



DNA Binding Interactions of Amitrole Metal Chelates

*Sambo, B. U., Siraj, I. T., and Sadiq, I. A.

Department of Pure and Industrial Chemistry, Bayero University, Kano, Nigeria

*Corresponding Author: busambo.bus@gmail.com

Accepted September 24, 2026 **Published Online:** October 8, 2026

ABSTRACT

Amitrole derivative ligand was synthesized through condensation reaction of 1H-1,2,4-Triazole-3-amine with 2-hydroxycarbaldehyde in equimolar ratio by reflux via acid catalysis. Metal chelates of Mn(II), Fe(II) and Co(II) with the synthesized ligand were also synthesized by refluxing the ligand with corresponding metal ion in 2:1 mole ratio. Molar conductivity measurement, FT-IR, magnetic susceptibility, CHN elemental analysis, UV-Visible spectroscopy were carried out. Deoxyribonucleic acid (DNA) binding ability was evaluated by electronic absorption titration. FTIR spectra of the ligand showed a strong band at 1611 cm^{-1} assigned to C=N stretching vibrations. The band shifted to higher frequencies in the range of $1614\text{--}1640\text{ cm}^{-1}$ in the spectra of the chelates, indicating chelation between the metals and the nitrogen of the ligand. Low molar conductivity data ($27.8\text{--}45.3\text{ }\Omega^{-1}\text{cm}^2\text{mol}^{-1}$) obtained for the chelates indicated non-conducting nature. Magnetic moments values (3.94-5.84 BM) obtained suggested paramagnetic nature and octahedral geometry of the chelates. CHN elemental analysis showed strong agreement with theoretical values for the ligand and the chelates. UV-Visible spectroscopy data (232-424 nm) revealed transitions suitable for chelation. The data of the electronic absorption titration revealed that all the synthesized compounds bonded to DNA with intrinsic binding constant values in the range $8.5 \times 10^3\text{--}2.2 \times 10^4\text{ M}^{-1}$.

Keywords: Amitrole chelates, Condensation reaction, DNA interaction, Spectroscopy.

INTRODUCTION

The therapeutic potential of metal chelates in cancer therapy is of particular research interest, as metals present several characteristics, such as redox activity, different coordination modes, reactivity towards the organic substrate among others, which is essential in the design of antitumor agents. They must be able to selectively interact with the bio-molecular target and subsequently alter the cellular mechanism of proliferation. The development of effective antitumor drugs with

high selectivity and low toxicity is currently a major challenge for the scientific community. Therefore, the evaluation of potential metal-based drug-binding properties for DNA interaction is a crucial step toward identifying the ultimate targets of compounds and consequently towards understanding their modes of action [1].

Nucleic acids are primary therapeutic targets and understanding drug-DNA interactions is essential to the discovery of new clinical agents. In order for a compound to become a cancer therapeutic agent, it must possess the ability to reach the vicinity of the DNA double helix and interact with the nucleic acid molecule. The main metal binding domains on nucleotides are the O atoms contained in the anionic phosphate groups, the sugar hydroxyls and the heteroatoms (N, O) on the organic bases units [2-4]. There are several mechanisms known to be involved in DNA binding. They are covalent and non-covalent interactions. The covalent interaction or metal base coordination is an irreversible binding represented by an intra or inter strand cross-link. The non-covalent interaction is generally a reversible binding represented by intercalation between DNA base pairs, insertion, major or minor groove binding and electrostatic interactions with the sugar-phosphate DNA backbone [5, 6]. Cis-platin and other clinically approved anticancer platinum based agents interact with DNA covalently by forming intra or inter strand cross-links [7, 8]. On the other hand, non-covalent interactions between DNA and small molecules could also be based on thermodynamic stabilization through hydrogen bonding, hydrophobic interactions and π -stacking interactions [9].

Recent progress in probing small molecule interactions with DNA were reported by Simon *et al.*, 2025 [10]. The study of how metal-based compounds interact with DNA is a cornerstone of bioinorganic and medicinal chemistry, particularly in designing anticancer therapeutics, artificial restriction enzymes and diagnostic biosensors [11]. Bio-essential transition metals such as copper, cobalt and nickel chelates have shown their efficiencies as potential DNA binders and anticancer agents [12, 13], thus offering a safe and more effective alternative to the available platinum-based drugs with higher toxicity, tumor resistance and severe side effects [13].

