synthesize and characterize a novel Schiff base ligand, 2-

hydroxybenzylideneamino]-N-isoxazol-3-yl-benzenesulfonamide, derived from sulfamethoxazole and benzaldehyde, and its corresponding Co(II) and Ni(II) complexes. The synthesized compounds are characterized using standard physicochemical and spectroscopic techniques, and their antibacterial activities are evaluated against selected bacterial strains.

The significance of this study lies in contributing new insight into the coordination chemistry and biological potential of sulfamethoxazole-based Schiff bases. The findings are expected to deepen understanding of structure–activity relationships in Schiff base metal complexes and support the development of metal-based antimicrobial agents with improved efficacy compared to conventional drugs.

2.0 Materials and Method

2.1 Chemicals and Solvents

All the chemicals used were of analytical grade and were used without further purification.

2.2 Synthesis of 2-Hydroxybenzylideneamino benzenesulfonamide (HBABS)

The synthesis was prepared according to the procedure reported in the literature (Anacona *et al.,* 2022) with slight modification. Equimolar solutions of sulfamethoxazole (5.06 g; 2 mmol) in ethanol (45 cm^3) solution was added to 2.12 cm^3 (2 mmol) of 2-hydroxy benzaldehyde with constant stirring. The solution was stirred and refluxed for 3 hours. The product was filtered off, washed several times with H_2O, ethanol and dried in a dessicator. The equation of reaction is shown in Scheme 1. The yield was calculated.

2.3 Preparation of 2-hydroxybenzy - lideneamino benzenesulfonamide metal (II) complexes [M(HBABS)n2H$_2$O]

To hot solution of HBABS, (7.14 g; 2 mmol) in ethanol (45 cm^3), 45 cm^3 each of aqueous solution of $CoCl_2.6H_2O$ and $NiCl_2.6H_2O$ (4.76 g; 2 mmol) was added and refluxed for 2 hours. The solutions obtained were filtered and evaporated to half of its volume. The concentrated solutions were left overnight at room temperature for precipitation to take place. The product was filtered off, washed several times with H_2O, ethanol for purification and dried in a desiccator. The yield was calculated.

2.4 Characterization

The melting points and decomposition temperature of the novel Schiff base ligand and the metal [M(HBABS)n2H$_2$O] complexes were determined using melting point apparatus (Gallen Kamp). Infrared spectra of solids (in a KBr pellets) were recorded in the 4400 – 350 cm^{-1} region on a Perkin-Elmer spectrum Bx FT-IR spectrophotometer. ^{1}H NMR and ^{13}C NMR were determined using Bruker NMR spectrophotometer (tetramethylsilane was used as internal standard and DMSO-d6 as solvent). UV spectra were obtained on a UV-1800 series spectrophotometer. Microanalysis (C, H, S and N) of the synthesized ligand and complexes were carried out using Perkin-Elmer 240B elemental analyzer. The conductivity of the schiff base ligand and their corresponding metal [M(HBABS)n2H$_2$O] complexes were measured by Jenway Conductivity Meter 4510 model at room temperature in a concentration of 10^{-3} M DMSO solution (DuekeEze *et al.,* 2014).

2.5 Antimicrobial

The Schiff base ligand and metal (II) complexes were screened (*in-vitro*) for their antibacterial and antifungal activities against four Gram-negative *(E.coli, K. pneumonia, S. typhi,* and *N. gonorrhoea)* and four Gram positive *(M. tuberculosis, S. aureus, B. cereus,* and *S. pyogenes)* bacterial strains and four fungal strains- *A. flavus, C. albicans, T. rubrum,* and *A. niger* using the agar Well (2018) diffusion method.

The bacteria and fungi used in the antimicrobial test were obtained and confirmed at the Microbiology Laboratory of the Federal Medical Center, Uyo, Akwa

Ibom State, Nigeria, and were used as test organisms.

3.0 Results and Discussion

Table 1 shows that the HBABS ligand and [M(HBABS)·2H2O] complexes are colored microcrystalline solids, decomposing between 188.24 °C and 240.09 °C. The observed coloration confirms the formation of metal-ligand coordination complexes. The measured molar conductance values of HBABS and [M(HBABS)·2H2O] complexes were 10.45, 25.66, and 22.75 $S\cdot cm^2\cdot mol^{-1}$, respectively, indicating their non-electrolytic nature in DMSO (Geary, 1971). Geary (1971), reported that coordination compounds with molar conductance above 100 $Ohm^{-1}cm^2mol^{-1}$ are electrolytes indicating that those below this threshold value are weak electrolyte.

