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RESEARCH

Diamagnetic Al^{3+} Doped Ni–Zn Spinel Ferrite: Rietveld Refinement, Elastic, Magnetic, Mössbauer, and Electrical Explorations

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Abstract

$Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ that has been synthesized using a solution-gelation method and calcined at 600 °C for 4 h was characterized using X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM), and transmission electron microscopy (TEM). A single-phase cubic spinel structure belonging to the Fd-3 m space group was confirmed by Rietveld refinement. The cation distribution that was anticipated using the XRD data deviated from the preferential occupancy, and the results of the magnetization analysis supported this. The two absorption bands in the FTIR spectra corresponding to the tetrahedral and octahedral sites further support the establishment of the ferrite skeleton. Al^{3+} doping was found to have a considerable impact on the Debye temperature, bulk modulus, and stiffness modulus measured using FTIR data. Interatomic bonding became stronger, increasing elastic moduli. The morphology was examined using SEM, whose results showed a cluster of grains. Additionally, spherical nanoparticles with an average size of 28 nm were visible in the TEM image, which is in good agreement with the crystallite size given by the Williamson-Hall method. The Mössbauer analysis and M–H data showed a soft magnetic behavior with coercivity fluctuation. According to Arrhenius plots, all samples displayed a semiconducting characteristic. With Al^{3+} doping, dielectric studies revealed a declining trend.

Keywords Rietveld · Cation distribution · Coercivity · Mössbauer · DC Resistivity · Dielectric loss

1 Introduction

Metal oxides and ferric oxides have diverse applications [1–5], which make up ferrites, are classified as spinel, hexagonal ferrites and garnet. Transformers, filters, digital tapes, surface mounting devices, ferroelectric and piezoelectric devices, medical imaging, anti-microbial activity, antennas, information storage devices, inductors, ferrofluids, magneto-caloric refrigeration, battery electrodes, magnetic hyperthermia, etc. are a few examples of these applications [6–13]. For, spinel ferrites, the most notable result is the strong relationship between metallic occupancy over interstitial sites and the method of preparation for structure, morphology, magnetic, Mössbauer, electrical, optical and dielectric properties. Two interstitial sites: tetrahedral (A) and octahedral [B] coordinated with four and six oxygen atoms, respectively, are present in the spinel structure. The typical representations of the overall distribution of cations of the general formula MFe_2O_4 over the (A) and [B] sites are $(M^{2+}_{1-x}Fe^{3+}_{x})and[M^{2+}_{x}Fe^{3+}_{2-x}]O^{2-}_{4}$, respectively. The divalent cation in this instance is designated as "M" and the inversion parameter is "x". They are categorized into three classes based on the inversion parameter: normal, inverse, and mixed when x = 0, x = 1 and 0 < x < 1 respectively. It is important to note that the synthesis method and preparation variables have a significant impact on the cation distribution in addition to the atomic size of iron, valences, and

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crystal field. As a result, academicians and scientists are ever improving the preparation processes [14–17] to get these materials with better qualities. These methods of synthesis include co-precipitation, hydrothermal, micro-emulsion, sol–gel, etc. The sol–gel self-combustion method is the most promising of these methods due to its low processing temperature, high yield, high product purity and crystallinity, improved homogeneity, and ultrafine particle production.

Numerous studies have looked into the structural, magnetic, and electrical properties of Ni–Zn nanocrystalline spinel ferrites [18–21] for their potential use in high frequency devices, gas sensing, magneto-dielectric, magneto-optic, magneto-caloric, as RADAR absorbing materials, and other activities [22–24]. Ni–Zn spinel ferrites are naturally ferrimagnetic materials possessing mixed crystal structure belonging to the Fd-*3 m* space group. The chemical stability, high permeability, moderate magnetism, high Curie temperature, low coercivity, and low dielectric losses are further characteristics of Ni–Zn spinel ferrites. Numerous studies have shown that the technique of preparation, sintering temperature, type, and concentration of dopant all affect the magnetic properties of Ni–Zn spinel ferrites. Therefore, by changing the preparation process and substituting appropriate metal ions, Ni–Zn ferrites can have their physical, magnetic, Mössbauer, optical, electrical, dielectric, etc. properties modified.

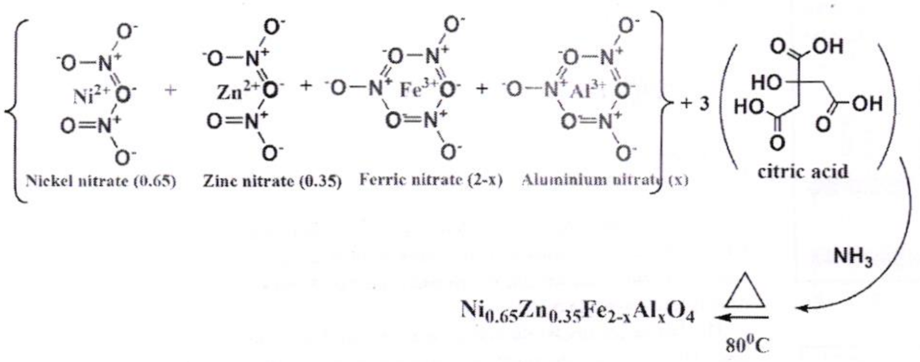
$Ni_{1-x}Zn_xFe_2O_4$ was produced by Deshmukh et al. [25] using a urea-assisted combustion process, and examined its structural, magnetic, and Mössbauer properties. According to experimental findings, a single-phase cubic spinel structure formed. Up to x = 0.4, magnetization enhanced, and for other values of x, it decreased. The linewidth widened due to dispersion of the hyperfine field. The Mössbauer finding supports the M-H results. This study revealed that the $Ni_{0.6}Zn_{0.4}Fe_2O_4$ composition has the potential for enhanced properties and technological applications. $Ni_{0.6}Zn_{0.4}Fe_{1.5}Al_{0.5}O_4$ was made by Massoudi et al. [26] using the sol–gel method and the impact of annealing on its different properties was assessed. As the annealing temperature increased, the produced nanoparticles grew from the nanoscale to the microscale. The physical parameters were tweaked, and the crystallite size varied in relation to the annealing temperature. It is revealed that a key factor in tailoring the properties of spinel ferrites is the substitution of specific cations. Qing Ni et al. [27] looked into the synergistic effects of Li-Al codoping on the microstructure, magnetic and dielectric properties of Ni–Zn ferrites. The grain development and crystal structure were significantly influenced by the amount of codoping. By using resonant stimulation, Gray et al. [28] showed that the spinel complex $Ni_{0.65}Zn_{0.35}Fe_{1.2}Al_{0.8}O_4$ is an excellent source of spin current. For the first time, an aluminium-substituted Ni–Zn system was prepared by Dessai et al. [29] utilizing malic acid as a fuel. The single-phase cubic spinel structure development was verified by the structural analysis. All of the components of the prepared spinel ferrites were present as mapped by EDS mapping. It was discovered that the Curie temperature decreased with the concentration of aluminium.

Other metal oxides that have been doped with various dopants and made using various synthesis techniques imply that the physicochemical and other properties have been significantly influenced. These materials are excellent for a variety of technical applications, such as microwave absorption, supercapacitor electrodes, and electromagnetic interference (EMI) shielding etc. [30–34]. Thus, to improve the physical properties of materials and increase their appropriateness for various applications, it is crucial to choose the appropriate substituent [35].

Superexchange interactions, which may be further strengthened by trivalent Al^{3+} ions, are responsible for the altered magnetic and dielectric properties of Ni–Zn ferrites. It is a well known fact that changing a nonmagnetic material, such Fe^{3+} to Al^{3+}, raises resistance and lowers saturation magnetization, changing both the electrical and magnetic properties. All things considered, it can be said that the insertion of Al^{3+} ions results in a major modification in structure and cationic organization. Furthermore, this helps to lower magnetic coercivity and dielectric loss. In light of this, the present study concentrates on the preparation of nanoparticles and how the trivalent Al^{3+} ions impact the structure and cationic organization of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ with x = 0.0, 0.5, and 1.0. Furthermore, it aims to assess the effects of structure and cation distribution on elastic, magnetic, Mössbauer, DC electrical and dielectric properties via Al^{3+} inclusion.

2 Experimental

Ni–Zn ferrite that has Al^{3+} ($Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ with x = 0.0, 0.5, and 1.0) integrated into it was prepared using the sol–gel self-combustion approach. Citric acid ($C_6H_8O_7$), a reducing agent of AR grade, and all nitrates, a source of metal ions, were utilized as received with no further purification. The respective metal nitrates and fuel ratio was chosen in a 1:3 in accordance with a propellant chemistry technique. Separately, stoichiometric amount of $C_6H_8O_7$ and each metal nitrate was dissolved in distilled water. Then, these various solutions were combined in a beaker and stirred for few minutes. Ammonium solution was added drop by drop to adjust the pH level to a neutral range (7 pH). The wet gel was then created by heating this solution at 80 °C for 4 h. The temperature was further increased to 120 °C once the viscous gel had formed. The viscous gel started to bubble as soon as all of the water molecules evaporate. A little while later, it began to fire and burn alongside the blazing flints. The auto combustion was finished quickly, producing soft ash. Our past reports provide a more thorough explanation of the synthesis process [19, 36]. A schematic of the chemical reaction to be carried out is presented as follows.



A mortar and pestle was used to grind the loose powder. It was then heated at 600 °C for 4 h to improve crystallinity. With the aid of advanced equipment, the annealed powder was characterized for structural, morphological, elastic, magnetic, Mössbauer, DC electrical and dielectric investigations.

2.1 Characterization

Using a Cu target, Kα radiation, 40 kV, and 40 mA a Philips X-ray diffractometer (XRD), all samples were characterized. The cation distribution and several structural parameters were inferred from the XRD results. A Perkin Elmer spectrometer was used to conduct FTIR analyses of all samples in the 400–4000 cm^{-1} range. The elastic properties were assessed using FTIR data. For morphological analyses, a scanning electron microscope (SEM, JEOL JSM 6360) was used. Furthermore, a transmission electron microscope (TEM, Philips, CM 200) was used to determine the morphology and particle size. A pulse field hysteresis tracer was used to measure the magnetization as a function of the applied magnetic field, which was ± 5000 Oe at room temperature. The Mössbauer measurements were also performed using a ^{57}Co source and a Mössbauer spectrometer (FAST Com Tec 070906), and each spectra was examined using the MossWinn 4.0 application. A natural iron absorber served as the velocity calibrator. A two-probe technique was used to measure the DC electrical properties as a function of temperature in the range from ambient temperature to 850 K. The electrical parameters such as DC resistivity, activation energy, drift mobility, charge carrier concentration, and diffusion coefficient were obtained using the DC electrical measurements. Furthermore, a two-probe technique was used to measure the dielectric properties as a function of frequency in the range of 50 Hz to 1 MHz. The dielectric constant for each sample was calculated using capacitance that was measured in parallel.

3 Results and Discussion

3.1 Rietveld Analysis

The Rietveld refinement patterns of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ for x = 0.0, 0.5, and 1.0 samples are shown in Fig. 1. The lines of black, red, and blue, respectively, denote the lines of experimental intensities, computed intensities, and the difference between them. Since the discrepancy between the experimental and calculated XRD patterns is so minor, that they match quite well. Moreover, the XRD pattern showed no extra peaks, supporting pure phase formation across all samples. All of the XRD patterns with the Miller indices (220), (311), (222), (400), (420), (511), (440), (620), and (533) attest to the creation of a single-phase cubic spinel structure that belongs to the Fd-3 m space group. Additionally, the refinement parameters are also included in each refined XRD pattern. These numbers show that the refinement is in line with the experimental results. The different structural parameters, including the lattice parameter (a), crystallite size (D), X-ray density (d_x), porosity (P), dislocation density (δ), and strain (ε) of all samples, were calculated from the XRD data using formulas given in [37]. These results are listed in Table 1.

$$a = d\sqrt{h^2 + k^2 + l^2}\,\text{Å} \tag{1}$$

$$D = \frac{0.9\lambda}{\beta cos\theta} nm \tag{2}$$

$$d_X = \frac{Z \times M}{V \times N_A}\frac{gm}{cm^3} \tag{3}$$

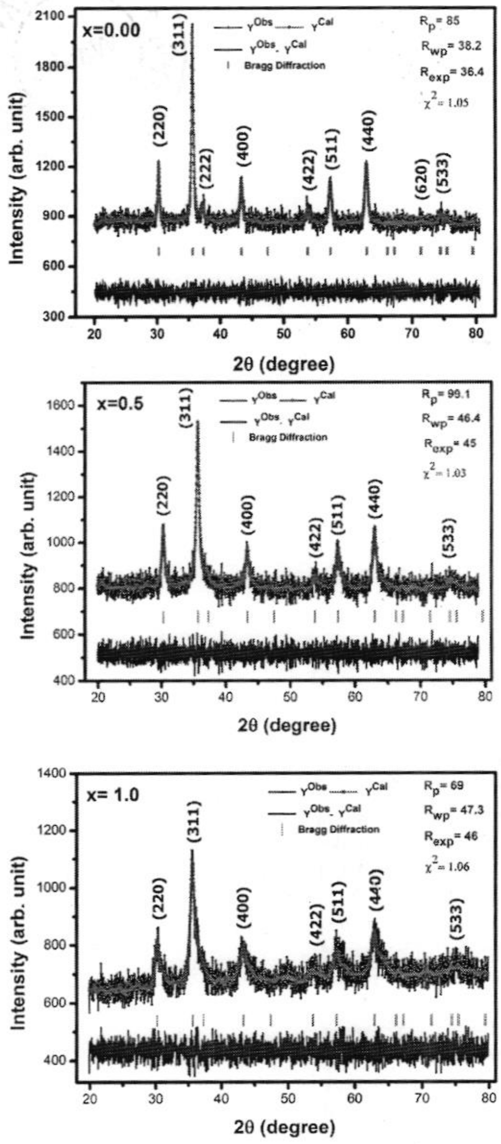


Fig. 1 Rietveld refined XRD patterns of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x = 0.0, 0.5, and 1.0 samples

$$P = 1 - \frac{d_B}{d_X}\% \tag{4}$$

$$\delta = \frac{1}{t^2} lines/m^2 \tag{5}$$

$$\varepsilon = \frac{\beta Cos\theta}{4} \tag{6}$$

where, d interplanar spacing, (h, k, l) Miller indices, λ wavelength, β full width at half maxima, θ angle, Z number of atoms per unit cell, M molecular weight, N_A Avogadro number, d_B bulk density and t-average particle size