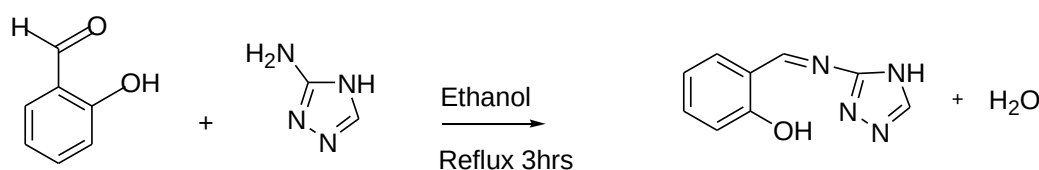
In an effort to explore more metal-based anticancer therapeutic candidates, this study reports the synthesis, characterization and DNA interaction of amitrole derived chelates as a crucial step in cancer therapeutic agents' development.

MATERIALS AND METHODS

The reagents used in this work are of analytical grade and were used without further purification. They were obtained in high purity from Sigma-Aldrich. The glass ware used in this experiment were soaked in concentrated HNO_3 and washed with detergent then rinsed with distilled water and dried in an oven at 120°C . Mettler balance model AB54 was used for weighing. Infrared spectral analysis was conducted using Agilent technologies Cary 630 Fourier transform infrared spectrophotometer, conductivity measurement was carried out using Jenway 4010 conductivity meter, melting point and decomposition temperature was carried out using Gallenkamp melting point apparatus MPD 350 series, magnetic susceptibility measurement was conducted using magnetic susceptibility balance MK1 model and electronic spectra was obtained from Perkin Elmer LAMBDA 365 UV-Visible spectrophotometer. Atomic absorption spectroscopy was carried out using Perkin Elmer PinAAcle 900H and CHN micro analysis was obtained using Perkin Elmer series II 2400 elemental analyzer. DNA binding ability was determined through electronic absorption titration using calf thymus DNA.

Synthesis of Amitrole Ligand

An ethanolic solution of 2-hydroxycarbaldehyde (0.12212 g, 1 mmol) with few drops of acetic acid added and heated at 80°C for 15 minutes, then a solution of 1H-1,2,4-Triazole-3-amine (0.08408 g, 1 mmol) also in ethanol was added and the mixture refluxed with continuous stirring for 3 hours (Scheme 1). The resulted product was obtained after cooling, then filtered, recrystallized in ethanol and dried in a desiccator over P_4O_{10} [14].

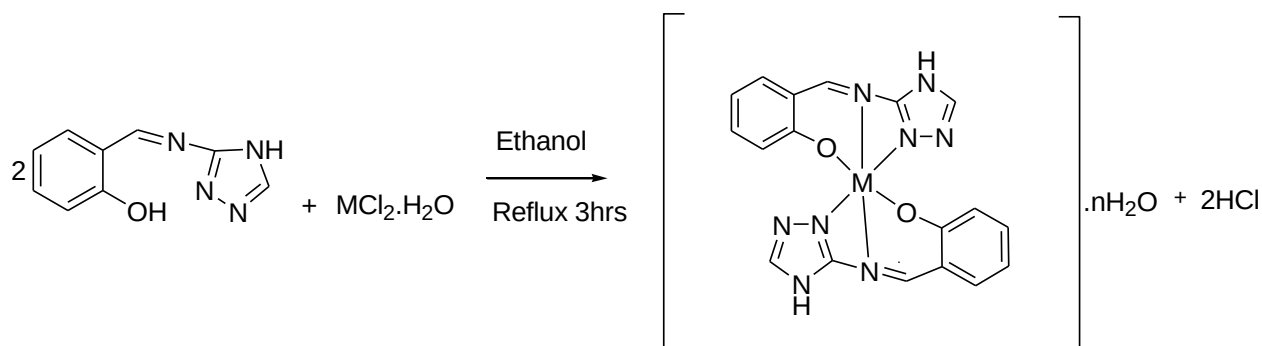


Scheme 1: Synthetic Reaction of Amitrole Ligand

Synthesis of Amitrol Metal Chelates

The metal(II) chelates were synthesized from the reaction of corresponding metal salts $\text{MCl}_2 \cdot n\text{H}_2\text{O}$ 1 mmol in 25 cm^3 ethanol and a stirred ethanolic solution of the synthesized amitrole ligand (0.3764 g, 2 mmol) as shown in Scheme 2. The mixtures were refluxed at 80°C with continuous

