

**SUSTAINABLE TRENDS IN ARTS,
HUMANITIES, ENGINEERING, IT, SCIENCES,
AND SOCIAL SCIENCES**



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Dr. Ajay Jain



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A GREEN SOLUTION TO CO₂ CORROSION OF MILD STEEL USING A LEAF EXTRACT CORROSION INHIBITOR

**Gitalee Sharma^{1*} Parijat Burhagohain², Sanghamitra Sarmah²,
Satarupa Priyadarshini²**

^{1*}Department of Chemistry, DUIET, Dibrugarh University, Dibrugarh-786004,
Assam, India

²Department of Chemistry, Dibrugarh University, Dibrugarh-786004, Assam,
India

Abstract - CO₂ corrosion poses a substantial challenge in the oil and gas sector. Organic corrosion inhibitors have been extensively studied to mitigate CO₂ corrosion of mild steel. However, their toxic properties have posed a challenge to their practical applications. In this context, plant extracts have been proven to be effective as green corrosion inhibitors on extensive testing. This paper investigates the inhibitory effects of Eclipta alba leaf extracts in a CO₂ saturated 2% NaCl solution on mild steel via the use of gravimetric and electrochemical methods. At numerous concentrations of the inhibitor, a significant level of inhibition, ranging from 90% to 94%, was observed. As the concentration of the inhibitor raised, there was a noticeable increase in the % inhibition efficiency. The surface morphology was analysed using SEM and SEM-EDX. In addition, Eclipta alba extract physically adsorbed onto the mild steel surface and obeyed the Langmuir isotherm indicated by the linear correlation coefficient value (R²) of 0.9992. The study thus implied that Eclipta alba extract shows promise as an environmentally friendly corrosion inhibitor for mild steel in a CO₂ environment. This discovery has important implications for the Oil and Gas industries' effort towards achieving the Sustainable Development Goals.

Keywords: Plant Extract, CO₂ Corrosion, Inhibition Efficiency, Mild steel.

1. INTRODUCTION

The degradation of materials due to corrosion is a risk that could arise in the oil and gas sector [1]. Mild steel is significantly utilized in numerous oil and gas industries for transporting and storing fuel because of its adaptability. Unfortunately, mild steel is susceptible to corrosion owing to aggressive environments and corrosive substances, even if it has many desirable qualities [2]. It is to be noted that a substantial portion of oil-field corrosion is attributed to CO₂ corrosion, as mild steel materials are highly vulnerable to CO₂ environments [3]. The presence of CO₂ in the environment leads to the formation of carbonic acid (H₂CO₃), which then generates carbonate, bicarbonate, and hydrogen ions. This process accelerates the rate of corrosion [4]. As corrosion mitigation measures, several techniques have been employed, with the use of corrosion inhibitors being a widely adopted method [5]. Recent breakthroughs have focused more attention on the use of safer and less

expensive materials for chemical synthesis. As a result, researchers are increasingly interested in the use of non-toxic, readily available, and cost-effective inhibitors in corrosion prevention so that the Sustainable Development Goals of the Oil and Gas industries are achieved [6]. Extracts prepared from various parts of plants in green solvents such as water, methanol, and ethanol include active components with structures like traditional organic corrosion inhibitors and can be called "green" inhibitors above synthetic ones. Therefore, plant extracts have been extensively explored as corrosion inhibitors for reducing CO₂ corrosion of mild steel. Extracts such as *Momordica charantica*, *Colotropis procera*, *Ficus carica*, *berberine*, *Coptis cinesis*, *Piper nigrum*, and *Ginko bibola* fruit have been researched as green corrosion inhibitors for mild steel and found to be efficient against CO₂ corrosion [7-16].

Researchers have reported that *Eclipta alba* plant extract is an effective inhibitor for a variety of acidic media, including hydrochloric acid (HCl) and chloride media, among others, with inhibition efficiency greater than 90% [9]. The effect of CO₂ on mild steel corrosion, however, has not been investigated till date. Thus, this paper reports the inhibitory effects of *Eclipta alba* plant extracts on mild steel in CO₂ saturated 2% NaCl solution by employing gravimetric and electrochemical methods such as Electrochemical Impedance Spectroscopy (EIS) and Potentiodynamic Polarization (PDP) measurements. Further, the surface morphology was examined using SEM and SEM-EDX characterization techniques. The data obtained was analyzed to find adsorption behaviour for different adsorption isotherms.