Elemental analysis results closely match the calculated values, providing further confirmation of the successful synthesis of the HBABS ligand and its [M(HBABS)·2H2O] complexes. The high yields of the ligand and metal complexes indicate the efficiency of the synthetic procedures and the purity of the obtained products. The analytical data suggest a 1:1 metal-to-ligand stoichiometry for the Co(II) and Ni(II) complexes.

Table 1: Some physical parameters and analytical data of HBABS and their metal (II) complexes

Schiff Base Ligands / Complexes	HBABS	$[Co(HBABS)_2H_2O]$	$[Ni(HBABS)_2H_2O]$
Calculated (found) %			
C	57.08 (58.00)	45.14 (44.20)	45.12 (45.15)
H	4.20 (4.25)	3.32 (4.18)	4.20 (4.26)
N	11.75 (12.64)	9.29 (8.35)	9.29 (9.34)
S	8.95 (8.00)	7.08 (8.04)	7.08 (7.10)
M	–	13.04 (12.99)	12.98 (12.97)
Colour	Yellow	Brown	Greenish white
Molar conductance (Ω^{-1} cm² mol⁻¹)	16.40	25.66	22.75
Yield (%)	82.10	78.69	85.86
Melting point (°C)	188.24	240.09	216.81
Magnetic moment (B.M.)	–	4.81	3.12

Table 2 indicates that the HBABS ligand and [M(HBABS)·2H2O] complexes are insoluble in non-polar solvents (n-hexane, petroleum ether), slightly soluble in polar protic solvents (water, methanol, ethanol, chloroform), and fully soluble in polar aprotic solvents (DMF, DMSO), reflecting their polar character.

Table 2: Solubility data of the HBABS and $[M(HBABS)n\ 2H_2O]$ complexes in various solvents

Schiff Base Ligand/ Complexes	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8
(HBABS)	SS	SS	IS	SS	IS	S	S	SS
$[Co(HBABS)n\ 2H_2O]$	SS	SS	IS	SS	IS	S	S	SS
$[Ni(HBABS)n2H_2O]$	SS	SS	IS	SS	IS	S	S	SS

Key: S-1 = **Distilled Water, S-2 = methanol, S-3 = n-hexane, S-4 = chloroform, S-5 = petroleum ether, S-6 = DMF, S-7 = DMSO and S-8 = ethanol. S-soluble, SS-Slightly Soluble, and IS-Insoluble**