The lattice parameter decreased with the Al^{3+} ion content. The observed decrease was attributed to the ionic radii of Fe^{3+} and Al^{3+} ions being different. The decrement is caused by the substitution of lower ionic radii Al^{3+} ions (0.064 nm) for higher ionic radii Fe^{3+} ions (0.067 nm). This decrease is consistent with studies in the literature [38]. Scherrer's formula and Williamson-Hall (W–H) plot (Fig. 2) study showed that the average crystallite size reduced with an increase in Al^{3+} ions, from 25 to 10 nm and 28 nm to 15 nm, respectively. The crystallite size values discovered using W–H analysis is in agreement with those discovered through the Debye–Scherrer formula. Table 1 demonstrates that the X-ray density rises as the Al^{3+} amount does. The lattice parameter and the X-ray density are inversely connected. Therefore, the drop in lattice parameter can be used to explain the observed rise in X-ray density. Using the Archimedes principle, the bulk densities of all samples were calculated, and the results are shown in Table 1. According to Table 1, bulk density values ranged from 3.638 gm/cm^3 to 3.587 gm/cm^3. Additionally, it is noted that the bulk density values are significantly lower than the X-ray density values, leading to high porosity values. Because of the increasing value of the X-ray density, the % porosity computed from relation (5) reported in Table 1 enhanced with the Al^{3+} content. Furthermore, the agglomeration of particles during the synthesis is to account for the high values of porosity (32% to 46%). According to relation (6), the dislocation density (δ) values of all samples fall between 4.41×10^{15} and 38.71×10^{15} lines/m^2. Table 1 lists the lattice strain values, which range from 1.61×10^{-3} to 7.1×10^{-3}.

Table 1 Structural parameters of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x = 0.0, 0.5 and 1.0) samples

Sample code	a (Å)	V (Å)^3	d_x (g/cm^3)	d_B (g/cm^3)	P (%)	D (nm)		δ (lines/m^2)	ε (%)
						XRD	W–H		
x = 0.0	8.372	586.9	5.358	3.638	32	25	28	4.41×10^{15}	1.61×10^{-3}
x = 0.5	8.325	577.1	5.759	3.617	40	14	17	11.45×10^{15}	2.30×10^{-3}
x = 1.0	8.298	571.6	6.129	3.587	46	10	15	38.71×10^{15}	7.10×10^{-3}

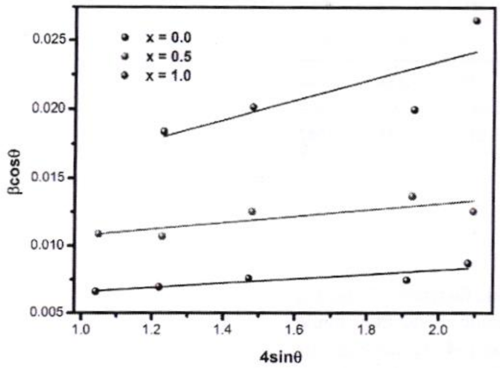


Fig. 2 W–H plots of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x=0.0, 0.5, and 1.0 samples

3.2 Hopping Length (LA and LB)

The following relations were used to determine the hopping length for the tetrahedral (A) (L_A) and octahedral [B] sites (L_B) [39].

$$L_A = a\sqrt{3/4} \tag{7}$$

$$L_B = a\sqrt{2/4} \tag{8}$$

Table 2 lists the values for the L_A and L_B hopping lengths. Both L_A and L_B decrease with Al^{3+} content, as shown in Table 2. The reduction in the lattice parameter with Al^{3+} content is the cause of the decrease in hopping length.

The standard relations provided were used to calculate the tetrahedral bond length (d_{AX}), octahedral bond length (d_{BX}), tetra edge (d_{AXE}), octa edge (d_{BXE}), and (d_{BEU}) for all samples $d_{AX} = a\sqrt{3(u - \frac{1}{4})}, d_{BX} = a\sqrt{3u^2 - \frac{11}{4}u + \frac{43}{64}}$, $d_{AXE} = a\sqrt{2(2u - \frac{1}{2})}, d_{BXE} = a\sqrt{2(1 - 2u)}, d_{BEU} = a\sqrt{4u^2 - 3u + \frac{11}{16}}$

Table 2 provides the values for each of these structural parameters. All of these metrics decrease with increasing Al^{3+} content, as seen in Table 2. This is so because the lattice parameter directly affects these parameters.

3.3 Ionic Radii (r_A and r_B)

The lattice parameter "a" and the oxygen positional parameter "u" (0.381) can be used to compute the ionic radius of the tetrahedral A-site (r_A) and the octahedral B-site (r_B), respectively. Table 2 lists the tetrahedral and octahedral ionic radii's respective values.

$$r_A = \left(u - \frac{1}{4}\right)a\sqrt{3} - r(O^{2-}) \tag{9}$$

$$r_B = \left(\frac{5}{8} - u\right)a - r(O^{2-}) \tag{10}$$

where the radius of oxygen anions is shown by the symbol r $(O)^-$. Table 2 lists the tetrahedral and octahedral ionic radii values. Both of these values fall as the Al^{3+} content rise.

3.4 Interionic Distances and Bond Angles

The spinel ferrite structure is presented schematically in Fig. 3 together with a bond length and bond angle [40]. The interionic distance between ions, i.e. the cation-cation (Me–Me) distances (b, c, d, e, f) and cation–anion (Me–O) distances (p, q, r, s), were computed taking into account the experimentally observed values of the lattice parameter and

Table 2 Structural parameters of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x=0.0, 0.5 and 1.0) samples

Sample code	L_A (Å)	L_B (Å)	d_{AX} (Å)	d_{BX} (Å)	d_{AXE} (Å)	d_{BXE} (Å)	d_{BXEu} (Å)	r_A (Å)	r_B (Å)
x=0.0	3.625	2.960	1.899	2.044	3.102	2.818	2.961	0.579	0.723
x=0.5	3.605	2.435	1.889	2.032	3.084	2.802	2.945	0.569	0.711
x=1.0	3.593	2.428	1.883	2.026	3.075	2.793	2.936	0.563	0.704

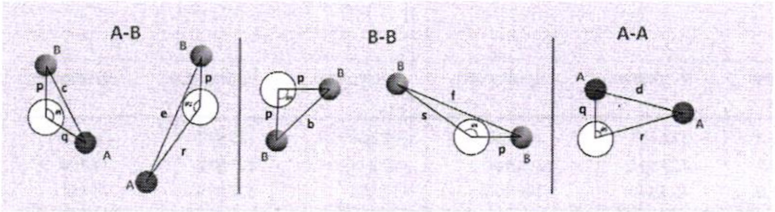


Fig. 3 Schematic for interionic distances and bond angles of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, (x=0.0)

Table 3 Interionic distance values (p, q, r, s, b, c, d, e and f) of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x=0.0, 0.5 and 1.0) samples

Sample code	p (Å)	q (Å)	r (Å)	s (Å)	b (Å)	c (Å)	d (Å)	e (Å)	f (Å)
x=0.0	2.043	1.898	3.636	3.654	2.961	3.471	3.625	5.438	5.127
x=0.5	2.031	1.888	3.617	3.633	2.943	3.451	3.605	5.407	5.098
x=1.0	2.024	1.883	3.605	3.622	2.934	3.441	3.593	5.391	5.082

oxygen positional parameter (u=0.381 Å). These interionic distances are crucial in determining the magnetic properties and are helpful in describing the crystallographic structure. The following relations are used to estimate the interionic bond distances between cations and cation-anions, and their values are provided in Table 3:

3.5 Me–Me distances

$$b = \sqrt{2}\left(\frac{a}{4}\right)$$

$$c = \sqrt{11}\left(\frac{a}{8}\right)$$

$$d = \sqrt{3}\left(\frac{a}{4}\right)$$

$$e = \sqrt{3}\left(\frac{3a}{8}\right)$$

$$f = \sqrt{6}\left(\frac{a}{4}\right)$$

3.6 Me–O distances

$$p = a\left(\frac{5}{8} - u\right)$$

$$q = a\sqrt{3}\left(u - \frac{1}{4}\right)$$

$$r = a\sqrt{11}\left(u - \frac{1}{4}\right)$$

$$s = a\sqrt{3}\left(\frac{u}{3} + \frac{1}{8}\right)$$

According to Table 3, the interionic distances all shorten as the Al^{3+} content rises. The interionic connection should become stronger when the Me-Me and Me-O distances are reduced. The literature [41] contains similar findings for sol–gel combustion-produced nanocrystalline spinel ferrites. The following relations are used to determine the bond angles, namely θ_1, θ_2, θ_3, θ_4 and θ_5, between the cations and cation-anions:

3.6.1 Bond angles

$$\theta_1 = Cos^{-1}\left(\frac{p^2 + q^2 - c^2}{2pq}\right)$$

$$\theta_2 = Cos^{-1}\left(\frac{p^2 + r^2 - e^2}{2pr}\right)$$

$$\theta_3 = Cos^{-1}\left(\frac{2p^2 - b^2}{2p^2}\right)$$

$$\theta_4 = Cos^{-1}\left(\frac{p^2 + s^2 - f^2}{2ps}\right)$$

$$\theta_5 = Cos^{-1}\left(\frac{r^2 + q^2 - d^2}{2rq}\right)$$

The calculated bond angles are shown in Table 4, which indicates that θ_1, θ_2 and θ_5 decrease with Al^{3+} content, while bond angles θ_3 and θ_4 increase with Al^{3+} substitution. This behavior can be attributed to the A–A and A–B exchange interaction being weaker, while the B–B exchange interaction becoming stronger. The variations in bond angle values

Table 4 Bond angle values (θ_1, θ_2, θ_3, θ_4, θ_5) of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x=0.0, 0.5 and 1.0) samples

Sample code	θ_1 (degrees)	θ_2 (degrees)	θ_3 (degrees)	θ_4 (degrees)	θ_5 (degrees)
x=0.0	123.355	145.017	92.828	125.912	74.523
x=0.5	123.343	144.961	92.848	125.916	74.489
x=1.0	123.340	144.946	92.853	125.918	74.481

are attributed to cation rearrangement with varying superexchange interactions. As a result, we can anticipate a decrease in magnetization with Al^{3+} replacement owing to changes in bond angles.

3.7 Cation Distribution

The cation distribution was established to establish the site occupancy of the cations over interstitial sites (A) and [B], which is highly beneficial for understanding the structural features of spinel ferrites. For this objective, the relative intensity calculations approach employing Eq. 11 [42] was used to calculate the intensity ratios for all samples.

$$I_{hkl} = |F|^2_{hkl} P L_p \tag{11}$$

where I_{hkl} is the intensity ratio, F is the structure factor, P is the multiplicity factor and L_p is the Lorenz-polarization factor. The multiplicity factor P for powder photographs of the cubic system, i.e., for 422, 440, 220 and 400 plane multiplicities of 24, 12, 12 and 6 Å, respectively. Only Bragg's diffraction angle determines Lorentz polarisation, which is determined by Eq. 12 [43].

$$L_p = \left[\frac{1+\cos^2 2\theta}{\sin^2\theta\cos\theta}\right] \tag{12}$$

For the intensity ratio calculations, the (hkl) planes (220), (400), and (422) were taken into account. $Ni_{0.65}Zn_{0.35}Fe_{2-x}Al_xO_4$ (x = 0.0, 0.5, and 1.0) samples cation distribution were estimated using some of the peak intensity ratio combinations with the highest sensitivity for cation distribution, such as I_{400}/I_{220}, I_{422}/I_{220}, and I_{422}/I_{400} [44, 45]. These intensity ratio combinations and the measured intensity ratios were compared. Although there is some discrepancy between the estimated and observed intensity ratios (Table 5), the closer agreement between ratios was deemed to represent the ideal cation distribution, and Table 6 reflects this.

Table 6 demonstrates that on the Al^{3+} ions incorporation, nickel ions occupied both the (A) and [B] sites whereas the divalent zinc ions heavily moved to the [B] locations. Previous investigations [46–49] have also noted this occupancy preference for spinel ferrites synthesized via the sol–gel auto combustion method, particularly for Zn^{2+} ions. Additionally, Table 6 demonstrates that Al^{3+} is present at both the (A) and [B] sites. Ni–Zn ferrites are reported to have a mixed spinel structure, with Zn^{2+} having strong preference for tetrahedral (A) sites, Ni^{2+} and Fe^{3+} having preference for both (A) and (B) sites, and Al^{3+} having preference for (B) sites. The surface energy is insufficient at a nanoscale dimension to locate the cations in their typical locations. Redistribution of cations in contrast to their typical occupancy is thus feasible. This results in extraordinary properties due to the size-dependent cation dispersion. Additionally, the estimated cation distribution was used to calculate the magneton number (B_{cal}) for all three samples, which matches the observed magneton number (B_{obs}) calculated using magnetization data quite well. As a result, both the estimated cation distribution from magnetization data and that from XRD data are validated and reported in Table 6.