stirring for 4 hours, the resulted products were filtered after cooling, then recrystallized in ethanol and dried over P₄O₁₀ in a desiccator [14].



Scheme 2: Synthetic Reaction of Amitrole Metal(II) Chelates

Where M = Metal (Mn(II), Fe(II) and Co(II)); n=Stoichiometric number

DNA Binding Studies

The DNA binding ability of the synthesized amitrole ligand and its respective metal(II) chelates were carried out through electronic absorption titration experiment. Calf thymus deoxyribonucleic acid (ct-DNA) solution at different concentration of 20, 40, 60 and 80 μ M were prepared in Buffer medium (50 mM NaCl, 5 mM *Tris-HCl*, and pH 7.2) and the synthesized compounds were dissolved in DMSO to give 25 μ M concentrations. The two solutions (ct-DNA and the respective compounds) were mixed together keeping the concentration of the compounds constant while varying the concentration of the ct-DNA and then incubated for about 5 minutes. The absorbance in the UV-Visible region 250-400 nm were taken [15]. The obtained spectra were used to calculate the intrinsic binding constant of the compounds to DNA with the help of Wolfe-Shimmer equation (I) [16].

$$\frac{[DNA]}{E_a - E_f} = \frac{[DNA]}{E_b - E_f} + \frac{1}{K_b(E_b - E_f)} \quad \text{Equation I}$$

Where [DNA] is the concentration of ct-DNA, E_a is the apparent absorption coefficient corresponding to $A_{obs}/[\text{compound}]$, E_f is the extinction coefficient of the free compound and E_b is the extinction coefficient of the compound when fully bounded to ct-DNA. From the plot of $[DNA]/(E_a - E_f)$ versus [DNA]. The intrinsic binding constant, K_b can be calculated from the ratio of the intercept to the slope.

RESULTS AND DISCUSSION

The synthesized compounds were obtained at an appreciable yield of 70-77.6% which reflected the proper optimization of the reaction. Distinctive color intensities were observed for the compounds and this may be attributed to transitions due to the presence of chromophores in the compounds and probably charge transfer in the case of the metal(II) chelates. The melting point value of the ligand (180 °C) and the decomposition temperatures of the metal(II) chelates in the range 290-320 °C indicated the stability of the synthesized compounds with respect to heat. The data are reported in Table 1.

Table 1: Physiochemical Properties of the Ligand and its Metal(II) Chelates

Compound	Colour	Yield(%)	M. Point (°C)	D. Temp.(°C)
L	Yellow	77.60	180	-
[Mn(L) ₂].H ₂ O	Deep Yellow	73.10	-	320
[Fe(L) ₂].2H ₂ O	Dark Green	87.00	-	300
[Co(L) ₂].2H ₂ O	Light Purple	76.30	-	290

Key: L = C₉H₈N₄O, M. Point = Melting point temperature, D. Temp. = Decomposition temperature.

The solubility test of the synthesized compounds carried out in common solvents revealed that the ligand was soluble in acetone, DMF and DMSO. The ligand was soluble in ethanol at elevated temperature while slightly soluble in ethanol, methanol and H₂O but insoluble in the rest of the solvents. The metal(II) chelates were also soluble in DMF and DMSO. The data indicated that the synthesized compounds are likely mixed polar and non-polar substances. Moreover, the decrease in solubility of the chelates may be as a result of chelation as explained by Tweedy chelation theory. The data are presented in Table 2.