2. EXPERIMENTAL

2.1. Preparation and Characterization of *Eclipta alba* Extract

Fresh *Eclipta alba* leaves were gathered, sun-dried, and then left in an oven overnight at 100 °C to eliminate moisture. After weighing the dried leaves, they were ground into a powder and stored in a different container. 10 g of the dried powder was dissolved in 100 mL of ethanol in a round-bottom flask, refluxed it for 6 hours at 60°C, and then left it overnight at room temperature. It was then filtered and stored in a labelled container that served as stock solution. Further, dilution of the stock solution was done to create concentrations of 40, 60, 80, and 100 ppm of *Eclipta alba* leaf extracts.

The prepared plant extracts were characterized using FTIR and UV-Visible spectroscopy. The FTIR spectra (KBr) was recorded in transmittance mode with the help of a SHIMADZU IRAffinity-1 Spectrophotometer. The peaks as recorded in IR (KBr: ν/cm^{-1}) were 3442.78, 2376, 2189, 1647, 1564, 1045. The active component of *Eclipta alba* plant is shown in figure 1.

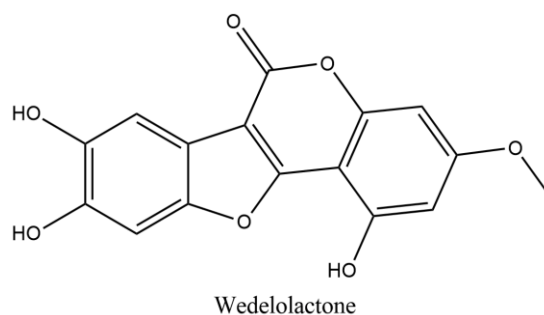


Fig. 1 The active component of *Eclipta alba* plant extract

2.2. Preparation of Mild Steel Specimen

Mild steel for gas transportation pipeline with composition C = 0.28, Mn = 1.4, P = 0.3, S = 0.3, V-Nb = Ti ≤ 15%, and Fe = balanced was employed for the study. For weight loss investigations, steel samples were cut into 3.0 cm x 1.0 cm x 1.0 cm coupons. Electrochemical measurements were done with cold-mounted 1.0 cm x 1.0 cm x 1.0 cm coupons. The steel specimens were polished with different grades of emery paper, cleaned with double distilled water, and degreased with acetone. To avoid contamination, washing was done in triplicates.

2.3. Gravimetric and Electrochemical Measurements

To determine gravimetric weight loss, dry steel specimens were weighed before being immersed in a 2% NaCl test solution produced by dissolving laboratory grade NaCl in double distilled water. For two hours at room temperature, 700 psi of CO₂ gas was pumped through the test solution. Finally, the samples were dried and weighed. The specimens were coated with the studied plant extract, and weight loss experiments were carried out in a similar fashion. All measurements were taken in triplicate, and the average weight loss was calculated.

The % Inhibition Efficiency and corrosion rate are calculated using equation (1) and (2) [17]

$$\%IE = \left(1 - \frac{\Delta W_i}{\Delta W}\right) \dots \dots \dots (1)$$

where, ΔW is the average weight loss in absence of inhibitor, ΔW_i is the average weight loss in presence of inhibitor.

$$\text{Corrosion Rate} = \frac{8.76 \times 10^4 \times \Delta W}{\sigma \times t \times \rho} \dots \dots \dots (2)$$

where, σ = exposed surface area of steel specimen in cm², t = immersion time in hours, ρ = density of the metal in g/cm³, ΔW = average weight loss in g and the quantity (8.76X10⁴) is multiplied to give corrosion rate in mmpy.

Electrochemical measurements are made with a Metrohm Autolab Potentiostat/Galvanostat PGSTAT302N and three electrode system. Cold-

mounted X60 steel was the working electrode, Ag/AgCl was the reference electrode, and Stainless steel rod as the auxiliary electrode. ASTM G-59, G-102, and Nova Software were utilized for data analysis and curve fitting [18, 19]. Stabilization for 30 minutes was permitted to reach a constant open circuit potential before electrochemical testing. The potentiostatic EIS tests were conducted at $\pm 10\text{mV}$ amplitude and 10mHz to 100kHz frequency range. Potentiodynamic Polarization (PDP) measurements were taken at a scan rate of 0.25mV/s from OCP at a potential range of $\pm 250\text{mV}$. All electrochemical tests were done at ambient temperature ($250\text{C}\pm 1$).