3.8 FTIR

The successful development of spinel structures and the existence of the other functional entities in Al^{3+}-substituted Ni–Zn spinel ferrites were investigated using Fourier transform infrared (FTIR) spectroscopy. The transmittance spectra captured in the wavenumber range of 350 cm^{-1} to 4000 cm^{-1} are shown in Fig. 4. The spectra contain the two dominant vibrational mode frequencies (υ_1

Table 5 Intensity ratios and their differences used for the estimation of cation distribution of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x = 0.0, 0.5 and 1.0) samples

Sample	I_{400}/I_{220}			I_{422}/I_{220}			I_{422}/I_{400}		
	obs	cal	diff	obs	cal	diff	obs	cal	diff
x = 0.0	0.9017	0.9006	0.0011	0.7981	0.4679	0.3302	0.8862	0.5188	0.3673
x = 0.5	0.9135	0.8623	0.0512	0.8045	0.4703	0.3342	0.8807	0.5454	0.3353
x = 1.0	0. 9958	0.9586	0.0372	0.8692	0.4776	0.3916	0.9067	0.4653	0.4272

Table 6 Cation distribution from XRD and magnetization as well as magneton number (experimental (Obs) and theoretical (Cal)) of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x = 0.0, 0.5 and 1.0) samples

Sample	Cation distribution from XRD		Cation distribution from Magnetization		η_B (μ_B)	
	(A) site	[B] site	(A) site	[B] site	Obs	Cal
0.0	$(Ni_{0.14}Zn_{0.03}Fe_{0.83})$	$[Ni_{0.51}Zn_{0.32}Fe_{1.17}]$	$(Ni_{0.15}Zn_{0.024}Fe_{0.826})$	$[Ni_{0.50}Zn_{0.326}Fe_{1.174}]$	2.45	2.44
=0.5	$(Ni_{0.11}Zn_{0.09}Al_{0.11}Fe_{0.68})$	$[Ni_{0.53}Zn_{0.26}Al_{0.39}Fe_{0.82}]$	$(Ni_{0.11}Zn_{0.09}Al_{0.11}Fe_{0.68})$	$[Ni_{0.53}Zn_{0.26}Al_{0.39}Fe_{0.82}]$	1.53	1.52
x = 1.0	$(Ni_{0.07}Zn_{0.12}Al_{0.30}Fe_{0.51})$	$[Ni_{0.58}Zn_{0.23}Al_{0.70}Fe_{0.49}]$	$(Ni_{0.07}Zn_{0.13}Al_{0.29}Fe_{0.51})$	$[Ni_{0.58}Zn_{0.22}Al_{0.71}Fe_{0.49}]$	0.93	0.92

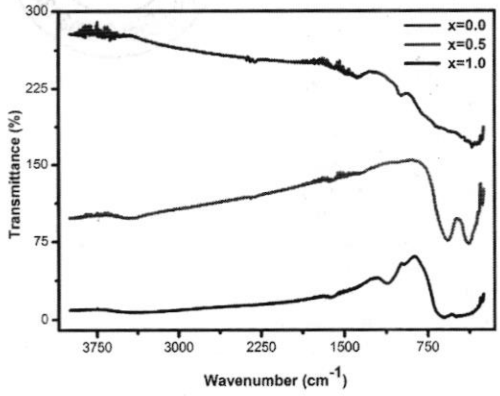


Fig. 4 FTIR spectra of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x=0.0, 0.5, and 1.0 samples

and υ_2), which are located between 570 and 600 cm^{-1} and 380 and 400 cm^{-1}, respectively. Table 7 lists the values of the vibrational mode frequencies υ_1 and υ_2. The stretching at the interstitial tetrahedral (A) and octahedral (B) sublattices is responsible for these vibrational mode frequencies, respectively. Table 7 demonstrates how Al^{3+} substitution caused a compositional shift in the vibrational mode frequencies, moving them toward higher levels. This change in frequency amplifies the fact that the generated mixed Ni–Zn spinel ferrite matrix underwent cationic redistribution following the substitution of Al^{3+} ions. The accommodation of the Al^{3+} ions at both interstitial sublattice locations is thus shown by the current outcome of shifting in vibrational mode frequencies. The cation distribution calculated from the XRD and magnetization data shows the same thing (Table 6). Additionally, the change in the Fe^{3+}-O^{2-}distance between the octahedral (1.99 Å) and tetrahedral (1.89 Å) complexes is likely to account for the variation in the vibrational band locations [50]. Additionally, using the following equations and the Waldron technique [44], the force constants per atom for the the tetrahedral (A) and octahedral (B) sites were calculated:

$$k_t = 7.62 \times M_A \times \nu_1^2 \times 10^{-7} N/m \tag{13}$$

$$k_o = 10.62 \times \frac{M_B}{2} \times \nu_2^2 \times 10^{-7} N/m \tag{14}$$

where, M_A and M_B stand for the average molecular weights of the cations at the (A) and [B] sites respectively. The molecular weights of the (A) and [B]-sites were calculated taking into account the estimated site occupancy and the results are shown in Table 7. Furthermore, Table 7 lists the values for all samples and the Debye temperature (D) determined by Eq. 15.

$$\theta_D = \frac{\hbar c \upsilon_{mean}}{k} \tag{15}$$

where $\hbar = h/2\pi$ here h is Planck's constant, c is the velocity of light, $\nu_{mean} = \frac{\nu_1 + \nu_2}{2}$ is the average frequency of principle band positions at the (A) and [B] sites, and k is the average force constant; its values are given in Table 7. The band positions also move towards higher values as the Debye temperature with Al^{3+} content rises proportionally to them.

Table 7 IR absorption bands υ_1 and υ_2, force constant (k_t, k_o) at the (A) and [B]-sites, average force constant (k) and Debye temperature for $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x=0.0, 0.5 and 1.0) samples

Sample	υ_1 (cm^{-1})	υ_2 (cm^{-1})	k_t (N/m)	k_o (N/m)	k (N/m)	θ_D (K)
x=0.0	545.00	356.00	127.69	78.27	102.98	648
x=0.5	572.85	391.54	133.04	85.55	109.29	694
x=1.0	605.29	413.00	138.58	85.34	111.96	733

Table 8 The bulk modulus (B), longitudinal (V_L) transverse (V_t) and mean (V_m) wave velocities, rigidity modulus (G), and Poisson's ratio (P) for $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x=0.0, 0.5 and 1.0) samples

Sample	B (m/s)	V_L (m/s)	V_t (m/s)	V_m (m/s)	G (GPa)	P (GPa)
x=0.0	123.00	4791	2766	3579	41.00	0.45
x =0.5	131.44	4777	2758	3569	43.81	0.48
x=1.0	134.86	4691	2708	3504	44.95	0.49

3.9 Elastic Properties

According to stiffness constants C_{11} and C_{12}, the bulk modulus (B) is determined as $B = \frac{1}{3}\left(C_{11} + 2C_{12}\right)$. According to Waldron [51], for isotropic materials with cubic structure $C_{11} \approx C_{12}$, it may be figured out that $C_{11} = k/a$, in this case because k is the average force constant; therefore $B = k/a$. Table 8 lists the values of the bulk modulus. According to Table 8, the bulk modulus increases as the Al^{3+} content increases. The calculated values for the longitudinal and transverse elastic wave velocities ($V_l = \sqrt{C_{11}/d_x}$) and ($V_t = V_l/\sqrt{3}$) are shown in Table 8. We discovered that the $Al.^{3+}$ content causes a drop in both elastic velocities. Additionally, elastic moduli including the rigidity modulus (G), Poisson's ratio (P), and mean elastic wave velocity (Vm) for all samples were computed using the formulas listed below [52], and their values are listed in Table 8

$$V_m = \frac{1}{3}\left(\frac{2}{V_l^3} + \frac{1}{V_t^3}\right)^{-\frac{1}{3}} \tag{16}$$

$$G = d_x V_t^2 \tag{17}$$

$$P = 3B - \frac{2G}{6B} + 2G \tag{18}$$

With more Al^{3+} substitution, the elastic modulus values marginally rise, which can be attributed to stronger interatomic bonding between various atoms of the spinel lattice. With Al^{3+} substitution, the interatomic bonds between different atoms get stronger over time, increasing the elastic modulus.

3.10 SEM and TEM

Figure 5, which shows the porous and foam-like structure, was used to conduct the morphological examinations on all of the samples. Additionally, it can be seen that grains are aggregated. Because of the high surface energy and magnetic interactions between the nanoparticles, aggregations have been formed. A non-uniform grain size can therefore be seen in the SEM images. Moreover, TEM of a typical sample $Ni_{0.65}Zn_{0.35}Fe_2O_4$ (x = 0.0) was carried out, and the TEM image and particle size distribution histogram are shown in Fig. 6. The TEM image amply demonstrates the spherical shape and little agglomeration of the particles. The average particle size as obtained by TEM as presented in TEM histogram is ~ 29 nm, which is consistent with the size of the crystallites as established by XRD data and W–H plots.

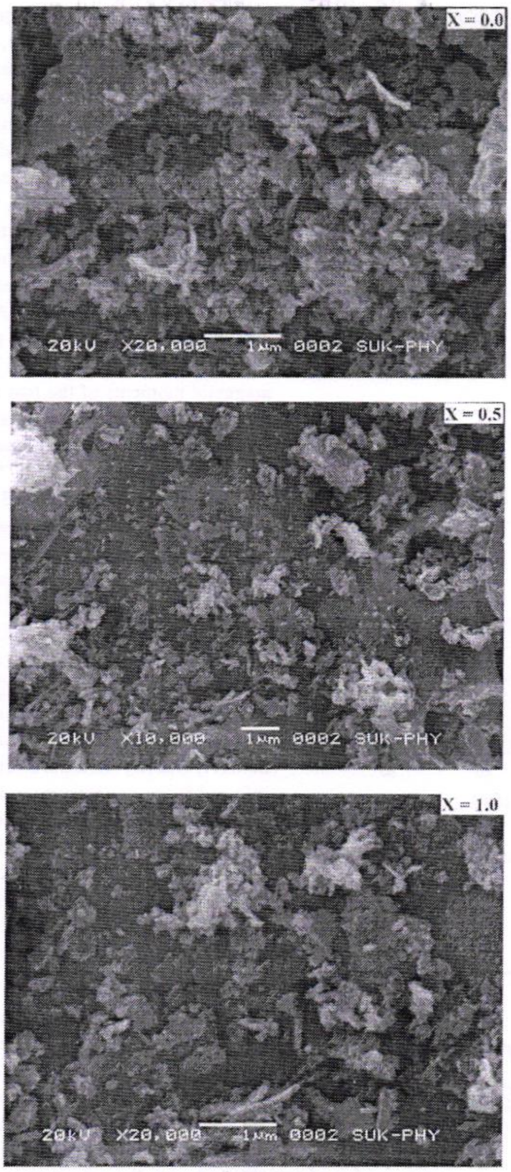


Fig. 5 SEM images of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x = 0.0, 0.5, and 1.0 samples

3.11 Magnetization

The M-H hysteresis graphs of each sample taken at room temperature are displayed in Fig. 7. A symmetric hysteresis curve with soft magnetic behavior can be seen in all of the

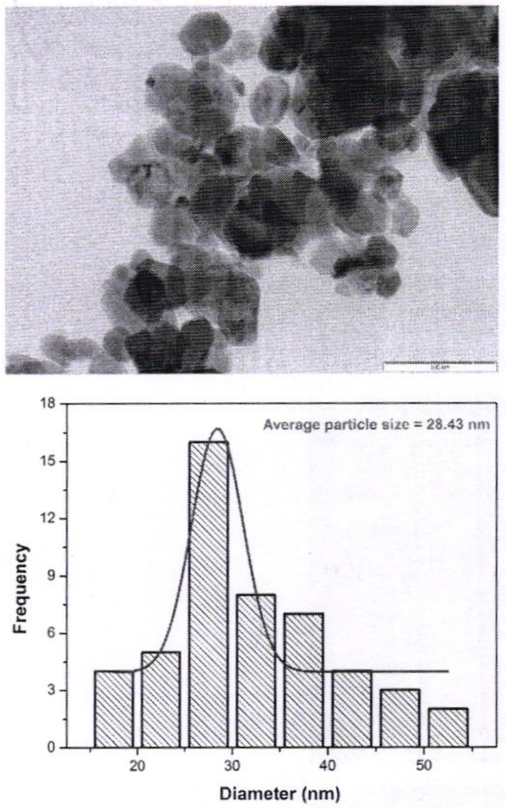


Fig. 6 TEM image and particle size distribution histogram of a typical sample $Ni_{0.65}Zn_{0.35}Fe_2O_4$ (x = 0.0)

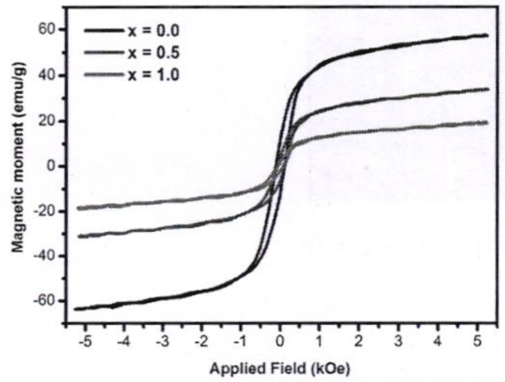


Fig. 7 M-H plots of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x = 0.0, 0.5, and 1.0 samples

M-H plots. Table 9 lists the values for magnetic properties such as magneton number (η_B), coercivity (H_C), saturation magnetization (M_s), and remanence magnetization (M_r). M_s significantly drops with Al^{3+} ion substitution, as shown in Table 9. Along with M_s, M_r and H_C significantly dropped when Al^{3+} ions were substituted. The alterations in the (A)-[B] exchange interactions are associated with the decline in these magnetic parameters [29, 53, 54].