Table 2: Solubility Test of the Ligand and its Metal(II) Chelates in Some Common Solvents

Compound	nhexane	Benzene	D.Ether	CHCl ₃	Acetone	Ethanol	Methanol	DMF	DMSO	H ₂ O
L	IS	IS	IS	IS	S	SS	SS	S	S	SS
[Mn(L) ₂].H ₂ O	IS	IS	IS	IS	IS	IS	IS	S	S	IS
[Fe(L) ₂].2H ₂ O	IS	IS	IS	IS	IS	IS	IS	S	S	IS
[Co(L) ₂].2H ₂ O	IS	IS	IS	IS	IS	IS	IS	S	S	IS

Key: L = C₉H₈N₄O, S = Soluble, SS = Slightly soluble, IS = Insoluble.

Water of crystallization determination carried out by heating the measured sample in an oven at 110 °C until a constant weight was attained. The weight of the anhydrous sample was deducted from the weight of the original sample, the difference was considered as the mass of water lost which is used to calculate the percentage and number of water of crystallization present in each metal(II) chelate. The data as shown in Table 3 suggested the presence of water of crystallization in the synthesized chelates.

Table 3: Water of Crystallization Analysis of the Ligand and its Metal(II) Chelates

Compound	Hydration Temp.	Weight Loss(g)	%H ₂ O	Water of Hydration
		Observed (Calculated)		
[Mn(L) ₂].H ₂ O	110 °C	0.0179 (0.018)	4.024	1
[Fe(L) ₂].2H ₂ O	110 °C	0.0361 (0.0363)	7.722	2
[Co(L) ₂].2H ₂ O	110 °C	0.0361 (0.0363)	7.722	2

The ability of a compound to produce ions in solution is determined by its electrolytic nature. The molar conductance values of the synthesized metal(II) chelates in DMSO solvent at room temperature are presented in Table 4. The values obtained were in the range of 27.8-45.3 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$ (below 50 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$) and this suggested that the synthesized metal(II) chelates were non-electrolyte [17].

Table 4: Molar Conductance Measurement of the Metal(II) Chelates

Compound	Concentration (mol dm ⁻³)	Specific Conductance ($\Omega^{-1}\text{cm}^{-1}$)	Molar Conductance ($\Omega^{-1}\text{cm}^2\text{mol}^{-1}$)
[Mn(L) ₂].H ₂ O	1x10 ⁻³	39.4 x10 ⁻⁶	39.4
[Fe(L) ₂].2H ₂ O	1x10 ⁻³	45.3 x10 ⁻⁶	45.3
[Co(L) ₂].2H ₂ O	1x10 ⁻³	27.8 x10 ⁻⁶	27.8

In the FT-IR spectra of the ligand and its metal(II) chelates, the intense band due to azomethine $\nu(\text{C}=\text{N})$ stretch was observed at 1611 cm^{-1} in the spectrum of the ligand. The IR spectra of the chelates displayed absorption bands with upward shift in the range of 1614-1640 cm^{-1} indicating their participation in the chelation with the metal ions. A peak at 1577 cm^{-1} due to the presence of

aromatic C=N group has shifted to lower frequencies (1547-1559 cm^{-1}) in the spectra of the chelates suggesting their participation in the chelation. The metal-ligand bond was further substantiated by the appearance of absorption bands in the range of 611-633 cm^{-1} assigned to $\nu(\text{M-N})$ which were absent in the spectrum of the ligand. A broad band at 3100 cm^{-1} confirmed the presence of O-H group in the spectrum of the ligand, while the broader bands in the range of 3123-3141 cm^{-1} in the spectra of the chelates were due to the presence of water of crystallization outside the coordination sphere of the chelates. A band at 1276 cm^{-1} assigned to C-O in the spectrum of the ligand which was shifted to the range of 1208-1279 cm^{-1} in the spectra of the chelates suggested the involvement of deprotonated Phenolic-O in the chelates formation, this has been further supported by the appearance of bands in the range of 440-459 cm^{-1} assigned to $\nu(\text{M-O})$ stretching vibrations, which were absent in the spectrum of the ligand. The overall data suggested the ligand to be tridentate, chelated through N-N-O donor atoms. The FT-IR data are reported in Table 5.