2.4. SEM and SEM-EDX Spectroscopy

Inhibited and uninhibited steel coupons were soaked in varied test solution concentrations and dried at room temperature. Energy Dispersed X-ray Spectroscopy was utilized to determine steel sample elemental composition before and after test solution immersion. Micrographs and spectrum imaging were done with FESEM (Model Sigma). The gold coating was done at “Timed Gold” mode with sputter current 20mA and sputter time 59 seconds.

3. RESULTS AND DISCUSSION

3.1. Gravimetric Weight Loss Method

The results obtained from gravimetric weight loss measurements are tabulated in table 1. Table 1 suggest that weight loss of the steel specimen reduced for inhibitor coated samples. Corrosion rates were found to decrease after application of inhibitor, which decreased further with increase in inhibitor concentration. The percentage inhibition efficiency increases with increase in inhibitor concentration and highest value was obtained for 100 ppm concentration which is equal to 91%.

Table 1: Corrosion Parameters Obtained from Gravimetric Analysis

Sample	Inhibitor Concentration (%v/v)	Weight loss (g)	Corrosion rate(mmpy)	% Inhibition Efficiency
Uninhibited	0	0.32	14.97	--
<i>Eclipta alba</i>	40	0.18	8.37	43.8
	60	0.11	5.11	65.6
	80	0.07	3.25	78.1
	100	0.03	1.39	91.0

3.2. Electrochemical Impedance Spectroscopy

Nyquist plots (figure 2(a)), Bode-phase and Bode modulus plots (figure 2(b)) displays the electrochemical impedance spectroscopy data. Depressed semi-circular arc Nyquist graphs indicate capacitive polarization [20]. This arc corresponds to two Bode plot time constants, one at high frequency and one at low frequency. The high frequency capacitive loop is linked to the creation of an adsorption layer on steel surfaces viz. $R_f//CPE_f$ [21]. In contrast, the low frequency capacitive loop is linked to the creation of an electrical double-layer

at the electrode-electrolyte interface viz. $R_{ct} // CPE_{dl}$ [22]. Semi-circular plot distortion indicates rough metal surface texture [23, 24].

The equivalent circuit model is used to analyse EIS spectra using R_p as polarization resistance, R_s as solution resistance, CPE as constant phase element, and n as phase shift. The semicircle fits better with CPE instead of capacitor. Equation (3) calculates CPE impedance [21]:

$$Z_{CPE} = q^{-1}(i\omega)^{-1} \dots\dots\dots (3)$$

Here, q = CPE magnitude, i = imaginary number, ω = angular frequency, and n = phase shift. EIS inhibition efficiency was calculated using the equation (4) below [17]:

$$\%IE_{EIS} = \left(\frac{R_p^I - R_p}{R_p^I} \right) \times 100 \dots\dots\dots (4)$$

R_p was used for uninhibited solution and R_p^I for inhibited solution polarization resistance. Increased inhibitor concentration raises R_p values in inhibited solutions. R_p values increase because an adsorbed inhibitor layer on steel surfaces limits corrosion attack and charge and mass transfer. Inhibited solutions also have increased solution resistance (R_s).