There are three exchange interactions, namely (A)-(A), [B]-[B], and (A)-[B], according to Neel's two sublattice ferri-magnetism model, but the (A)-[B] exchange interaction is the dominant one [40]. Although they are not equal in size, the magnetic moments at the (A) and [B] locations line up in an anti-parallel way. The difference between the magnetic moments of the two sublattices, (A) and [B], is therefore the net magnetic moment. The amount of dopant cations and its magnetic moment play a major role in the exchange interaction. Fe^{3+}, Al^{3+}, Ni^{2+}, and Zn^{2+} have magnetic moments of 5 μB, 0 μB, 2 μB, and 0 μB, respectively. Octahedral [B] sites are more frequently occupied by Al^{3+} ions. As a result, the (A)-[B] exchange interaction is weakened and the [B]-[B] exchange interaction is expanded when the highly magnetic Fe^{3+} ions that were previously present in the octahedral sites are replaced by low magnetic Al^{3+} ions. The observed magnetization behavior can be explained using Neel's model $\eta_B^N = M_B - M_A$ where M_B and M_A are magnetic moments at octahedral [B] and tetrahedral (A) sites, respectively. Zn^{2+} and Ni^{2+} partially filled both (A) and [B] sites, according to the cation distribution inferred from magnetization data (Table 6). Therefore, a divergence from the usual cation preference is seen in the current work. Additionally, Al^{3+} substitution at (A) sites took the place of Fe^{3+} ions, lowering the magnetic moment there because it has zero magnetic moment. Overall, the saturation magnetization was decreased with Al^{3+} because lower magnetic moment Al^{3+} ions replaced higher magnetic moment Fe^{3+} ions. $\eta_B = \frac{MolWt*M_s}{5585}$ yields an experimental magneton number. The values of the theoretical and experimental magneton numbers (Table 6) are in good agreement with one another. The values of remanence and coercivity with Al^{3+} substitution in Table 9 only slightly vary, demonstrating the synthesized spinel ferrites soft magnetic properties. The range of the remanence ratio (M_r/M_s) was discovered to be between 0.181 and 0.121. Lower values of M_r/M_s recommended these materials for high frequency devices since they indicated the multidomain character of the particles that may interact through magnetostatic interactions. The magnetic spin orientation is determined by the magnetocrystalline anisotropy (H_k), which is calculated using Eq. 19 and binds magnetization in a preferred direction.

Table 9 Magnetic parameters of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x = 0.0, 0.5 and 1.0) samples

Sample code	M_s (emu/g)	M_r (emu/g)	H_c (Oe)	M_r/M_s	K (Oe)	H_k (erg/cm^3)
x = 0.0	57.64	10.45	109.34	0.181	227.79	6564.95
x = 0.5	34.05	4.21	82.31	0.123	171.47	2918.46
x = 1.0	19.58	2.37	25.74	0.121	53.63	525.01

$$H_K = \frac{2K}{M_s} \tag{19}$$

where K is the anisotropy constant and M_s is the saturation magnetization. The saturation magnetization and coercivity are connected by the anisotropy constant. Table 9 displays how magnetocrystalline anisotropy declines with Al^{3+} substitution.

3.12 Mössbauer Analysis

A strong tool for investigating data on the valence state and magnetic behavior is the Mössbauer technique. It also recognizes where the Fe ions are situated in the nanoferrite system within the crystal structure. In Fig. 8, employing DIST formation, the fitted Mössbauer spectra of all the samples collected at room temperature are shown. They were fitted with one magnetic sextet and one doublet referring to two interstitial sites, tetrahedral (A) and octahedral [B] sites. Table 10 lists the hyperfine parameters derived from fitted Mössbauer spectra. The increase in line width can be attributed to the hyperfine field distribution brought on by the distribution of cations over sublattices. In essence, the isomer shift values tell us something about the oxidation state of Fe-ions. The Fe^{3+} valence states are present and the Fe^{2+} valence state is denied when the isomer shift values are less than 0.5 mm/s. When compared to tetrahedral sites, octahedral sites have higher isomer shift values. This outcome can be explained by the fact that Fe^{3+}–O^{2-}compared to tetrahedral sites have a higher interionic distance. Fe^{3+} ions at octahedral sites are smaller than those at tetrahedral sites as a result of this overlap. As a result, octahedral sites have isomer shift values that are higher than tetrahedral sites. Sextets have incredibly low quadrupole splitting values (Table 10). This is explained by the continued cubic symmetry even after significant Al^{3+} ion substitution. Higher values of quadrupole splitting are a result of the noncubic symmetry brought on by the presence of Fe^{2+} ions. The magnetic moment, which with Al^{3+} substitution falls from 37.42 to 31.35 T, determines the hyperfine field proportional to spontaneous magnetization. The lower magneton number (0 μ_B) of Al^{3+} ions, which take the place of the greater magneton number (5 μ_B) Fe^{3+} ions, is responsible for the drop in the hyperfine field. As (A)-(A), (A)-[B], and [B]-[B] exchange interactions exist for spinel ferrites, it is important to note here that the (A)-[B] exchange interaction is preferable among the three exchange interactions. In the present study, the (A)-[B] exchange interaction was greatly subsidized by the inclusion of Al^{3+} ions into the $Ni_{0.65}Zn_{0.35}Fe_2O_4$ matrix. Furthermore, a reduction in particle size can be used to explain this. The collective magnetic excitations are weaker because the particle size is smaller. Our Mössbauer experiments are further supported by the fact that the saturation magnetization in our $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ reduced with the addition of Al^{3+}. The literature [55, 56] presents similar findings. Overall, the superexchange interaction seen in the saturation magnetization and the hyperfine interactions was decreased by Al^{3+} replacement.

3.13 DC Electrical Properties

Using a two-probe method, the DC resistivity of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, where x = 0.0, 0.5, and 1.0, was determined. The development of high-frequency devices at the nanoscale depends critically on the DC resistivity. Heat treatments, the kind and concentration of dopants, defects, porous nature of the material, density, and grain boundaries can all have an impact on how the DC resistivity varies. All of the samples DC resistivity plots as log v/s $1000/T.^{-1}$ were developed, as shown in Fig. 9. Verwey's hopping mechanism can be used to explain the electric transport mechanism in ferrites. According to this, electron hopping between ions of the same element with different valence states causes conduction in ferrite. The resistivity decreases with rising temperature, as seen by all DC resistivity charts (Fig. 9). An improvement in the mobile charge carriers and an increase in temperature are the primary causes. As a result, the DC resistivity drops as temperature rises. All DC resistivity charts adhere to the Arrhenius law, which is stated as follows [37]

$$\rho = \rho_0 e^{\frac{\Delta E}{KT}} \tag{20}$$

Additionally, Fig. 9 demonstrates that the Al^{3+} replacement enhanced the DC resistivity. Since they have a significant affinity for octahedral sites, the Al^{3+} sites prevail over them. But it took up space in both octahedral and tetrahedral structures. Al^{3+} ions take the place of Fe^{3+} ions,

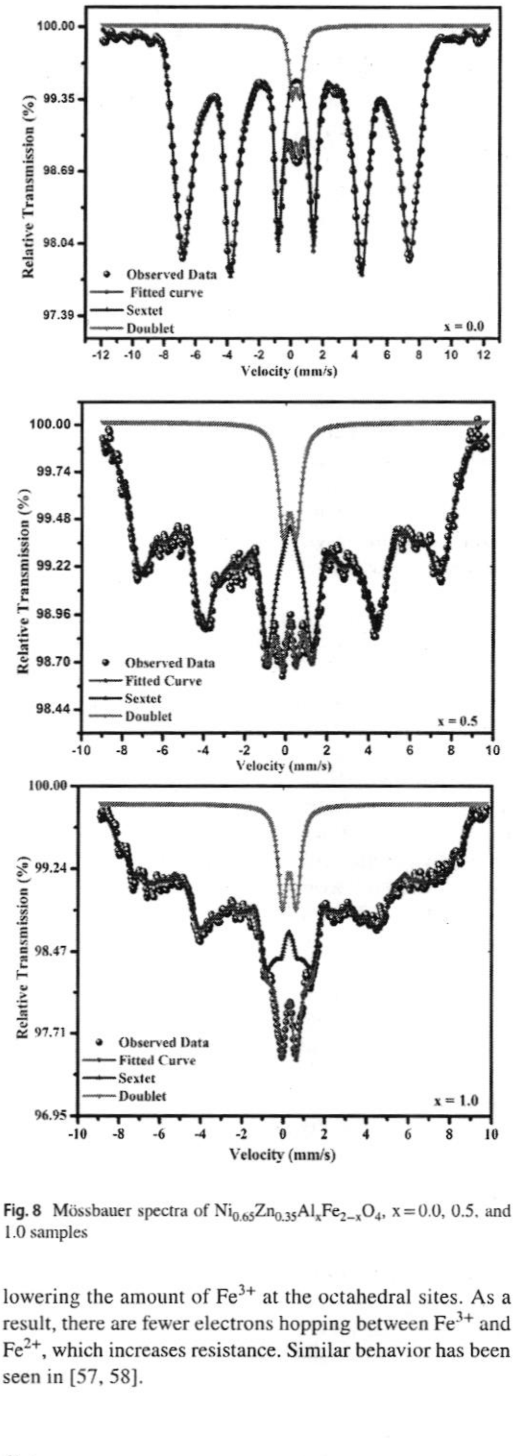


Fig. 8 Mössbauer spectra of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x = 0.0, 0.5, and 1.0 samples

lowering the amount of Fe^{3+} at the octahedral sites. As a result, there are fewer electrons hopping between Fe^{3+} and Fe^{2+}, which increases resistance. Similar behavior has been seen in [57, 58].

Table 10 The Mossbauer parameters line width (Γ), isomer shift (δ), quadrupole splitting (Δ) and hyperfine field (H_f) of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x = 0.0, 0.5 and 1.0)

Sample	Sub Spectrum	Γ (mm/s)	δ (mm/s)	Δ (mm/s)	H_f (T)
x = 0.0	S1	0.40	0.27	0.01	37.42
	D1	0.50	0.29	0.43	–
x = 0.5	S1	0.43	0.19	-0.01	34.45
	D1	0.42	0.18	0.63	–
x = 1.0	S1	0.45	0.28	0.00	31.35
	D1	0.50	0.29	0.67	–

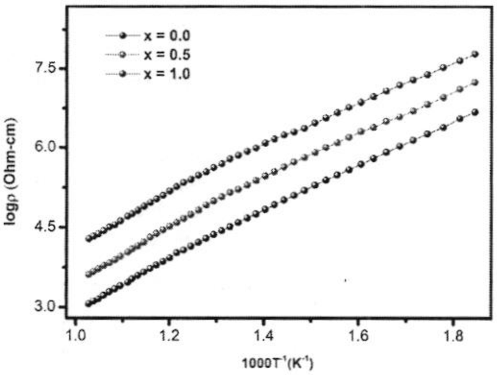


Fig. 9 DC resistivity plots of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x = 0.0, 0.5, and 1.0 samples

3.14 Curie Temperature and Activation Energy

The DC resistivity graphs also show that the curve represents the paramagnetic and ferrimagnetic areas, which are two distinct zones. These areas suggest unique conduction processes with variable activation energies. The paramagnetic region, which follows impurity conduction pathways, corresponds to the high-temperature area. The ferrimagnetic zone follows hopping mechanism and is present in the low temperature area. The Curie (T_C) temperature has a significant influence on the phase transition from the ferri-to-para magnetic region. The gradient of the straight line corresponding to the exchange interaction changes as the DC resistivity plot moves through the Curie point. The Curie temperature of that particular composition is determined by this change. Table 11 lists the expected Curie temperature for each sample. It is obvious that Al^{3+} substitution lowers the Curie temperature. The weakening of the A-B exchange interaction is responsible for this. The outcomes are comparable to those for

Table 11 Electrical parameters of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x=0.0, 0.5 and 1.0) samples

Sample	Activation Energies			$n\times10^{22}$ (atoms/cm^3)	Tc (K)	D (cm^2/s)		
	E_p (eV)	E_f (eV)	ΔE (eV)			At 473 k	At 723 k	At 973 k
x=0.0	1.31	0.99	0.32	9.59	823	9.9×10^{-8}	2.2×10^{-7}	4.4×10^{-7}
x=0.5	1.06	0.87	0.19	9.22	723	9.8×10^{-8}	1.9×10^{-7}	3.7×10^{-7}
x=1.0	0.81	0.78	0.13	8.85	613	9.7×10^{-8}	1.7×10^{-7}	2.9×10^{-7}

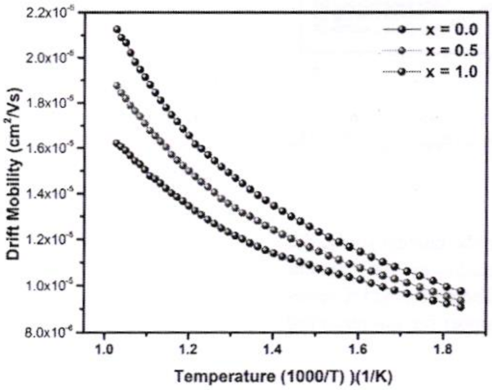


Fig. 10 Drift mobility plots of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x=0.0, 0.5, and 1.0 samples

micro spinel ferrite systems described in [59, 60]. For all of the samples, the activation energy was calculated using Eq. 20 and is shown in Table 11. The paramagnetic zone has larger activation energy than the ferrimagnetic region. This is attributed to the ferrimagnetic region's disordered magnetic spin relative to the ordered spin. The difference between the activation energies of the paramagnetic and ferrimagnetic areas is known as the net activation energy. With Al^{3+} substitution, a reduction in activation energy is seen. On the basis of a reduction in the lattice parameter with Al^{3+} substitution, this can be explained. The interionic distances decrease as a result of the decrease in lattice parameter. As a result, the number of Al^{3+} ions increases while the activation energy drops.