Table 5: Infrared Spectral Data of the Ligand and its Metal(II) Chelates

Compound	$\nu(\text{C=N})_{\text{azomethine}}$	$\nu(\text{C=N})_{\text{triazole}}$	$\nu(\text{M-N})$	$\nu(\text{M-O})$	$\nu(\text{C-O})$	$\nu(\text{H}_2\text{O})$
L	1611	1577	-	-	1276	3100
$[\text{Mn}(\text{L})_2] \cdot \text{H}_2\text{O}$	1614	1544	633	440	1279	3123
$[\text{Fe}(\text{L})_2] \cdot 2\text{H}_2\text{O}$	1640	1536	629	459	1208	3123
$[\text{Co}(\text{L})_2] \cdot 2\text{H}_2\text{O}$	1633	1547	611	444	1231	3141

The presence of unpaired electrons in the orbitals of the metal(II) chelates according to the data obtained (Table 6) revealed their paramagnetic nature and the values of the magnetic moment obtained (5.84, 5.16 and 3.94 BM) indicated octahedral geometries [18].

Table 6: Magnetic Susceptibility Measurement of the Metal(II) Chelates

Compound	χ_g ($\text{ergG}^{-2}\text{g}^{-1}$)	χ_m ($\text{ergG}^{-2}\text{mol}^{-1}$)	μ_{eff} (BM)	Number of unpaired electrons
$[\text{Mn}(\text{L})_2] \cdot \text{H}_2\text{O}$	3.3385×10^{-5}	1.4332×10^{-2}	5.84	5
$[\text{Fe}(\text{L})_2] \cdot 2\text{H}_2\text{O}$	2.5946×10^{-5}	1.1162×10^{-2}	5.16	4
$[\text{Co}(\text{L})_2] \cdot 2\text{H}_2\text{O}$	1.5001×10^{-5}	6.500×10^{-3}	3.94	3

The CHN elemental data of the synthesized compounds as shown in Table 7 differs in the range of 0.021–0.269 % with the theoretical data, suggesting good agreement of both data and consistent with 1:2 metal-ligand ratio of the synthesized metal(II) chelates.

Table 7: Elemental Microanalysis of the Ligand and its Metal(II) Chelates

Compound	%C	%H	%N
	Found (Calculated)	Found (Calculated)	Found (Calculated)
L	57.401 (57.440)	4.259 (4.280)	29.501 (29.770)
[Mn(L) ₂].H ₂ O	48.111 (48.330)	3.479 (3.610)	24.950 (25.050)
[Fe(L) ₂].2H ₂ O	46.206 (46.370)	3.811 (3.890)	25.903 (26.030)
[Co(L) ₂].2H ₂ O	46.001 (46.070)	3.799 (3.870)	23.800 (23.880)

The metals were determined by analyzing the corresponding samples of the synthesized compounds solutions in atomic absorption spectrometer. The values obtained (Table 8) confirmed the presence of metal ions in all the synthesized chelates and the derived stoichiometric ratio of metal ions from the obtained data were in good agreement with the CHN elemental analysis data.

Table 8: Atomic Absorption Spectroscopy (Metal Content of the Chelates)

Compound	Mass(g) _{Metal}	% Metal	Number _{Metal}
[Mn(L) ₂].H ₂ O	0.0553	12.28	1
[Fe(L) ₂].2H ₂ O	0.0563	11.98	1
[Co(L) ₂].2H ₂ O	0.0590	12.56	1

The electronic absorption spectra of the ligand showed intra ligand $\pi \rightarrow \pi^*$ transitions in the region of (331–342 nm) and also displayed $n \rightarrow \pi^*$ inter ligand transitions band at 356 nm which may be due to the presence of C=N chromophores and auxochromes in the ligand. Subsequently, the bands of both $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ were shifted in the distinctive wavelength regions of 232–345 nm and 326–374 nm respectively, in the spectra of the chelates indicating that chelation may have taken place. Additionally, new bands in the range of 334–424 nm assigned to charge transfer transitions appeared in the spectra of the synthesized chelates which further supported the formation of the metal(II) chelates. The values are presented in Table 9.