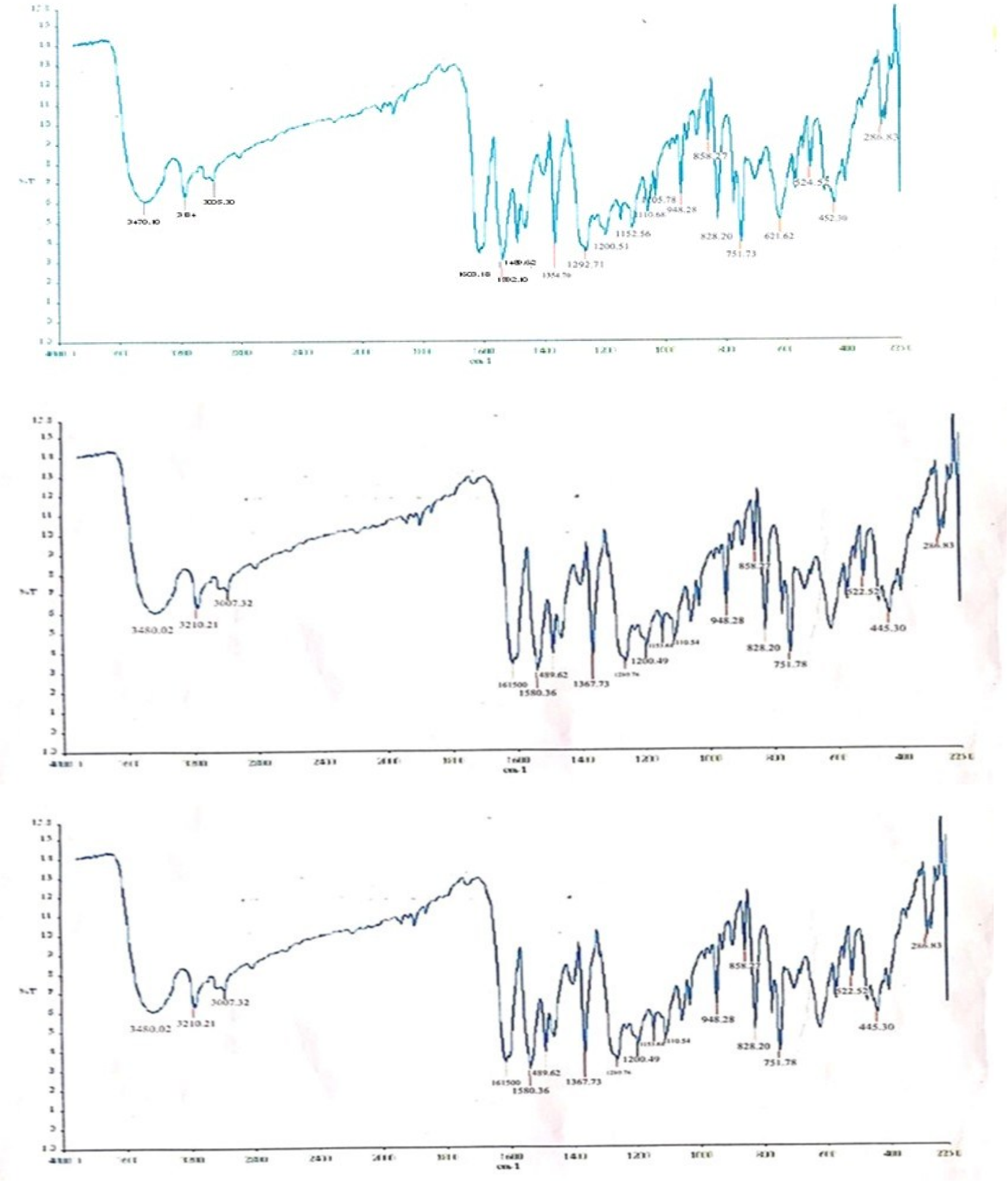

Fig. 1: IR Spectrum of HBABS, [Co(HBABS)n2H₂O], [Ni(HBABS)n2H₂O]

The FTIR spectrum of HBABS (Fig. 1) shows a strong absorption at 1615 cm^{-1}, assigned to the azomethine ν(C=N) stretching vibration. On comparison with [M(HBABS)n $2H_2O$] complexes, this band was shifted to lower wave numbers 1604 and 1603 cm^{-1}. This indicates the participation of the azomethine nitrogen in coordination with

Co (II) and Ni (II) during complexation (Otuokere *et al.,* 2020, 2024). The characteristics ring vibrations at 3017 cm^{-1}, 3000 cm^{-1} and 3005 cm^{-1} in the spectrum of the ligand have been assigned as aromatic and aliphatic rings. The ν(N-H) stretch of the HBABS ligand at 3210 cm^{-1} shifts to 3190 cm^{-1} in the [M(HBABS)·2H2O] complexes, indicating the participation of the sulfonamide nitrogen in metal coordination (Asogwa & Otuokere, 2024).