3.15 Drift Mobility and Diffusion Coefficient

Additionally, the diffusion coefficient and drift mobility were assessed using the following relations [61]:

$$\mu_d = \frac{1}{ne\rho} \tag{21}$$

$$n = \frac{N_A d_b P_{Fe}}{M} \tag{22}$$

$$D = \frac{\sigma k_B T}{Ne^2} \tag{23}$$

where, μd is the drift mobility, n is the charge carrier concentration, e is the charge on the electron, ρ is the resistivity, NA is Avogadro's number, dB is the bulk density, PFe is the number of iron atoms, M is the compositions molecular weight, D is the diffusion coefficient, σ is the conductivity, kB is the Boltzmann constant, T is the temperature, and N is the number of atoms/cm^3.

Figure 10 displays the drift mobility graphs as a function of temperature. As the DC resistivity decreases and displays semiconducting characteristics, there can be a noticeable increase in drift mobility with temperature. In addition, it decreased with Al^{3+} substitution as DC resistivity increased. This can be accounted by a decrease in charge carrier concentration with Al^{3+} ions substitution. Table 11 shows the predicted charge carrier concentration using Eq. 22, which ranges from 9.59 to 8.85 × 10^{22} atoms/cm^3. Table 11 displays the values of the diffusion coefficient at three different temperatures. The findings showed that the diffusion coefficient increased with temperature while falling with Al^{3+} replacement. This is explained by the substitution of Al^{3+} ions in the sub-lattice, which results in the production of cation vacancies and a decrease in oxygen vacancies. Drift mobility and diffusion coefficient exhibited behavior that was quite similar, according to findings [58].

3.16 Dielectric Properties

By measuring the dielectric constant (ε′) and dielectric loss tangent (tanδ), the dielectric behavior of all the samples was investigated as a function of frequency at room temperature. Dipolar, ionic, electrical, and interfacial polarization play a major role in the dielectric response at the nanoscale. In the low-frequency range, the dipolar and interfacial polarizations predominate.

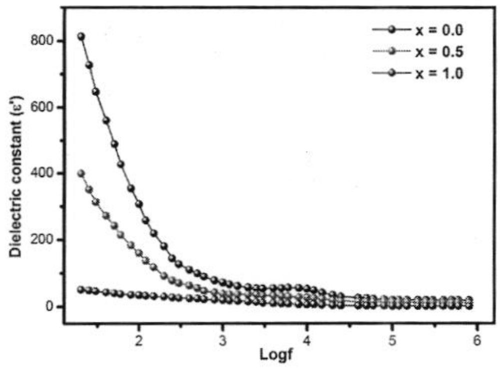


Fig. 11 Dielectric constant as a function of frequency of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x = 0.0, 0.5, and 1.0 samples

3.16.1 Dielectric constant

Using Eq. 24, the dielectric constant (ε′) values were calculated and plotted versus logF, as seen in Fig. 11.

$$\varepsilon' = \frac{Ct}{\varepsilon_0 A} \tag{24}$$

where C is the capacitance, t is the thickness of the sample, A is the area and ε'_0 is the free space permittivity.

Investigations into the variations in dielectric constant were conducted between 50 Hz and 5 MHz. A large dispersion was seen at lower frequencies, and it steadily decreased to a consistent value in the higher frequency range. This illustrates a typical property of the dielectric constant. The electron hopping mechanism, which causes electric dipoles, can explain the observed dielectric behavior. According to the Maxwell–Wagner model of interfacial polarization correlated to cation polarization is connected with the dramatic reduction in the lower frequency range. It is connected to Koop's theory and is exposed to the varied structure made up of the poorly conductive grain boundary. The polarization reduces as frequency increases, which causes the dielectric constant to drop. The applied frequency and the polarization could not be synchronized. As a result, the applied frequency is not kept up with by the electrical exchange between Fe^{3+} and Fe^{2+}. Moreover, with Al^{3+} replacement, the reduced dielectric constant is also noticeable. This is due to the Al^{3+} ions being substituted in Ni–Zn spinel ferrite which suppress the production of Fe^{2+} and polarization. As a result, the dielectric constant drops that can be explained by the fewer electric dipoles because there is less electron hopping between Fe^{3+} and Fe^{2+}. According to [62], Al^{3+}-substituted Ni–Zn ferrites behaved similarly. It is important to note that the compositional dependence of dielectric constant conflicts with the DC resistivity. In the current study, the dielectric constant dropped with regard to the Al^{3+} content while the DC resistivity increased. Therefore, the DC resistivity behavior provides strong support for the observed dielectric behavior.

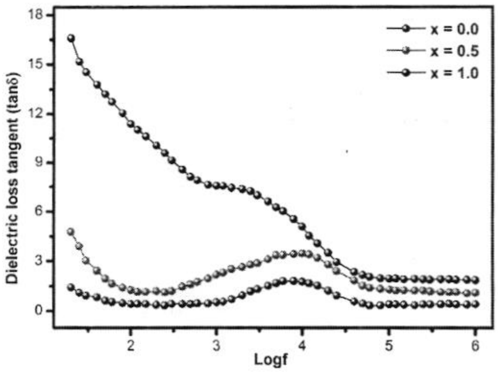


Fig. 12 Dielectric loss tangent as a function of $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$, x = 0.0, 0.5, and 1.0 samples

3.17 Dielectric Loss Tangent

The energy dissipation in dielectric materials is measured by the dielectric loss tangent (tanδ), which is dependent on structural homogeneity, stoichiometry, and ferric ion concentration. Figure 12 shows how the dielectric loss tangent varies in relation to the applied frequency. At low frequencies, it drops exponentially and shows a rapid decline, whereas at higher frequencies, it decreases gradually and approaches a nearly constant value. The polarization of cations is thought to be the cause of the abrupt drop in response at low frequency. This can be explained according to the Maxwell–Wagner interfacial polarization model [63], which is based on a heterogeneous structure made up of grains with low conductivity grain borders. Furthermore, it is in line with Koops' theory [64]. It is well known that grain boundaries with good conductivity are active at high frequencies, while those with weak conductivity are more active at low frequencies. Moreover, the dielectric loss tangent at low frequency is maximum if the applied signal frequency is less than the hopping frequency of the ions between $Fe^{3+} \leftrightarrow Fe^{2+}$. As a result, the electrons obey the field by hopping between $Fe^{3+} \leftrightarrow Fe^{2+}$, and the maximum loss is seen. As the hopping frequency of ion exchange cannot follow the applied signal at higher frequencies, the minimal dielectric loss tangent is seen. This is the primary cause of both the large dielectric loss tangent seen at low frequencies and the low dielectric loss tangent seen at high frequencies. Thus, the dielectric loss tangent falls rapidly at low frequency because the electrons hopping frequency cannot match the applied frequency. However, abnormal behavior was seen in the form of peaks at specific frequencies. The observed abnormal behavior of the dielectric loss tangent can be explained by the resonance effect. It occurs when the applied frequency and the frequency at which electrons hopping occur from the $Fe^{3+} \leftrightarrow Fe^{2+}$ transition are almost similar. Peaks are observed that result in power loss when the oscillating ions receive the majority of their energy when the hopping frequency of the charge carriers coincides with the applied frequency of the electric field. The resonance effect in the present study was observed between 5 and 25 kHz. Although it spans the specified frequency range, its highest frequency is around 20 kHz. This occurs when the maximum power is delivered to the oscillating ions. According to [62], trivalent ion-substituted Ni–Zn ferrite systems exhibit a similar loss tangent behavior.

4 Conclusion

Through a solution-gelation process, nanocrystalline $Ni_{0.65}Zn_{0.35}Al_xFe_{2-x}O_4$ (x = 0.0, 0.5, and 1.0) was successfully prepared. A single-phase cubic spinel structure with the Fd-3 m space group was discovered via Rietveld analysis. The presence of two distinct vibrational frequency bands correspond to tetrahedral and octahedral sites, validated the creation of the spinel ferrite structure using FTIR. Additionally, it was discovered that Al^{3+} substitution had a considerable impact on the Debye temperature, bulk modulus, and stiffness modulus assessed using FTIR data. An aggregation of grains and a floppy morphology were visible in the SEM pictures. Additionally, TEM scans showed that the particles were spherical in shape. Neel's sublattice model was used to explain magnetic findings and support their trend with Al^{3+} replacement. XRD measurements support the cation distribution predicted from magnetization. Moreover, it was discovered that after Al^{3+} substitution, the hyperfine field calculated from Mossbauer had a significant impact. The DC electrical resistivity behavior suggested that the sample were semiconducting. With Al^{3+} replacement, the dielectric studies revealed a declining trend. To summarize, these ferrite systems are excellent for high frequency devices due to their high DC electrical resistivity, low dielectric loss, and moderate magnetic characteristics.

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Declarations

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THE INFLUENCE OF IRISH HISTORY AND FOLKLORE IN EDNA O'BRIEN'S NOVEL *MOTHER IRELAND*

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Abstract: This research paper explores the profound impact of Irish history and folklore on the narratives and themes found within Edna O'Brien's body of work, with a particular focus on her novel "Mother Ireland." Through an in-depth analysis of the historical context of Ireland, as well as the incorporation of rich folklore and mythological elements, this paper delves into the intricate tapestry that O'Brien weaves to portray the complex layers of Irish identity and cultural heritage. It investigates the role of Irish history in shaping O'Brien's characters, settings, and plots, revealing how O'Brien's personal experiences intersect with the larger historical narrative. The paper also examines how Irish folklore and mythology are utilized to enhance the depth of her storytelling, infusing her novels with a distinct sense of Irishness. By exploring specific themes, motifs, and character development, this research paper highlights the profound and lasting influence of Irish history and folklore in Edna O'Brien's novel *Mother Ireland* and underscores her significant contribution to Irish literature.

Key Words: (The Troubles, Celtic Mythology, The Banshee, Pooka or the AosSí, Otherworldly Figures)

Introduction: Edna O'Brien is a highly influential Irish author known for her compelling and thought-provoking literary contributions. Born in County Clare, Ireland, in 1930, she has garnered international recognition for her works, which often explore the complex landscape of Irish identity, culture, and history. O'Brien's writing style is characterized by its lyrical prose, deep emotional resonance, and a keen sensitivity to the human condition. Throughout her career, she has tackled both the personal and the political, delving into themes such as love, desire, conflict, and the enduring impact of Irish history and folklore on the modern psyche. Her literary cannon comprise *The Country Girls, Girl with Green Eyes, Girls in their Married Bliss. Down by the River, Night, A Pagan Place, August is a Wicked Month, Casualties of Peace, Johnny I Hardly Knew You, The High RoadTime and Tide, House of Splendid Isolation, Wild December, In the Forest, The Light of Evening. The Little Red Chairs, Sister Imelda, and Crossing.*

Edna O'Brien has made a substantial and lasting contribution to Irish literature by addressing a wide range of themes and issues in her works. Her writing is characterized by a lyrical and evocative style that captures the complexities of Irish identity, history, and culture. Some key aspects of her broader contribution to Irish literature include:

Exploration of Irish Identity: O'Brien's works often delve into the multifaceted nature of Irish identity, especially in the context of modernity and the challenges of historical legacies. She examines the tensions between tradition and progress, often with a focus on the personal and emotional struggles of her characters.

Feminism and Gender: O'Brien is known for her feminist perspectives and exploration of gender dynamics in Irish society. Her writings have highlighted the struggles and aspirations of women, contributing to a broader feminist discourse within Irish literature.

Capturing Irish Rural Life: O'Brien's early works, including *The Country Girls* trilogy, are celebrated for their vivid portrayal of rural Ireland. She provides a window into the lives, traditions, and challenges of Irish rural communities.

Engagement with History and Folklore: As exemplified by *Mother Ireland*, O'Brien has a unique ability to weave history and folklore into her narratives. Her work bridges the gap between the past and the present, emphasizing the enduring influence of history and culture on the Irish people.