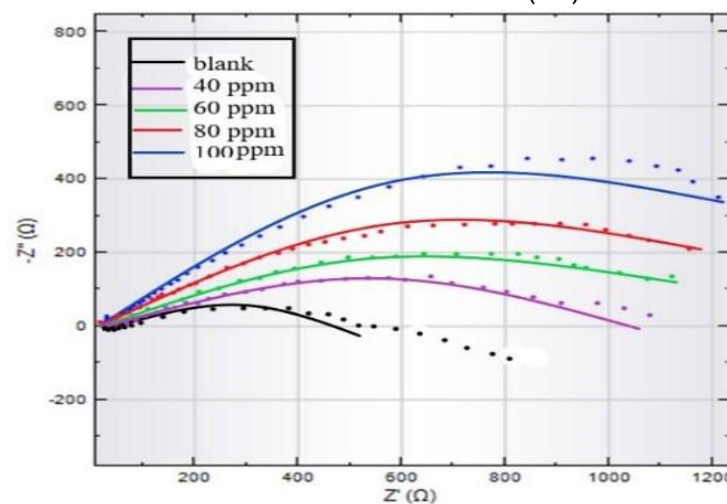


Fig. 2 (a) Nyquist plot

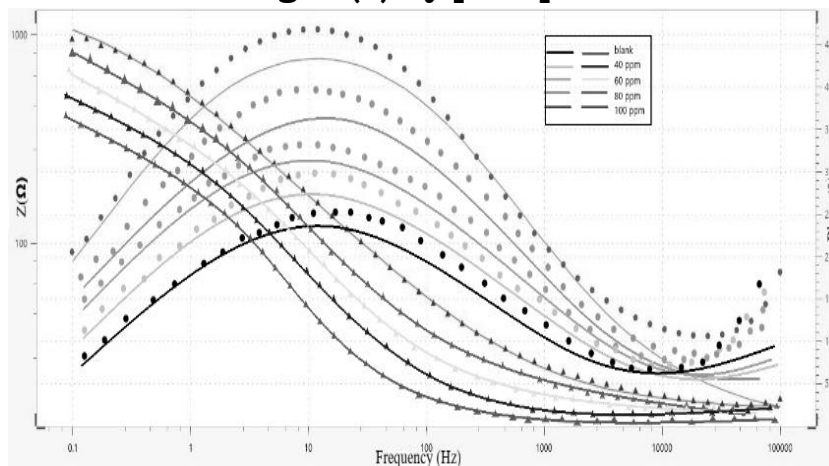


Fig. 2 (b) Bode-phase and Bode modulus plots

The Nyquist plot displays that the inhibited solution's semi-circular capacitance arc is bigger than that of the uninhibited one. Semicircular diameter increases with inhibitor concentration, peaking at 100ppm of plant extract concentration with % IE of 90.1%. Due to inhibitor molecules adsorption on the electrode-electrolyte interface, steel surface becomes more corrosion-resistant and increases in diameter. Increased inhibitor molecule surface covering boosts inhibition efficiency with concentration. Bode graphs show that inhibited solutions have a bigger semi-circular part and rise with inhibitor concentration. As with Nyquist plots, this behaviour can be explained. The EIS data is tabulated in table 2.

Table 2: Corrosion Parameters Obtained from EIS Studies

Inhibitor name	Inhibitor concentration (ppm)	CPE.YO (F)	Rp. R(Ω)	Rs. R (Ω)	CPE. N	% IE
<i>Eclipta alba</i> (EA)	0	0.00421	377	46.8	0.992	--
	40	0.00018	822	20.8	0.991	54.1
	60	0.00004	2538	135.5	0.995	85.1
	80	0.00002	3421	405.6	0.991	89.0
	100	0.00001	3828	425.2	0.992	90.1

3.3. Potentiodynamic Polarization Study

Potentiodynamic polarization (PDP) is a technique used to gather information about both cathodic and anodic reactions in a destructive manner [21]. Potentiodynamic polarization investigations were conducted utilizing a broader potential range of 200 mV to 400 mV to obtain a greater amount of information. The cathodic current densities have significantly decreased after the application of the inhibitor, as demonstrated in table 3. This phenomenon can be attributed to the suppression of cathodic reactions caused by the inhibitors. The E_{corr} readings exhibited a movement towards less negative values in the inhibited solutions. The corrosion current (I_{corr}) values are lower for the inhibited solutions compared to the uninhibited solutions, and this drop progresses as the inhibitor concentration increases. However, no consistent pattern was detected in the E_{corr} values, suggesting that the applied inhibitor functions as a mixed-type inhibitor. The PDP studies exhibited a %IE of 94% at 100ppm concentration.