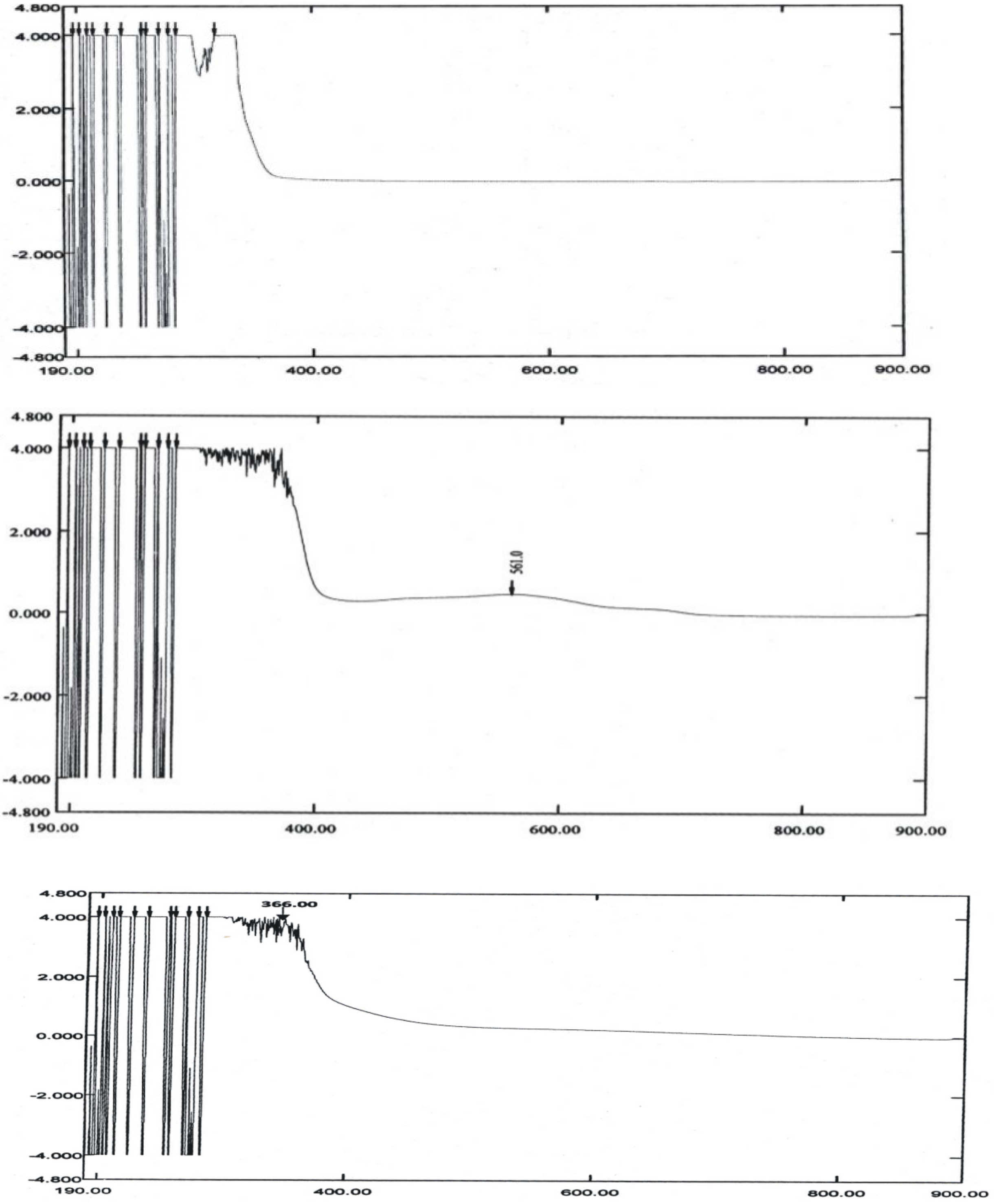

Fig. 2: Uv/Vis spectrum of HBABS, [Co(HBABS)n2H$_2$O] and [Ni(HBABS)n2H$_2$O]

This suggests the involvement of ν(N-H) in coordination with cobalt and nickel. The FTIR vibration band observed at 1367 cm^{-1} in the spectrum of the Schiff base was assigned ν(S=O). In the [M(HBABS)n 2H$_2$O] complexes, the ν(S=O) stretch shifted to lower wave numbers 1351 and 1354 cm^{-1}. This indicates the involvement of ν (S=O) in coordination with Co and Ni (Asogwa & Otuokere, 2024). The band at 1280 cm^{-1} was assigned to ν(C-O) stretch in the HBABS ligand. In the [M(HBABS)n2H$_2$O] complexes, the ν(C-O) stretch shifted to higher wave numbers 1295 cm^{-1}and 1292 cm^{-1}.This suggests the involvement of ν(C-O) in coordination with cobalt and Nickel during complexation. Similarly, shifts in the ν(S=O) and ν(C-O) bands confirm coordination through the sulfonamide oxygen and phenolic oxygen, consistent with tetradentate binding of HBABS to Co(II) and Ni(II).

The Uv-Visible spectra (Fig. 2) of HBABS and [M(HBABS)n 2H$_2$O] absorbed at wavelength maxima at 207.50, 216.50, 229.5, 244.50, 250.50, 254.50, 261.50, 271.50, 280.50, 293.50, 309.50 and 317.50 nm and these absorptions were as a result of chromophores present in the HBABS ligand.