In this context, *Mother Ireland* is a significant work by Edna O'Brien, published in 1976. This novel (basically a Non-fiction) presents a poignant exploration of the enduring legacy of Irish history and the profound influence of the land itself on the Irish people. The narrative revolves around Fidelma, the central character, who returns to Ireland after years of living abroad. Fidelma's journey is a quest to reconnect with her homeland, her family, and her roots. As she navigates her past and the present, the novel delves into themes of identity, displacement, the impact of history, and the deep ties between the Irish people and their native land.By-and-large, *Mother Ireland* is a significant addition to Edna O'Brien's body of work, reflecting her overarching themes and writing style. The novel fits into her oeuvre due to her continues exploration of Irish identity, the impact of history, and the enduring connection between the Irish people and their homeland. It builds upon her previous works that delve into these themes. O'Brien is always distinctive for lyrical prose and it's the hallmark of *Mother Ireland*, just as it is in her earlier novels. Her evocative language is consistently present, immersing readers in the world she creates. *Mother Ireland* primarily focuses on the broader themes of Irish history and folklore; it still contains elements that reflect O'Brien's engagement with feminism, as seen through the complex female characters in the novel.The novel also retains O'Brien's characteristic style, blending a sense of realism with elements of magic and the otherworldly figures. This blending of the everyday and the mystical is a recurring feature in her works.

This paper aims to provide a comprehensive analysis of the influence of Irish history and folklore in Edna O'Brien's *Mother Ireland*. Through a detailed exploration of the historical context, the incorporation of folklore and mythology, thematic elements, and character development, this research also aims to illuminate the depth and significance of O'Brien's narrative. By examining how O'Brien intertwines history and folklore within the novel, this paper seeks to shed light on her role in the broader context of Irish literature and her contribution to the exploration of Irish identity. Ultimately, this research paper will contribute to a deeper understanding of Edna O'Brien's literary legacy and the enduring impact of Irish history and culture on her work. And how Edna O'Brien's *MotherIreland* reflects and draws upon Irish history and folklore to convey a sense of Irish identity and cultural heritage.

As, the historical backdrop of Ireland during the time of *MotherIreland* (published in 1976) was characterized by several significant events and ongoing issues. Understanding this context is crucial in appreciating how it influenced Edna O'Brien's writing and her portrayal of Irish history within the novel:

The Troubles: During the 1970s, Northern Ireland was engulfed in the ethno-nationalist conflict known as "The Troubles." This period saw intense sectarian violence, political unrest, and the British army's presence in Northern Ireland. The Troubles had a profound impact on the entire island of Ireland and cast a long shadow over its history.

Social and Cultural Change: The 1970s brought about social and cultural changes in Ireland, particularly in the Republic of Ireland. It was a time of transition from a more conservative and narrow-minded society to a more modern and globalized one. This shift had implications for Irish identity and cultural dynamics.

Economic Challenges: Ireland faced economic challenges during this period. The country grappled with high unemployment, emigration, and an economic downturn that affected the lives of many Irish people.

Edna O'Brien's *Mother Ireland* reflects the turbulent historical context of 1970s Ireland in several ways to address few:

The Troubles: O'Brien's portrayal of Irish history and its lasting impact on the Irish people is intertwined with the Troubles. The novel alludes to the conflict and its consequences, showcasing how historical trauma continues to reverberate in the lives of the characters. It delves into themes of division, loss, and the enduring psychological scars left by the Troubles.

Cultural Shifts: The novel captures the changing cultural landscape of Ireland during the 1970s. O'Brien's writing reflects the tension between tradition and modernity, exploring how Irish identity is affected by evolving cultural norms and values.

Economic Hardships: Economic challenges and emigration are depicted in the novel, especially through the experiences of returning emigrants like Fidelma. O'Brien's characters grapple with the economic difficulties of the era, shedding light on the relationship between economic struggles and Irish history.

O'Brien's portrayal of Irish history in *Mother Ireland* is not just a static representation of the past but a dynamic engagement with the historical context of her time. She weaves these historical threads into the narrative to create a tapestry that reflects the multifaceted nature of Irish history and its enduring impact on the Irish psyche. By doing so, she contributes to a broader conversation about how history and folklore shape Irish identity and cultural heritage, making her work a significant contribution to Irish literature.

So, identifying instances of Irish Folklore and Mythology, *Mother Ireland* by Edna O'Brien is imbued with the rich tapestry of Irish folklore and mythology, intertwining these elements with the narrative to create a vivid portrayal of Irish identity and cultural heritage. Here are some prominent instances:

Celtic Mythology: The novel references Celtic mythology, particularly through the symbolism of the land and its connection to the Irish people. The landscape, with its ancient hills, rivers, and natural features, is personified and revered, echoing the reverence found in Celtic myths for the land and nature.

The Banshee: The Banshee, a supernatural figure from Irish folklore associated with death and mourning, makes an appearance in the novel. This element adds an eerie and mystical dimension to the narrative, reflecting the influence of folklore on the characters' beliefs and perceptions.

Mythical Figures: O'Brien introduces mythical and archetypal figures who embody the spirits and essence of the Irish landscape. These figures are reminiscent of characters from Irish folklore, such as the Pooka or the AosSí (the supernatural race of fairies), and they contribute to the novel's dreamlike, otherworldly atmosphere.

By and large, folklore and mythology in *Mother Ireland* play a crucial role in accentuating the novel's central themes. The reverence for the land, for example, underscores the theme of Irish connection to the homeland. The Banshee's presence emphasizes themes of death, mourning, and the enduring influence of the past.The characters in the novel are deeply influenced by Irish folklore and mythology. Fidelma, the protagonist, experiences a profound connection with the land, shaped by the mythical elements of Irish culture. The otherworldly figures encountered throughout the narrative evoke a sense of enchantment and mystery, impacting the characters' perceptions of their own identities and the world around them.Folklore and mythology are interwoven into the plot to create a sense of mysticism and to highlight the characters' journeys of self-discovery. The Banshee's appearance, for instance, marks a pivotal moment in the story, where the characters confront their past and the weight of Irish history.At the same time, folklore and mythology serve as a lens through which Irish identity is portrayed in *Mother Ireland*. They embody the deep-rooted connection between the Irish people and their land, encapsulating a profound sense of place and heritage. These elements reflect the enduring influence of Ireland's cultural and mythological past on the present, conveying a sense of continuity and shared history. The folklore and mythology in the novel contribute to the broader understanding of Irish identity as something intimately tied to the land, the past, and the enduring spirit of the Irish people. They add depth and dimension to the novel, making it a powerful representation of Irish culture and heritage.

Mother Ireland by Edna O'Brien is rich with recurring themes and motifs that serve as the backbone of the narrative, underpinning its exploration of Irish history and folklore. Some of the prominent themes and motifs include:

Homeland and Identity: The concept of homeland and its significance in shaping personal and collective identity is a central theme. Fidelma's return to Ireland and her quest to reconnect with her roots represent the theme of identity anchored in the Irish landscape. Also, the theme of homeland and identity is intricately linked to Irish history. The novel explores how Irish history, particularly the struggle for independence and the enduring presence of British colonialism, has shaped the Irish people's connection to their homeland. This historical context informs Fidelma's journey and the characters' complex relationship with Ireland.

Family and GenerationalDynamics: Family relationships and generational dynamics are recurrent motifs. The tensions and bonds within Fidelma's family mirror the complexities of Irish history and the legacy passed down through generations.The tensions within Fidelma's family mirror the generational conflicts that have arisen from Ireland's turbulent history. The novel delves into how historical events, such as the Troubles, have left lasting scars on families and communities, affecting the relationships between parents and children.

The Land and Nature: The Irish landscape, with its hills, rivers, and natural beauty, is a motif that symbolizes the connection between the Irish people and their land. The land is not merely a backdrop but a character in its own right, embodying the essence of Irish folklore's reverence for nature. As wellthe motif of the Irish landscape aligns with the reverence for the land found in Irish folklore and mythology. It portrays the enduring connection between the Irish people and their natural surroundings, emphasizing how history has influenced this deep bond.

Death and Mourning: The Banshee, a supernatural figure associated with death and mourning in Irish folklore, is a recurring motif. It underscores themes of loss and the enduring impact of historical traumas and conflicts.The presence of the Banshee serves as a symbol of death and mourning, linking the novel to Irish folklore. It evokes the emotional weight of Irish history, particularly the violence and loss experienced during the Troubles, which continue to cast a shadow on the Irish psyche.

Mythical Figures and Folklore: Throughout the novel, mythical and folkloric figures make appearances, adding an element of mysticism and fantasy. These figures symbolize the deeper, spiritual connection of the Irish people to their cultural heritage.The appearance of mythical and folkloric figures underscores the mystical and enchanting aspects of Irish culture. These figures represent the enduring presence of folklore in Irish life, connecting the characters to their cultural heritage and the myths and legends that have shaped their worldview.The recurring themes and motifs in Mother Ireland not only provide depth to the narrative but also offer a lens through which to explore the profound influence of Irish history and folklore on the characters, their experiences, and their sense of identity. These themes and motifs add layers of complexity to the story, emphasizing the intertwined relationship between the Irish people and their cultural heritage, which has been deeply influenced by the historical context in which they live.

In *Mother Ireland*, Edna O'Brien crafts characters whose backgrounds and experiences are intricately linked to Irish history and folklore. These characters serve as means of expressionfor the exploration of Irish cultural and historical context, and their interactions with folklore and history play a pivotal role in shaping their development:

Fidelma: Fidelma, the novel's protagonist, embodies the diasporic Irish experience. Having spent time abroad, she returns to Ireland with a deep longing for her homeland. Fidelma's connection to Irish history is reflected in her sense of displacement and her quest to rediscover her Irish identity. Her interactions with folklore, particularly through the presence of the Banshee, highlight the weight of historical trauma on her psyche and her journey of self-discovery.

Fidelma's Mother: Fidelma's mother represents an older generation, one that lived through significant historical events such as the struggle for Irish independence and the Troubles. Her experiences reflect the generational impact of Irish history, with the memories of conflict and loss deeply ingrained in her character. Her connection to folklore and traditional beliefs mirrors the enduring presence of these elements in the lives of the older Irish population.

Otherworldly Figures: Throughout the novel, characters encounter mythical and folkloric figures that embody the spirits of Irish history and culture. These figures, often associated with the land and natural elements, serve as catalysts for the characters' personal and spiritual development. They blur the boundaries between reality and mythology, highlighting the profound influence of folklore on the characters' perceptions and their sense of Irish identity.

The Community: The broader community in the novel reflects the collective experience of the Irish people. Their interactions with one another and with the land underscore the communal ties to Irish history and folklore. These interactions reveal the shared cultural heritage and the enduring impact of historical events on the community's identity.Thus, the characters in *Mother Ireland* collectively represent different facets of the Irish experience, influenced by the historical and folkloric elements that permeate their lives. Their individual journeys of self-discovery and their relationships with folklore and history provide a nuanced portrayal of the multifaceted Irish identity. Through these characters, O'Brien explores the ways in which Irish history and folklore have shaped the collective and personal narratives of the Irish people, shedding light on the enduring impact of the past on the present.

Mother Ireland by Edna O'Brien has garnered significant attention from scholars and critics, who have examined the novel's portrayal of Irish history and folklore. Their interpretations shed light on the role of these elements in the narrative. Here are some critical perspectives on the novel:

The Lyrical Weaving of History and Folklore: Many scholars have praised O'Brien's lyrical prose and her skillful integration of Irish history and folklore into the narrative. They argue that her poetic style enhances the reader's immersion into the cultural and historical context, making the novel a profound exploration of Irish identity.

The Legacy of Historical Trauma: Critics often emphasize the novel's portrayal of the lasting impact of historical trauma, particularly the Troubles. They argue that Mother Ireland serves as a poignant reflection on how Irish history has left emotional and psychological scars on the characters, illustrating the collective trauma of the Irish people.

The Revival of Folkloric Elements: Scholars have highlighted how O'Brien revives and re-imagines traditional Irish folklore and mythology. They see this as a conscious effort to connect with the cultural roots and beliefs of the Irish people, emphasizing the enduring presence of folklore in modern Irish life.

Conflict and Identity: Many interpretations focus on the theme of conflict, both personal and societal, and its relationship with Irish identity. The characters' struggles and interactions with the Banshee, as a representation of conflict and death, symbolize the complexity of Irish identity in a historical context marred by violence and division.

Generational Dynamics: Critics have explored the generational dynamics within the novel, particularly how older characters who lived through historical events like the struggle for independence view the world differently from younger characters like Fidelma, who are grappling with the aftermath of those events. This generational gap reflects the evolving nature of Irish identity.

The Land as a Character: Scholars often note the land's role as a character in its own right, highlighting the significance of nature and the environment in the lives of the characters. The Irish landscape, as described by O'Brien, is seen as a representation of the enduring connection between the Irish people and their homeland.In précis, *Mother Ireland*underscores the novel's profound exploration of Irish history and folklore. Scholars recognize O'Brien's skill in blending these elements with lyrical prose to create a vivid portrayal of Irish identity and the enduring impact of history and culture. The novel serves as a poignant reflection on the lasting effects of historical trauma, the importance of folklore in modern Irish life, and the complexities of Irish identity in a changing world. These critical insights contribute to a deeper understanding of the novel's significance in the context of Irish literature and its exploration of cultural and historical themes.

In conclusion, *Mother Ireland* aligns with Edna O'Brien's wider contributions to Irish literature by exploring Irish identity, history, and culture, while maintaining her signature writing style and thematic concerns. The novel adds depth to her literary legacy, offering a poignant examination of Irish history and folklore and their role in shaping the identity of the Irish people, thereby solidifying her position as a significant figure in Irish literature.

In researching Mother Ireland by Edna O'Brien, several key findings have emerged:

Irish History and Folklore as Integral Elements:*Mother Ireland* weaves Irish history and folklore into its narrative, making them integral to the characters and themes of the novel.