Table 3 Data from PDP Measurements

Inhibitor name	IC (ppm)	β_a (V/dec)	β_c (V/dec)	E_{corr} (V)	I_{corr} (A)	CR (mm/year)	% IE
<i>Eclipta alba</i>	0	0.106	0.261	-0.497	1.59×10^{-4}	2.15	--
	40	0.131	0.164	-0.463	3.5×10^{-5}	0.47	77.4
	60	0.055	0.127	-0.517	3.1×10^{-5}	0.36	80.3
	80	0.152	0.179	-0.448	2.7×10^{-5}	0.27	83.0
	100	0.086	0.255	-0.494	1.1×10^{-4}	0.10	94.0

Tafel fit resulted in corrosion potential (E_{corr}), corrosion current (I_{corr}), cathodic Tafel slope (β_c), anodic Tafel slope (β_a) and corrosion rate in mmpy. The % inhibition efficiencies were calculated using equation (5) [17].

$$\%IE_{PDP} = \left(\frac{I_{corr} - I_{corr}^I}{I_{corr}} \right) \times 100 \dots\dots (5)$$

Where, I_{corr} and I_{corr}^I are the corrosion current for uninhibited and inhibited solutions respectively. The overlay of the Tafel plot (figure 3) showed a similar pattern at different concentration, which is in accordance with the data outlined in table 3.

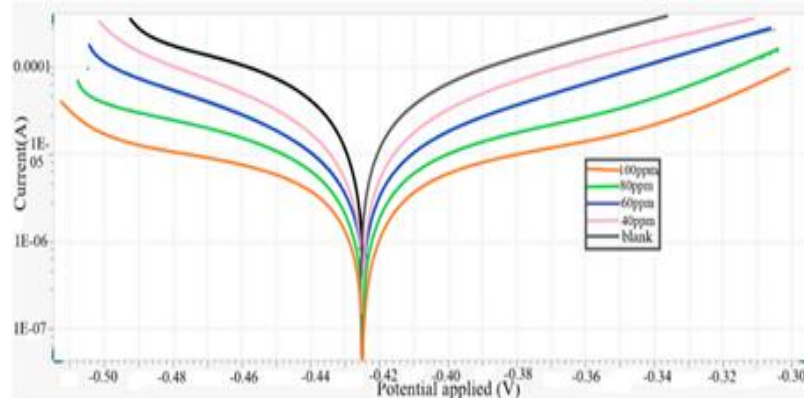
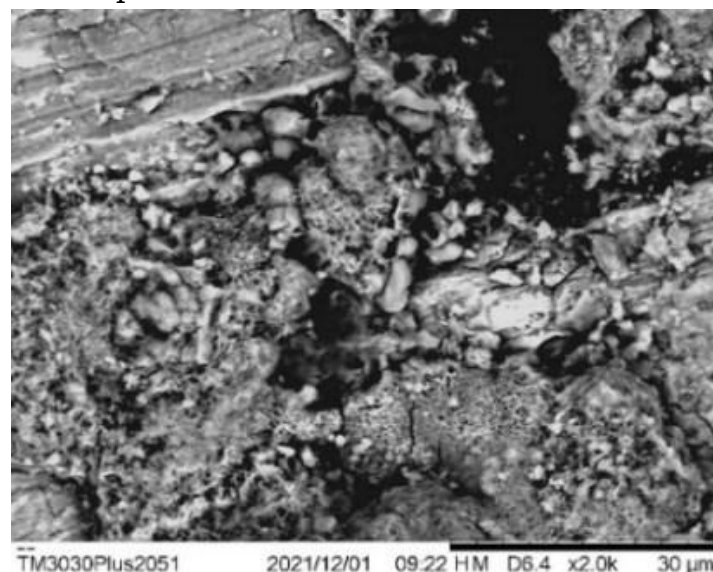


Fig. 3 Tafel lot for *Eclipta alba* plant extract

3.4. SEM and SEM-EDX Spectroscopy

The scanning electron microscopy investigation yielded micrographs, which are shown in figure 4 (a) and (b). Figure 4(a) depicts the morphology of the uninhibited steel surface, which exhibits imperfections and roughness due to corrosion. Figure 4(b) illustrates the surface of the steel specimen, coated with *Eclipta alba* leaf extracts at a concentration of 100 ppm, exhibits a flatten and more equal surface compared to the corroded one.