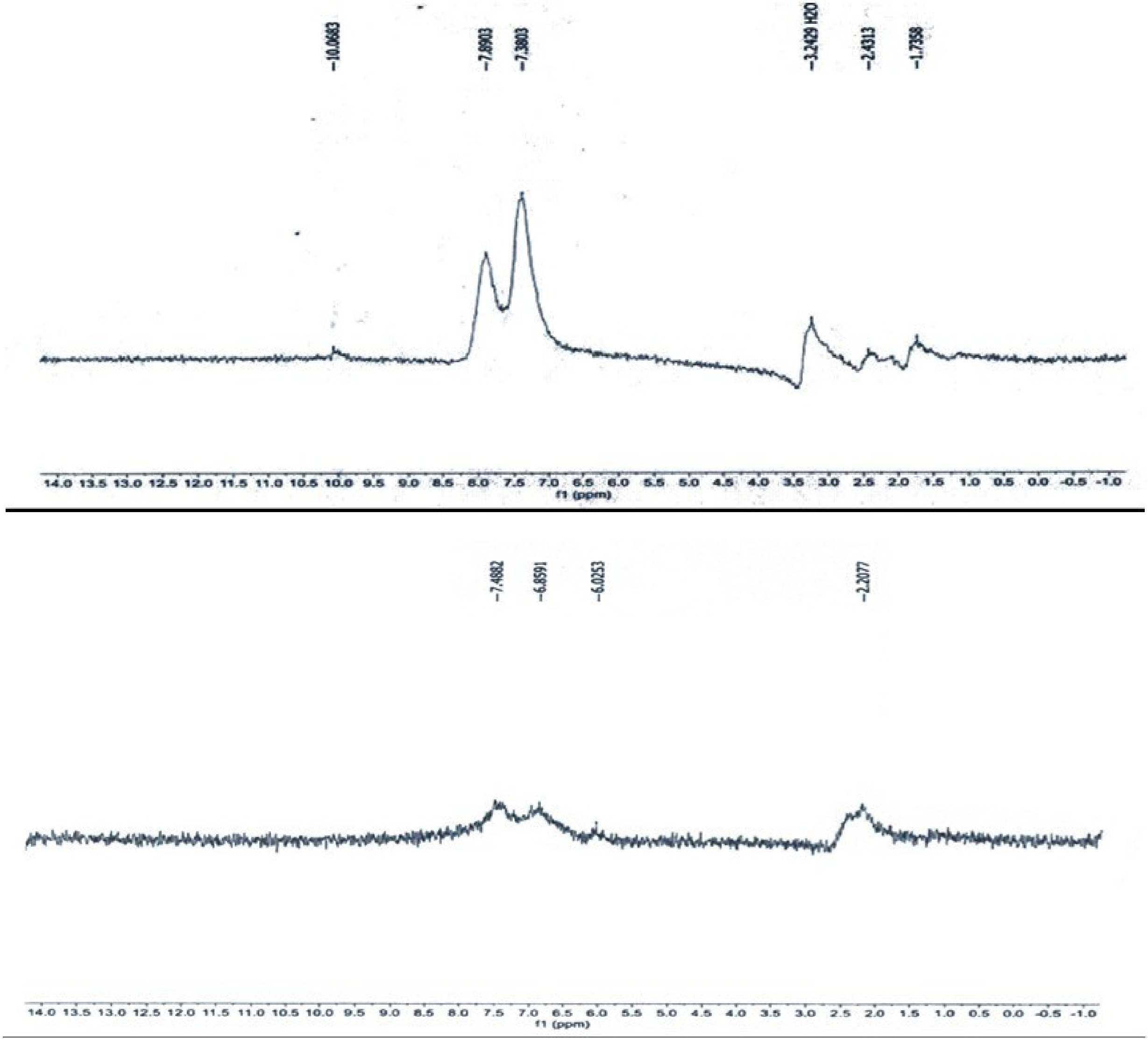

Fig. 3: ^{1}H NMR spectrum of HBABS, [Co(HBABS)n2H2O] and [Ni(HBABS)n2H2O]

The observed absorptions correspond to π→π and n→π intra-ligand transitions (ILCT). In the metal complexes, additional bands at 561.5 nm and 366.5 nm are attributed to ligand-to-metal charge transfer (LMCT), confirming complex formation. In the Uv/Vis spectra of the complexes, the ligand to metal charge transfer (LMCT) was observed at 561.50 nm and 366.50 nm. This suggested that complexation occurred.

The ¹H NMR spectrum of HBABS shows a hydroxyl proton at 10.07 ppm, which disappears in the spectra of the [M(HBABS)·2H2O] complexes, indicating deprotonation and coordination through the phenolic oxygen.