Enduring Impact of Historical Trauma: The novel underscores the lasting impact of historical trauma, particularly the Troubles, on the Irish people. This legacy continues to shape the characters' identities and their perceptions of the world.

Complex Irish Identity: The characters in the novel embody the complexity of Irish identity, where personal and collective identities are deeply intertwined with the historical and folkloric elements of Irish culture.

The Role of the Land: The Irish landscape is personified and revered in the novel, symbolizing the enduring connection between the Irish people and their homeland, reflecting Irish folklore's reverence for nature.

Generational Dynamics: The generational dynamics within the novel illuminate how historical events have affected different generations of Irish people, emphasizing the evolving nature of Irish identity.

Thus, the research findings emphasize the profound significance of Irish history and folklore in *Mother Ireland*. These elements are not mere background details but are intricately woven into the fabric of the narrative, shaping characters' identities, conflicts, and their relationship with the land. The novel serves as a poignant reflection on the enduring impact of Irish history and culture, shedding light on the collective trauma and complexity of Irish identity in the context of historical and folkloric influences. In the broader context of Edna O'Brien's body of work and Irish literature, *Mother Ireland* stands as a testament to her skill in capturing the complexities of Irish identity and the interplay between history and culture. It continues her exploration of these themes, employing her lyrical prose and her engagement with feminism, while also introducing an otherworldly and mythical dimension to her storytelling. The novel enhances her literary legacy and contributes to the broader conversation about Irish literature's role in preserving and evolving Irish identity and cultural heritage. *Mother Ireland* is a poignant and evocative representation of the enduring influence of Irish history and folklore on the Irish people and their ongoing search for identity and belonging.

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A CRITICAL ANALYSIS OF POPULAR CULTURE AND YOUTH IDENTITY IN ANITA BROOKNER'S NOVEL 'HOTEL DU LAC'

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Abstract: This article critically examines the portrayal of popular culture and youth identity in Anita Brookner's novel "Hotel du Lac." It explores how the protagonist's interactions with popular culture and her own evolving sense of identity reflect the broader cultural and societal context of the novel. Anita Brookner's "Hotel du Lac" is a classic work of literature known for its intricate character development and exploration of themes related to identity and social expectations. In this article, we delve into the representation of popular culture and youth identity in the novel, seeking to understand how these elements contribute to the broader narrative. In her each and every novel, women are the protagonist. The stories revolve around the female or woman character and the male characters are for the supporting but what kind of thought and what kind of psychology is there while depicting the Popular Culture and Youth Identity in her novels is very important and will be interesting to study.

Key words: Popular Culture, youth identity, 'Hotel du Lac'

Introduction: Anita Brookner's "*Hotel du Lac*" is a classic work of literature known for its intricate character development and exploration of themes related to identity and social expectations. In her each and every novel, women are the protagonist. The stories revolve around the female or woman character and the male characters are for the supporting but what kind of thought and what kind of psychology is there while depicting the Popular Culture and Youth Identity in her novels is very important and will be interesting to study. In this article, researcher investigates into the representation of popular culture and youth identity in the novel, seeking to understand how these elements contribute to the broader narrative.

Objectives:

The primary objectives of this research are to:

- Analyze the protagonist's engagement with popular culture and its impact on her identity.
- Investigate how Anita Brookner uses the novel to comment on the prevailing societal attitudes toward women's roles and expectations during the era in which the story is set.

Importance of the Research: This study is crucial in understanding the ways in which literature can reflect and critique popular culture and societal norms. "*Hotel du Lac*" serves as a microcosm of the cultural and social forces that shaped the lives of women in the late 20th century. The present study is A Critical Analysis of Popular Culture and Youth Identity in Anita Brookner's Novel *'Hotel du Lac'*.

Literature Review: *Hunger Art: The Novels of Anita Brookner* (1995), is a valuable article composed by Ann Fisher. Olga Kenyon in her book "*Women Novelists Today: A Survey of English Writing in the Seventies and Eighties,* (1989) MALCOLM, Cheryl Alexander. *Understanding Anita Brookner*. Columbia: University of South Press. Prior research has highlighted Anita Brookner's nuanced character development and her focus on the interior lives of her female protagonists. These studies provide a foundation for our analysis of popular culture and identity within "*Hotel du Lac*."

Methodology: For this analysis, we selected "*Hotel du Lac*" as the focal point. We closely examined the protagonist Edith Hope's relationship with popular culture, her evolving sense of identity, and how these aspects interact within the novel. Researcher has selected analytical method for Analysis of Popular Culture and Youth Identity in Anita Brookner's Novel *'Hotel du Lac'*.

Analysis and Findings: Anita Brookner is especially known as a feminist writer in the modern era. She depicted female characters in most her novels as a main character or as a protagonist. "*Hotel du Lac*" presents Edith Hope, a writer who grapples with the influences of popular culture on her identity. Her struggles with her own image and expectations are mirrored in her writing, reflecting the larger societal expectations of women at the time. Her interactions with other characters and the cultural artifacts of the era, such as books and magazines, reveal the external pressures that shape her sense of self.

Influence of Popular Culture on Identity: The novel showcases how popular culture exerts a significant influence on the protagonist, Edith Hope. Her awareness of societal expectations and the portrayal of successful individuals in popular culture create a conflict within her as she grapples with her own identity. This highlights the pervasive impact of popular culture on individuals' self-perception.

Challenges of Non-Conformity: Edith's decision to break away from societal norms, as seen in her chosen life of solitude in the hotel, illustrates the challenges individuals face when they resist the pressures of popular culture and societal expectations. Her isolation serves as a metaphor for the isolation that can come with non-conformity.

Critique of Gender Expectations: Through Edith's character, the novel offers a critique of the gender expectations and limitations placed on women during the time the story is set. The portrayal of Edith's inner conflicts and the role of popular culture in shaping her identity highlight the broader issue of how women were defined by societal norms and expectations.

Timeless Themes: Despite the novel's specific historical and cultural context, the themes of popular culture and identity explored in "*Hotel du Lac*" remain relevant. The pressures and influences of popular culture on one's sense of self are enduring concerns that resonate with readers across different eras.

Anita Brookner's Subtle Commentary: The novel's subtlety in addressing these themes is a testament to Anita Brookner's skill as a writer. She uses Edith's character and her interactions with popular culture as a means of offering a nuanced commentary on the complexities of identity and societal expectations.

Discussion: The novel highlights Edith's internal conflicts and societal pressures as she navigates the cultural expectations of femininity. Through Edith's character, Brookner critiques the limitations and expectations placed on women in her time. The novel serves as a commentary on how popular culture and societal norms influence women's identities.

Conclusion:"*Hotel du Lac*" by Anita Brookner offers a profound exploration of how popular culture and societal expectations can shape the identity of women. The novel's complex character development and narrative style allow us to understand the multifaceted ways in which individuals respond to and negotiate with popular culture in the quest for self-identity. Here are some conclusions that can be drawn from the analysis of popular culture and youth identity in Anita Brookner's novel *"Hotel du Lac":*

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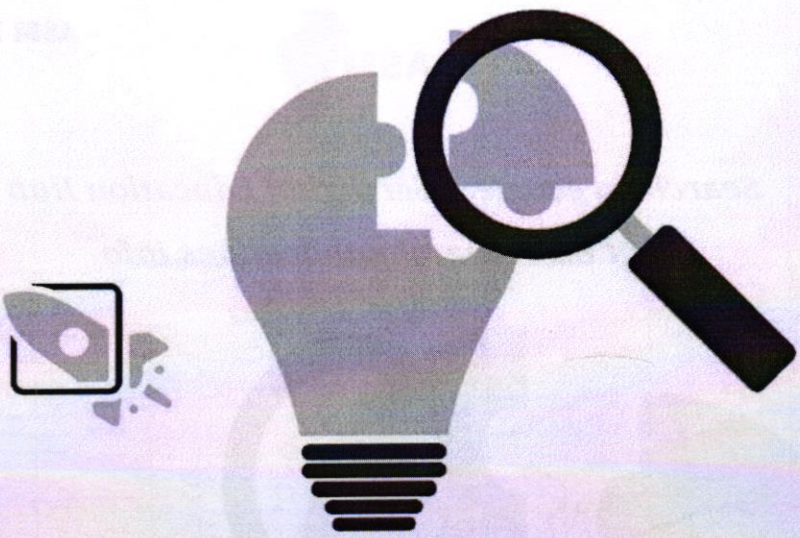

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CHILD LABOUR IN INDIA: A COMPREHENSIVE STUDY ON VIOLATIONS OF CHILD RIGHTS

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Abstract

This research paper examines the issue of child labour in India, focusing on its prevalence, root causes, consequences, and the effectiveness of existing legal and regulatory frameworks. The study aims to shed light on the violation of child rights within the context of labour exploitation and propose recommendations for policy improvements. Child Labour in India remains a significant and persistent issue, affecting millions of children across the country. It involves the engagement of children in economic activities, often under conditions that are exploitative and harmful. The problem is multifaceted, stemming from various socio-economic factors, cultural norms, and insufficient enforcement of existing laws.

Key Words: Poverty, Education, Law, Health, Trauma, NGOs, MGNREGA, ICPS, NCPL

Introduction

India has one of the highest numbers of child Labourers globally. Children are employed in diverse sectors such as agriculture, manufacturing, construction, and services. Child Labour involves children below the legal working age, typically ranging from 14 to 18 years, and sometimes even younger. Children are engaged in various types of work, including hazardous and strenuous tasks. Common occupations include working in brick kilns, carpet weaving, agriculture, and domestic service. Poverty is a primary driver, as families facing economic hardships may rely on the income generated by their children. Lack of access to quality education, social inequality, and cultural norms that accept child Labour further exacerbate the issue. Child Labour often deprives children of the opportunity to attend school, perpetuating a cycle of poverty and limiting their future prospects. While India has enacted legislation to prohibit and regulate child Labour, enforcement remains a challenge. Gaps in implementation and a lack of awareness contribute to the continued prevalence of child Labour. Efforts to address child Labour involve a combination of legal reforms, social initiatives, and economic interventions to uplift families from poverty. Despite progress in recent years, the persistence of child Labour underscores the need for continued advocacy, awareness, and sustained action to protect the rights and well-being of India's children. Child Labour refers to the employment of children in any work that deprives them of their childhood, interferes with their ability to attend regular schools, and is mentally, physically, socially, or morally harmful. It encompasses a wide range of activities, and various types can be identified:

Hazardous Labour: Involves work that poses a threat to the health, safety, or moral development of a child. This includes occupations with dangerous machinery, exposure to toxic substances, or physically demanding tasks.

Exploitative Labour: Encompasses situations where children are subjected to long hours, low wages, or harsh conditions, often without appropriate safeguards or legal protections.

Bonded Labour: Occurs when a child is forced to work to repay a debt owed by their family. This form of child Labour is often intergenerational, trapping families in a cycle of debt and exploitation.

Trafficking and Forced Labour: Involves the abduction or recruitment of children for forced Labour including in industries such as agriculture, manufacturing, or the sex trade.

Historical Context and Cultural Factors Contributing to Child Labour:

Historical Practices: Child Labour has deep historical roots, with children historically being an integral part of family-based economies. The Industrial Revolution exacerbated the problem as children were often employed in factories due to their small size and agility.

Poverty: Economic hardship remains a significant factor driving child Labour. Families facing poverty may view child Labour as a means of supplementing household income.

Lack of Educational Opportunities: Inadequate access to quality education contributes to child Labour. When educational opportunities are limited or unavailable, children are more likely to enter the workforce at an early age.

Cultural Norms: Societal attitudes and cultural norms can influence the acceptance of child Labour. In some communities, traditional practices may involve children contributing to family livelihoods from a young age.

Gender Roles: Gender stereotypes may play a role, with girls often subjected to domestic Labour, while boys may be engaged in activities such as agriculture or other manual Labour.

Understanding the historical context and cultural factors is crucial for developing effective strategies to combat child Labour. Efforts to address the issue must consider not only legal frameworks but also socio-economic conditions and cultural dynamics that perpetuate the exploitation of children in the workforce.

Prevalence of Child Labour in India:

Statistics and Data: According to the National Sample Survey Organization (NSSO), the number of child Labourers in India has been declining, but the issue persists. As of recent data, millions of children between the ages of 5 and 14 are still engaged in various forms of Labour.

Regional Variations: Child Labour is not uniformly distributed across India and shows regional disparities. States with high poverty rates, such as Bihar, Uttar Pradesh, and Rajasthan, often exhibit higher incidences of child Labour.

Industries with High Child Labour Incidence:

Agriculture: Many children work in agricultural activities, from planting and harvesting to tending livestock.

Manufacturing: Sectors like textiles, fireworks, and handicrafts employ a significant number of child Labourers.

Construction: Children can be found working on construction sites, often exposed to hazardous conditions.

Gender-Specific Considerations:

Boys: Engaged in various sectors, including agriculture, manufacturing, and services. They might work as Labour ers in construction, mechanics, or in hazardous industries.

Girls: Often involved in domestic work, agriculture, and the garment industry. In some cases, they may also be subjected to trafficking and forced Labour.

Impact of Legislation: The Child Labour (Prohibition and Regulation) Act, 1986, prohibits the employment of children in certain hazardous occupations and processes. Despite legislation, enforcement challenges persist, particularly in the informal and unorganized sectors.

Understanding the prevalence of child Labour in India involves recognizing regional variations, industry-specific trends, and the gender-specific nature of child Labour. Comprehensive efforts to address this issue require targeted interventions tailored to the unique challenges faced by different regions and sectors.