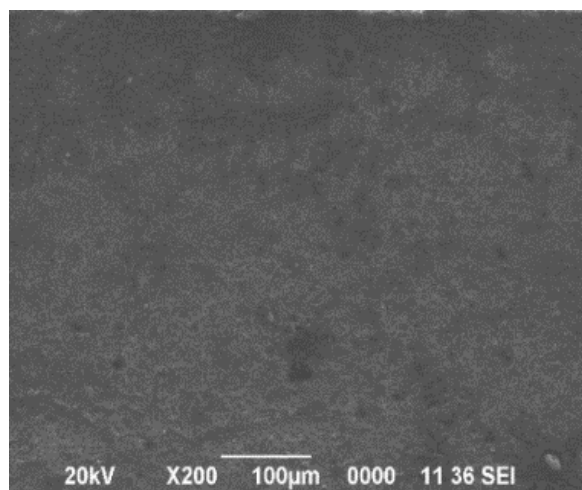
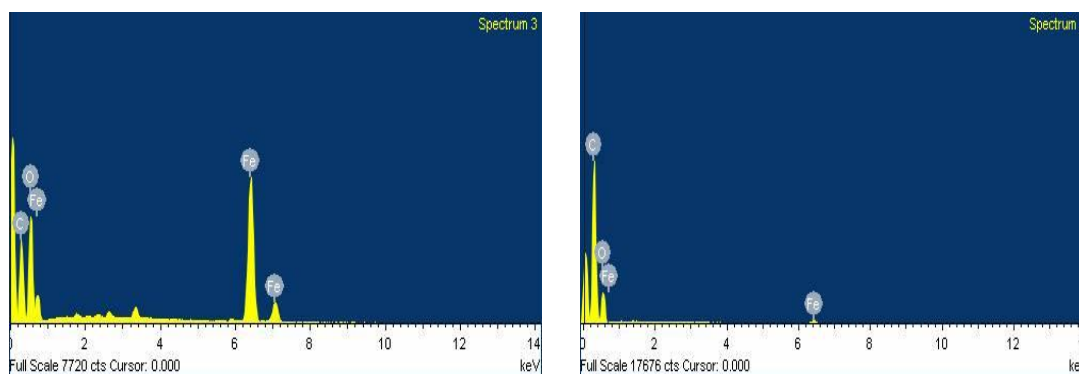


Fig. 4(a) SEM Micrograph for uninhibited steel (b) SEM Micrograph for inhibited steel with *Eclipta alba* extract

The elemental composition and spectrum of SEM-EDX imaging are detailed in Figure 5. Figure 5(a) illustrates the spectrum of the uninhibited steel surface, while figure 5(b) exemplifies the spectrum of the mild steel surface coated with plant extract. The spectrum unequivocally indicates that the uncoated steel surface has a greater concentration of iron than the inhibitor-coated steel surface. Conversely, an increase in the carbon and oxygen content is observed on the inhibited steel surface. This suggests that the active components of *Eclipta alba* plant extracts are responsible for the formation of a protective film on the mild steel surface.



Element	Weight %	Atomic %
C K	22.32	40.53
O K	29.95	40.83
Fe K	47.73	18.64

Element	Weight %	Atomic %
C K	63.87	70.56
O K	35.25	29.24
Fe K	0.87	0.21

Fig. 5(a). SEM-EDX spectrum for uninhibited steel, and (b). SEM-EDX spectrum for inhibited steel with *Eclipta alba* extract

3.5. Adsorption Studies and Mechanism of Adsorption

It has been theorized that the inhibitor compound inhibits steel through positive adsorption at the interface between the electrode and electrolyte [25]. Adsorption of steel results in the formation of a protective layer of inhibitor

compound, which reduces the detrimental effects of corrosive media on the steel surface. Adsorption can manifest via either chemisorption or physisorption mechanisms [26]. The data acquired from gravimetric and diverse electrochemical investigations were fitted to a few adsorption isotherms, with the Langmuir adsorption isotherm providing the most accurate fit. This is evident from the linear correlation coefficient value (R^2) being close to 1. The isotherm is a graph of $\log C/\theta$ in relation to $\log C$, as described by the equation (6) [27].

$$\frac{C}{\theta} = \frac{1}{k_{ads}} + C \dots\dots\dots (6), \text{ where } \theta = \frac{\%IE}{100}$$