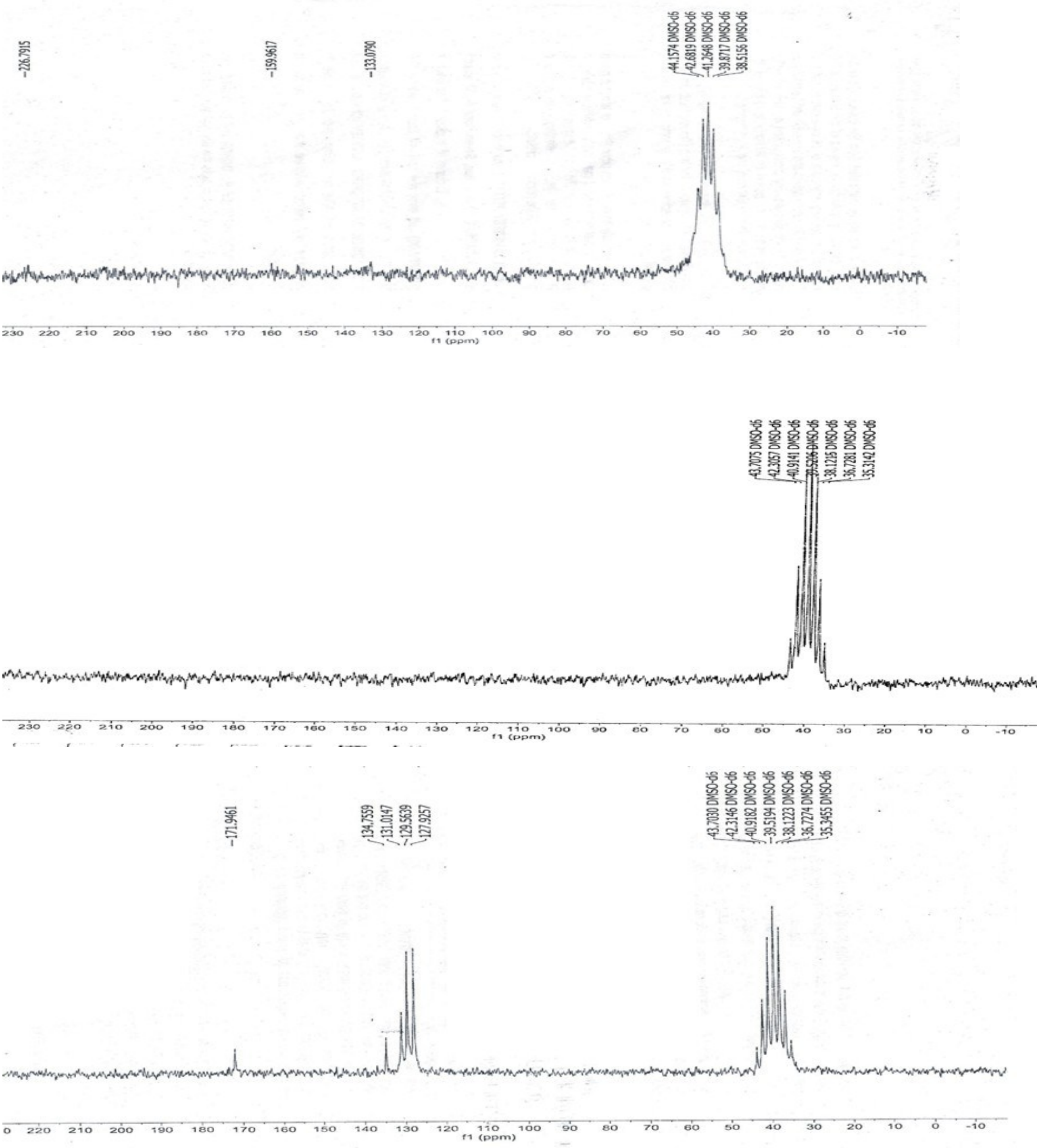

Fig. 4: ¹³C NMR spectrum HBABS, [Co(HBABS)n2H₂O], [Ni(HBABS)n2H₂O]

The chemical shift was absent in the ^{1}HNMR spectra of the complexes [M(HBABS)n $2H_2O$], indicating complexation. The azomethine proton signal at 8.00 ppm in HBABS disappears in the Co(II) complex and shifts to 8.04 ppm in the Ni(II) complex, indicating coordination through the azomethine nitrogen (Aliyu & Ozoro, 2024; DuekeEze *et al.*, 2014). This is suggestive that deprotonation occurred during complexation (Aliyu & Ozoro, 2024; DuekeEze *et al.,* 2014). The peak, which appeared as a singlet in the ligand (8.00 ppm), and 6.03 ppm - 7.97 ppm respectively were assigned aromatic protons. They also remained unchanged in the complexes (Otuokere *et al.,* 2024; Otuokere *et al.,* 2020).