Table 9: Electronic Spectra of the Ligand and its Metal(II) Chelates

Compound	$\pi-\pi^*(\text{nm})$	$\pi-\pi^*_{\text{Benzene}}(\text{nm})$	$n-\pi^*(\text{nm})$	C-T
L	331	342	356	
[Mn(L) ₂].H ₂ O	232	248	326	334
[Fe(L) ₂].2H ₂ O	340	345	374	424
[Co(L) ₂].2H ₂ O	234	296	330	340

Basically, five factors are considered in assessing interactions with DNA; hypochromic and hyperchromic effects with respect to absorbance, hypsochromic and bathochromic effects with respect to wavelength and the intrinsic binding constant. As such, the interaction can be investigated based on comparison of absorption spectra and/or shift in peaks position before and after the reaction with DNA [19, 20].

Hyperchromic and hypsochromic effects were observed in the spectra of the ligand and its metal(II) chelates. These indicated a surface binding interaction between the compounds and ct-DNA, probably groove binding. Based on the values obtained, Fe(II) chelate displayed the highest magnitude of change with 39.65 % chromism while Mn(II) showed highest affinity to ct-DNA with an intrinsic binding constant value of $K_b = 2.2 \times 10^4 \text{ M}^{-1}$.

Table 10: DNA Binding Spectral Data of L and its Metal(II) Chelates

Compound	$\lambda_{\text{max}}(\text{nm})$ (Free)	$\lambda_{\text{max}}(\text{nm})$ (Bound)	A_{max} (Free)	A_{max} (Bound)	Chromism (%)	$K_b (\text{M}^{-1})$
L	252	250	2.7158	3.4463	26.899	1.7×10^4
[Mn(L) ₂].H ₂ O	252	250	2.7158	3.1465	15.86	2.2×10^4
[Fe(L) ₂].2H ₂ O	252	250	2.7158	3.7925	39.65	1.6×10^4
[Co(L) ₂].2H ₂ O	252	250	2.7158	3.1183	14.82	8.5×10^3

CONCLUSION

Amitrole ligand and its Mn(II), Fe(II) and Co(II) chelates were synthesized and characterized successfully. The compounds were obtained in appreciable yields, stable, non-hygroscopic at room temperature with different color intensities and high melting and decomposition temperatures. The solution chemistry data revealed that all the synthesized compounds were soluble in DMF and DMSO. Water of crystallization were found in all the metal(II) chelates. Conductivity data revealed that the synthesized chelates were non-electrolytes. Based on the spectroscopic data octahedral geometry were assigned for the synthesized metal(II) chelates. The data also revealed paramagnetic nature of the chelates and is also in agreement with 1:2 metal-ligand ratio. All the synthesized compounds were found to significantly interact with ct-DNA forming DNA-chelates adducts.

Acknowledgements

The authors are thankful to the Central Laboratory Complex, Bayero University, Kano.

REFERENCES

- [1] Hangan, A.C., Oprean, L.S., Dican, L., Procopciuc, L.M., Sevastre, B. & Lucaciu, R.L. (2024). Metal-Based Drug–DNA Interactions and Analytical Determination Methods, *Molecules*. 29, 4361.
- [2] Cowan, J.A. (1997). Bioinorganic Chemistry: An Introduction Second Edition, Wiley-VCH: New York, NY, USA.
- [3] Pearson, R.G. (1966). Acids and bases, *Science*. 15, 172–177.
- [4] Barone, G., Terenzi, A., Lauria, A., Almerico, A.M., Leal, J.M., Busto, N. & Garcia, B. (2013). DNA-binding of nickel(II), copper(II) and zinc(II) complexes: Structure–affinity relationships, *Coordination Chemistry Review*. 257, 2848–2862.
- [5] Muhammad, A. (2018). Central Dogma of Molecular Biology.
<https://muhammadasif88.medium.com/central-dogma-of-molecular-biology-294d2600a484>
(accessed on 9 September 2024).
- [6] Almaqwashi, A.A., Paramanathan, T., Rouzina, I. & Williams, M.C. (2016). Mechanisms of small molecule–DNA interactions probed by single-molecule force spectroscopy, *Nucleic Acids Research*. 44, 3971–3988.