Where, C is concentration of inhibitor, θ , the surface coverage and k_{ads} , the adsorption constant, whose values are calculated from equation (6). The graph of $\log C/\theta$ against $\log C$ was found to be a straight line with slope close to 1 which confirms that the adsorption of plant extract on steel surface follows Langmuir Adsorption isotherm. The R^2 values are tabulated in table 4. The type of adsorption is determined by calculating Gibb's energy of adsorption. The adsorption constant, k_{ads} is related to Gibb's free energy change of adsorption by equation (7) [28, 29]:

$$\Delta G_{ads}^0 = -RT \ln(1 \times 10^6 K_{ads}) \dots\dots\dots (7)$$

In general, when $\Delta G_{ads}^0 \leq -20 \text{ kJ mol}^{-1}$, it is postulated that adsorption takes place via the physisorption mechanism. Conversely, if $\Delta G_{ads}^0 \geq -40 \text{ kJ mol}^{-1}$, the mechanism of adsorption is chemisorption [30]. Based on data presented in Table 4, it has been determined that ΔG_{ads}^0 lies close to -20 kJ mol^{-1} . This value affirms that adsorption of *Eclipta alba* plant extract on the mild steel specimen have taken place via physisorption mechanisms only.

Table 4 Data from Adsorption Studies

Method adapted	Inhibitor concentration (%v/v)	% IE	θ	R^2	k_{ads} (ppm)	ΔG_{ads}^0 (kJ mol ⁻¹)
Gravimetric analysis	40	43.8	0.43	0.90	0.14	-23.5
	60	65.6	0.65			
	80	78.1	0.78			
	100	91.0	0.91			
EIS	40	54.1	0.54	0.95	0.02	-24.7
	60	85.1	0.85			
	80	89.0	0.89			
	100	90.1	0.90			
PDP	40	77.4	0.77	0.98	0.06	-27.3
	60	80.3	0.80			
	80	83.0	0.83			
	100	94.0	0.94			

The inhibitory mechanism of *Eclipta alba* plant extract on the mild steel is expected to occur via the formation of a metal-inhibitor complex on the steel surface, due to the presence of π -electrons and heteroatoms in the active components of the examined plant extracts [31]. The active components in *Eclipta alba* may interact with the mild steel surfaces through three types of interaction, electrostatic, chemical, or coordinate bonding [32]. However, as predicted by adsorption studies, the possibility of adsorption via chemical bond formation is ruled out in the present studied inhibitor system. Thus, coordinate bonding is the only possible mechanism of *Eclipta alba* inhibitor adsorption in the specimen mild steel surface. This is depicted in fig 6.

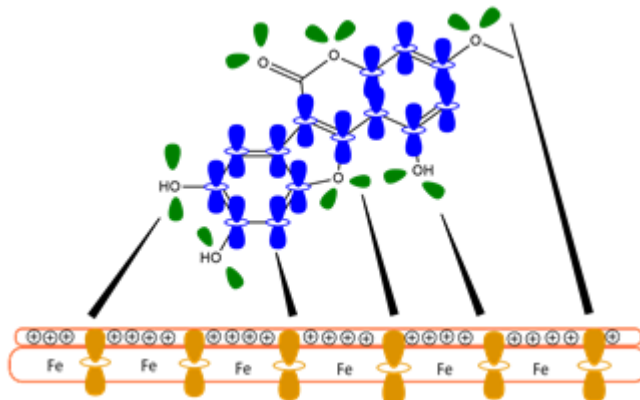


Fig. 6 Adsorption of active components of plant extract on steel surface.

4. CONCLUSIONS

Eclipta alba plant extract was discovered to offer potential as a green corrosion inhibitor. Electrochemical experiments revealed the maximum inhibitory efficiency of 94%. The gravimetric and electrochemical analyses were in good agreement. The inhibition efficiency was observed to rise with increasing inhibitor concentration. EIS measurements proved the capacitive nature of the inhibitor molecule. Polarization investigations revealed that the inhibitor acts as a mixed type of inhibitor, inhibiting both cathodic and anodic processes. The adsorption of inhibitor on steel surface was found to follow Langmuir adsorption isotherm through physisorption mechanism. Overall, the produced plant extract has proven to be an effective green corrosion inhibitor for mild carbon steel in CO₂ saturated 2% NaCl solution. The results implies that *Eclipta alba* plant extract may provide a sustainable solution to the oil and gas industries corrosion snags.