The ^{13}C NMR spectrum of HBABS (Figs. 10 to 12) exhibits an azomethine carbon resonance at 226.79 ppm. In the Co(II) complex, this signal is broadened beyond detection, while in the Ni(II) complex, it shifts upfield to 171.95 ppm, confirming coordination of the azomethine nitrogen. Similar upfield shifts in the sulfonamide carbon signals (C-SO_2NH) further confirm the involvement of sulfonamide nitrogen and oxygen in complexation.The shielding effect revealed coordination of the azomethine nitrogen (N) to the Nickel metal atom. Shielding effect was also observed in the sulfonamide carbon (C-SO_2NH) of the HBABS ligand with 159.96 ppm while in ^{13}C NMR spectra of Cobalt and Nickel complexes, upfield shifting was observed due to loss of signal. This is indicative of coordination and subsequent complexation.

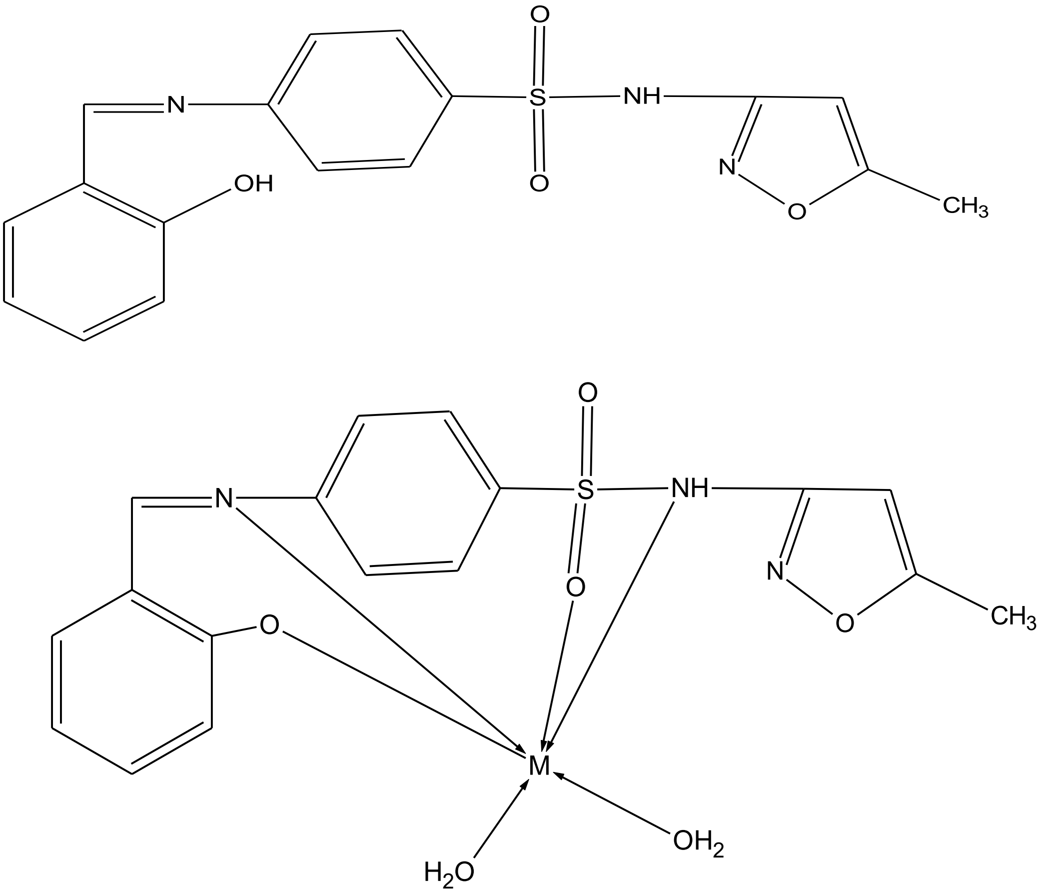

Fig 5: Proposed structure for HBABS and [M(HBABS)n $2H_2O$]

Table 3: Antibacterial studies of the HBABS and [M(HBABS)n 2H$_2$O] complexes in various solvents

Ligand/ complexes	**(Gram + ve) Bacteria *S. aureus***	**(Gram + ve) Bacteria *E. coli***	**Fungal Strain *C. albicans***
HBABS	17.00 ± 0.02	16.00 ± 0.02	12.00 ± 0.02
[Co(HBABS)n2H$_2$O)	23.00 ± 0.03	18.00 ± 0.02	13.00 ± 0.02
[Ni(HBABS)n2H$_2$O]	20.00 ± 0.03	19.00 ± 0.02	9.00 ± 0.01
Distilled water	00.00 ± 0.00	00.00 ± 0.00	00.00 ± 0.00
Penicillin	38.00 ± 0.15	40.00 ± 0.17	35.00 ± 0.12