- [7] Jamieson, E.R. & Lippard, S. J. (1999). Structure, Recognition and Processing of cis-platin-DNA adducts, *Chemical Reviews*. 99, 2467-2498.
- [8] Dasari, S. & Tchounwou, P.B. (2014). Cis-platin in Cancer Therapy: Molecular Mechanisms of Action, *European Journal of Pharmacology*. 740, 364–378.
- [9] Paul, S. & Bhattacharya, S. (2012). Chemistry and Biology of DNA-Binding Small Molecules, *Current Science*. 102, 212–231.
- [10] Simon, P., Brionna, M., Christine, J.C & Andrew, K. (2025). Recent Progress in Probing Small Molecule Interactions with DNA, *Biophysical Reviews*. 17, 1157-1182.
- [11] Ali, S., Elisha, A.A., Mert, S. & Alparlan, K.D. (2021). DNA-Metal Interaction and the Biological Activities of Metal Complexes: An Overview in the Light of Recent Literature, *Revue Roumaine de Chimie*. 66(8-9), 701-711.
- [12] Kumar, R.S., Raj, K.B. & Perumal, P. (2012). Antioxidant activities of *Indigofera cassioides* Rottl. Ex. DC. Using various in vitro assay models, *Asian Pacific Journal of Tropical Biomedicine*. 2, 256–261.
- [13] Sahaa, M.R., Hasana, S.M.R., Aktera, R., Hossaina, M.M., Alamb, M.S., Alam, M.A. & Mazumder, M.E.H. (2008). In vitro free radical scavenging activity of methanol extract of the leaves of *Mimusops elengi* Linn, *Bangladesh Journal of Veterinary Medicine*. 6, 197–202.
- [14] Sumrra, S.H., Zafar, W., Asghar, M.L., Mushtaqa, F., Razaa, M.A., Nazar, M.F., Nadeem M.A., Imran, M. & Mumtaz, S. (2021). Computational investigation of molecular structures, spectroscopic properties, cholinesterase inhibition and antibacterial activities of triazole Schiff bases endowed metal chelates, *Journal of Molecular Structure*. 1238, 130382.
- [15] Jian, Z., Shuang, L., Xinyi, W., Gang, X. & Shaohua, G. (2019). Dinuclear Organoruthenium Complexes Exhibiting Antiproliferative Activity through DNA Damage and a Reactive-Oxygen-Species-Mediated Endoplasmic Reticulum Stress Pathway, *Inorganic Chemistry*. 58(3), 2208-2217.
- [16] Wolfe, A., Shimer, G.J. & Meehan, T. (1987). Polycyclic aromatic hydrocarbons physically intercalate into duplex regions of denatured DNA, *Biochemistry*. 26, 6392-6396.
- [17] Masokano, D.S.A., Sadiq, I.A. & Siraj, I.T. (2025). Antimicrobial Potential of N,N'-(4-bromo-1,2-phenylene)bis(1-(pyridine-2-yl)methanimine) and its Mn(II), Fe(II), Co(II) and Ni(II) complexes, *Arid Zone Journal of Basic and Applied Research*. 4(2), 90-100.

- [18] Dalal, M. (2017). A textbook of Inorganic Chemistry (I). Dalal Institute, Mumbai India.
- [19] Abdel-Rahman, L.H., El-Khatib, R.M., Nassr, L.A.E., Abu-Dief, A.M. & Ismael, M. (2014). Metal based pharmacologically active agents: synthesis, structural characterization, molecular modeling, CT-DNA binding studies and in-vitro antimicrobial screening of iron(II) bromosalicylidene amino acid chelates, *Spectrochim Acta A*. 117, 366–378.
- [20] Althagafi, I., Elghalban, M.G., Saad, F., Al-Fahemi, J.H., El-Metwaly, N.M., Bondock, S., Almazroai, L., Saleh, K.A. & Al-Hazmi, G.A. (2017). Spectral characterization, ct-DNA binding, DFT/B3LYP, molecular docking and antitumor studies for new nano-sized VO(II)-hydrazonoyl complexes, *Journal of Molecular Liquids*. 242, 662–677.