Root Causes of Child Labour:

Poverty as a Driving Force:

Limited Economic Resources: Families facing economic hardship may rely on the income generated by their children to meet basic needs.

Cycle of Poverty: Child Labour can contribute to a cycle of poverty, as children who work instead of attending school may have fewer opportunities for future economic advancement.

Lack of Access to Education:

Insufficient Educational Infrastructure: In many areas, there is a lack of schools, teachers, and educational resources, making it difficult for children to access quality education.

Financial Barriers: Even when schools exist, costs such as uniforms, books, and transportation can be prohibitive for families living in poverty.

Social and Cultural Factors Perpetuating Child Labour:

Cultural Norms: In some societies, traditional practices may involve children contributing to family livelihoods from a young age, perpetuating the acceptance of child Labour.

Gender Roles: Gender stereotypes may assign specific roles to boys and girls, influencing the type of work they are expected to perform.

Weak Enforcement of Child Labour Laws:

Inadequate Legal Frameworks: While legislation exists to regulate and prohibit child Labour, enforcement may be hindered by gaps or weaknesses in legal frameworks.

Limited Resources: Authorities may lack the resources and infrastructure necessary to effectively monitor and enforce child Labour laws, especially in informal or rural sectors. Addressing child Labour requires a multifaceted approach that tackles these root causes:

Poverty Alleviation: Implementing economic strategies to uplift families from poverty can reduce the economic necessity for child Labour.

Education Access: Strengthening educational infrastructure, making education accessible, and addressing financial barriers can encourage children to attend school rather than work.

Cultural Sensitivity: Raising awareness about the detrimental effects of child Labour while respecting cultural nuances can help shift societal attitudes.

Enhanced Enforcement: Strengthening legal frameworks and providing resources for effective enforcement can deter and penalize instances of child Labour.

A comprehensive strategy addressing these root causes is essential for creating lasting change in the fight against child Labour.

Consequences of Child Labour: Impact on Physical and Mental Health:

Physical Health Issues: Children engaged in Labour, especially in hazardous conditions, are susceptible to injuries, illnesses, and long-term health problems.

Stunted Growth: Lack of proper nutrition and exposure to strenuous work can lead to physical developmental issues, including stunted growth.

Implications for Education and Long-Term Opportunities:

Interrupted Education: Child Labour often results in disrupted or non-existent formal education, limiting a child's ability to acquire essential skills and knowledge.

Reduced Future Opportunities: Lack of education restricts future employment opportunities, perpetuating a cycle of poverty and limiting socioeconomic mobility.

Social Consequences within Families and Communities:

Family Dynamics: Child Labour can strain family relationships, as children may be forced to prioritize work over education and personal development.

Inter-Generational Impact: The cycle of child Labour may continue as children who were once child Labourers may perpetuate the practice in their own families.

Community Stigma: Communities with high instances of child Labour may face social stigma, impacting the overall well-being and development of the community.

Psychological and Emotional Toll:

Trauma: Exposure to harsh working conditions, exploitation, and sometimes abuse can result in psychological trauma for child Labourers.

Limited Social Development: Children engaged in Labour may miss out on crucial opportunities for socialization and emotional development.

Addressing the consequences of child Labour requires a holistic approach:

Healthcare Access: Providing healthcare services and addressing the specific health needs of child Labourers can mitigate physical consequences.

Education Reforms: Implementing and enforcing policies that ensure access to quality education for all children is crucial for breaking the cycle of child Labour.

Social Support Systems: Establishing community-based support systems can help address the social and psychological consequences of child Labour, promoting overall well-being.

Efforts to eradicate child Labour should not only focus on immediate remediation but also on long-term strategies that enhance the overall development and well-being of affected children and their communities.

Legal and Regulatory Framework for Child Labour in India:

Child Labour (Prohibition and Regulation) Act, 1986:

Prohibits Employment: The act prohibits the employment of children in certain hazardous occupations and processes.

Regulates Conditions: It regulates the working conditions for children in permissible forms of employment.

Juvenile Justice (Care and Protection) of Children Act, 2015:

Focus on Protection: This act addresses the broader aspect of child protection, covering issues beyond Labour, such as rehabilitation and reintegration of children in need of care and protection.

Right to Education Act (RTE), 2009:

Compulsory Education: RTE mandates free and compulsory education for all children aged 6 to 14 years, aiming to reduce the prevalence of child Labour by promoting access to education.

Effectiveness and Challenges in Enforcement:

Effectiveness:

Awareness and Advocacy: Increased awareness and advocacy have contributed to a better understanding of child Labour issues.

Government Initiatives: Various government initiatives aim to eliminate child Labour, including the National Child Labour Project and the Integrated Child Protection Scheme.

Challenges:

Informal and Unorganized Sectors: Enforcing child Labour laws in informal and unorganized sectors, where a significant portion of child Labour occurs, remains a challenge.

Lack of Resources: Limited resources, both in terms of manpower and infrastructure, can hinder effective monitoring and enforcement.

Complexity of the Issue: Child Labour is often deeply rooted in socio-economic factors, making it complex to address solely through legislation.

International Conventions and Treaties Related to Child Labour Ratified by India:

International Labour Organization (ILO) Conventions:

India has ratified ILO Convention No. 182 concerning the Worst Forms of Child Labour, committing to eliminate the most egregious forms of child Labour.

United Nations Convention on the Rights of the Child (CRC):

India is a signatory to the CRC, emphasizing the protection and well-being of children, including measures to address child Labour.

Sustainable Development Goals (SDGs):

India has committed to achieving SDG Goal 8.7, which aims to end child Labour in all its forms by 2025.

Despite these international commitments and national legislation, challenges persist in effectively eradicating child Labour. Continuous efforts are needed to strengthen enforcement mechanisms, increase awareness, and address the root causes that contribute to child Labour in India.

Case Studies on Child Labour in India:

Handicraft Industry in Uttar Pradesh:

Situation: Many children are engaged in traditional handicraft activities, including carpet weaving and embroidery.

Challenges: Poor working conditions, long hours, and exposure to hazardous materials.

Intervention: NGOs and government initiatives have implemented awareness programs, vocational training, and alternative income-generation activities for families.

Impact: Significant reduction in child Labour instances, improved working conditions, and increased enrolment in education.

Brick Kilns in Bihar:

Situation: Child Labour is prevalent in brick kilns, where families migrate for seasonal work.

Challenges: Lack of access to education, poor living conditions, and vulnerability to exploitation.

Intervention: Community-based programs providing education at brick kilns, advocating for improved working conditions, and addressing the root causes of migration.

Impact: Increased enrolment of children in schools, improved awareness among families, and reduced instances of child Labour during migration seasons.

Agricultural Sector in Rajasthan:

Situation: Children involved in various agricultural activities, including cotton farming.

Challenges: Exposure to pesticides, long working hours, and limited educational opportunities.

Intervention: Government schemes promoting organic farming, awareness campaigns on child rights, and initiatives providing school infrastructure in rural areas.

Impact: Gradual decline in child Labour instances, increased awareness among farmers, and improved access to education for children.

Examining Successful Interventions and Their Impact:

Integrated Child Development Services (ICDS):

Intervention: ICDS provides nutrition, health, and education services to children in the age group of 0-6 years.

Impact: Improved health and nutritional outcomes, increased enrolment in anganwadis (childcare centres), and a positive impact on reducing child Labour instances.

National Child Labour Project (NCLP):

Intervention: NCLP focuses on the rehabilitation of child Labourers, providing them with education, vocational training, and mainstreaming into formal schooling.

Impact: Successful rehabilitation of numerous child Labourers, enabling them to break free from the cycle of exploitation and access better opportunities.

Bachpan Bachao Andolan (Save the Childhood Movement):

Intervention: Grassroots movement advocating for children's rights, rescue operations, and rehabilitation efforts.

Impact: Notable success in rescuing and rehabilitating children from various forms of exploitation, creating awareness, and influencing policy changes.

These case studies demonstrate that targeted interventions, a combination of awareness programs, education initiatives, and community involvement, can effectively reduce child Labour instances and improve the overall well-being of affected children and their communities.

Role of Government and NGOs in Combating Child Labour: Government Initiatives and Programs Addressing Child Labour

National Child Labour Project (NCLP):

Objective: Rehabilitation of child Labourers through special schools, providing non-formal education, vocational training, and supplementary nutrition.

Impact: Successful in rescuing and rehabilitating children from hazardous work conditions.

Integrated Child Protection Scheme (ICPS):

Objective: Comprehensive program addressing the needs of vulnerable children, including protection from exploitation and abuse.

Impact: Focuses on preventing and responding to instances of child Labour, providing support for education, health, and nutrition.

MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act):

Objective: Provides 100 days of guaranteed wage employment to rural households, aiming to reduce economic vulnerability and prevent child Labour.

Impact: Addresses poverty-related factors contributing to child Labour in rural areas.

Contributions of Non-Governmental Organizations (NGOs):

Bachpan Bachao Andolan (BBA):

Focus: Advocacy, rescue, and rehabilitation of child Labourers, along with awareness campaigns.

Impact: BBA has played a crucial role in rescuing and rehabilitating children, raising awareness, and influencing policy changes.

Child Rights and You (CRY):

Focus: Campaigns for child rights, education, and healthcare, addressing root causes of child Labour.

Impact: Works towards ensuring the overall well-being and rights of children, including efforts to eliminate child Labour.

Save the Children:

Focus: Holistic approach to child rights, including education, protection, and health initiatives.

Impact: Implements programs to prevent child Labour, provide education, and support vulnerable families.

Areas of Collaboration and Improvement:

Collaboration:

Inter-Agency Cooperation: Strengthen collaboration between government agencies, NGOs, and international organizations to share resources, expertise, and data.

Community Involvement: Encourage active participation of local communities in the design and implementation of programs to address specific contextual challenges.

Improvement:

Enhanced Enforcement: Strengthen the enforcement of existing child Labour laws and regulations, ensuring penalties for violations.

Capacity Building: Invest in training and capacity building for government officials, law enforcement, and NGOs to enhance their ability to address child Labour effectively.

Monitoring and Evaluation: Implement robust monitoring and evaluation mechanisms to assess the impact of interventions and identify areas for improvement.

Policy Advocacy:

NGO-Government Collaboration: Facilitate dialogue and collaboration between NGOs and government bodies to shape and influence policies that address the root causes of child Labour.

Policy Reforms: Advocate for policy reforms that address socio-economic factors contributing to child Labour, focusing on poverty alleviation and education access.

Collaboration and continuous improvement are crucial for achieving sustainable results in the fight against child Labour. By combining efforts and addressing systemic challenges, both the government and NGOs can contribute to creating a safer and more secure environment for children.

Recommendations to Combat Child Labour:

Strengthening Enforcement Mechanisms:

Enhanced Monitoring: Increase the frequency and effectiveness of inspections in industries and areas prone to child Labour, ensuring strict enforcement of existing laws.

Penalties and Deterrence: Implement stringent penalties for employers violating child Labour laws to serve as a deterrent, and ensure timely legal actions against violators.

Enhancing Access to Quality Education:

Infrastructure Improvement: Invest in building and maintaining schools, especially in rural and marginalized areas, ensuring they have adequate facilities, teachers, and resources.

Eliminate Barriers: Implement measures to eliminate financial, social, and cultural barriers that prevent children from attending school, such as providing free textbooks, uniforms, and transportation support.

Addressing Root Causes through Poverty Alleviation Strategies:

Livelihood Opportunities: Develop and implement programs that provide sustainable livelihood opportunities for families living in poverty, reducing their reliance on child Labour for income.

Social Welfare Programs: Strengthen social welfare programs that provide financial support to economically disadvantaged families, ensuring their basic needs are met.

Advocating for Policy Changes at the National and International Levels:

Policy Reforms: Advocate for comprehensive policy reforms that address the socio-economic factors contributing to child Labour, emphasizing the importance of education and poverty reduction.

International Cooperation: Collaborate with international organizations and other countries to share best practices, research, and resources in the global fight against child Labour.

Community Engagement and Awareness:

Community Empowerment: Involve local communities in designing and implementing interventions, considering their unique challenges and perspectives.

Awareness Campaigns: Conduct widespread awareness campaigns on the detrimental effects of child Labour, emphasizing the value of education and promoting a collective responsibility to eliminate child Labour.

Child-Friendly Legislation:

Age Verification Measures: Implement mechanisms for age verification to ensure compliance with minimum age requirements for employment.

Legislation Review: Periodically review and update existing legislation to address emerging challenges and effectively tackle new forms of child Labour.

Implementing these recommendations requires collaboration between government bodies, NGOs, communities, and international partners. By addressing enforcement gaps, improving educational access, tackling root causes, and advocating for policy changes, a holistic approach can be employed to eradicate child Labour and ensure the well-being and development of children.

In conclusion, the comprehensive study on child Labour in India has revealed key findings that underscore the urgent need for concerted efforts to address this pervasive issue. The prevalence of child Labour, deeply rooted in socio-economic factors, poses severe consequences on the physical and mental well-being of children, their educational opportunities, and the overall fabric of communities. The root causes, including poverty, lack of access to education, cultural norms, and weak enforcement mechanisms, demand targeted interventions. Collective efforts are not just necessary; they are imperative to create a world where every child is free from exploitation, has access to education, and can realize their full potential. The fight against child Labour requires unwavering commitment and collaboration from all stakeholders to ensure a brighter, more just future for the children of India and beyond.

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