Key: >15 = significant, 10-14 = moderate <10 = weak

Table 4: Minimum Inhibitory Concentration (MIC) of the HBABS and [M(HBABS)n 2H$_2$O] complexes

Ligand/ complexes	**(Gram + ve) Bacteria *S. aureus***	**(Gram + ve) Bacteria *E. coli***	**Fungal Strain *C. albicans***
HBABS	5.0	5.0	-
[Co(HBABS)n2H$_2$O)	2.5	5.0	10.0
[Ni(HBABS)n2H$_2$O]	5.0	5.0	10.0

Table 3 shows that HBABS exhibits significant antibacterial activity (>15 mm) against S. aureus and E. coli, and moderate antifungal activity (12 mm) against C. albicans. [Co(HBABS)n2H$_2$O] complex showed better activity against *S. aureus* and *E. coli* but moderate activity against *Candida albicans* fungal strain. [Ni(HBABS)n2H$_2$O) complex showed good inhibition zones against *S. aureus* and *E. coli* bacterial strains but weak activity against *C. albicans* fungal strain. The positive control (penicillin) showed inhibition zones >35 mm for all tested bacterial and fungal strains, validating the assay conditions The enhanced antimicrobial activity of the metal complexes can be attributed to chelation, which reduces the polarity of the metal ions through electron delocalization with the ligand's donor atoms. This increases the lipophilicity of the complexes, facilitating their penetration through microbial cell membranes and enhancing their inhibitory effect. The minimum inhibitory concentration (MIC) results (Table 4) indicate that HBABS and its metal complexes effectively inhibit bacterial growth at 2.5–5.0 mg/mL, while fungal strains require 10 mg/mL, highlighting their potential as antibacterial and antifungal agents.

4.0 Conclusion

The study successfully synthesized the novel Schiff base ligand 2-hydroxybenzy lideneamino benzenesulfonamide (HBABS) and its Co(II) and Ni(II) metal complexes. The physical, analytical, and spectroscopic data confirmed the formation of the ligand and its complexes, revealing that HBABS acted as a tetradentate ligand coordinating through azomethine nitrogen, sulfonamide nitrogen and oxygen, and phenolic oxygen. The complexes were colored, microcrystalline solids with decomposition temperatures ranging from 216.81 to 240.09 °C, and exhibited low molar conductance values, indicating non-electrolytic behavior. Elemental analysis results were consistent with calculated values, confirming the proposed 1:1 metal-to-ligand stoichiometry. The solubility studies showed that the ligand and complexes were insoluble in non-polar solvents, slightly soluble in polar protic solvents, and fully soluble in polar aprotic solvents, reflecting their polar nature. FTIR and NMR spectral analyses demonstrated shifts in key vibrational and chemical shift signals upon complexation, providing evidence of coordination through the azomethine nitrogen, sulfonamide groups, and hydroxyl group. UV-Vis spectroscopy revealed intra-ligand charge transfer transitions in the ligand and additional ligand-to-metal charge transfer bands in the complexes, supporting complex formation. Antimicrobial studies indicated that HBABS exhibited significant antibacterial activity against Staphylococcus aureus and Escherichia coli and moderate antifungal activity against Candida albicans, while the Co(II) and Ni(II) complexes displayed enhanced antibacterial and moderate antifungal activities, likely due to increased lipophilicity and electron delocalization in the metal complexes. The minimum inhibitory concentration results further confirmed the effectiveness of the ligand and complexes against bacterial and fungal strains, highlighting their potential as antimicrobial agents. Based on these findings, it can be concluded that the synthesis of HBABS and its metal complexes was successful, and complexation with Co(II) and Ni(II) significantly improved antibacterial activity. It is recommended that further studies be conducted to explore the cytotoxicity, mechanism of action, and potential therapeutic applications of these complexes in pharmaceutical formulations, as well as the synthesis of other transition metal derivatives to expand their bioactivity profile.

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Authors' Contribution

Nkereuwem U. Nyah carried out the experimental work and interpreted the spectra. Brendan C. Asogwa assisted in the interpretation of the results and drafted the initial manuscript. Ifeanyi E. Otuokere and Okenwa U. Igwe conceptualized and supervised the study, led in result interpretation and contributed to manuscript revision. Kelvin O. Amadi assisted in the experimental research work