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THE IMPACT OF COVID-19 ON FAMILY ENVIRONMENT AND PSYCHOLOGICAL WELL-BEING: A SYSTEMATIC REVIEW

Thokchom Anand Singh

Research Scholar, Manipur International University

Abstract - This systematic review investigates the psychological effects of COVID-19, based on the literature from 2020 to 2022. It identifies and collates eight studies of really varied populations, including educators, students, health care workers, and older adults. The results show severe psychological distress related to the pandemic across these groups.

Key Findings:

- **Educational Environments:** An unprecedented rise in cases of stress and anxiety, with the sudden shift to learning remotely, also contributes to the increase in workload both for teachers and students. Burned out and emotionally exhausted, teachers saw their students unable to cope, which further heightened their anxiety.
- **Health Care Workers:** The pandemic accelerated the processes of stress and burnout in health professionals, who had to bear relentless work pressures in addition to emotional issues.
- **Older Adults:** As mentioned, the psychological changes were different in older adults: some felt more anxious or depressed related to isolation and health concerns, while others were more resilient as a function of effective coping mechanisms and personal support systems.

Limitations and Gaps: Longitudinal studies are scant, and comprehensive measures of psychological well-being were generally absent. Most research had a focus on short-term effects and specific populations. This precludes full understanding of long-term impacts and the multidimensional aspect of mental health.

Conclusion: The review has highlighted the need for a holistic approach in studying psychological wellbeing in relation to both the short-and-long-term effects. It is hoped that future studies fill these gaps with the use of broad measures of mental health and developing targeted interventions to support the populations affected during global crises.

Keywords: COVID-19, Psychological well-being, Teachers, Students, Health care workers, Older adults.

1. INTRODUCTION

The COVID-19 novel coronavirus diseases broke out at the end of December 2019 in Wuhan, China. Soon after that, it quickly spread worldwide, and by March 11, 2020, the World Health Organization declared a pandemic state (World Health Organization, 2019) has indeed brought changes to people's lives in many respects all over the world: from health to the mental and

psychological level. Indeed, it has brought about a number of lockdowns and work-from-home policies, giving great stressors and changes in daily activities across different industries.

World Health Organization, 2019. Initial studies indeed showed that during the COVID-19 pandemic, mental health burdens along with stress, anxiety, and depression problems rapidly increased and were added to by the unprecedented challenges associated with the pandemic (Gualano et al., 2020; Brooks et al., 2020). Psychological well-being in terms of hedonic and eudaimonic aspects, along with resilience, became an important focus in research in this context. (Tang et al. 2019)

2. REVIEW LITERATURE

Charry et al. (2020) investigated the Psychological Well-Being and Youth Autonomy: Comparative Analysis of Spain and Colombia. This research compared autonomy and psychological well-being in Spanish and Colombian youth by using Ryff's Scale of Psychological Well-being and the Transition to Adulthood Autonomy scales (EDATVA) in order to analyze their characteristic features. A sample of 1,146 aged between 16-21 years of age (506 Spaniards, 640 Colombians). The results indicate significant differences in the level of autonomy, as well as in two of the four dimensions proposed by EDATVA: self-organization and critical thinking. Similarly, conspicuous differences are seen in such aspects as positive relations and a purpose in life. This study underlines the role that contextual factors take in psychological well-being and autonomy during the transition to adulthood.

Lopez et al. (2020) studied the psychological well-being among older adults during the COVID-19 outbreak: a comparative study of the young-old and the old-old adults in Spain. The COVID-19 pandemic has brought a juddering halt to daily life, particularly in the health and wellbeing of older adults. The present study seeks to investigate the interaction of age as a moderator within the association of psychological well-being-both personal growth and purpose in life-using data of community-dwelling Spaniards aged between 60-80 years (N = 878). It is observed that older adults aged 71-80 years of age are not more psychologically worse off than younger seniors aged 60-70 years, though age negatively influences personal growth. This study emphasizes that the effects of COVID-19 on well-being are less an issue of the event itself than one of individual differences in appraisals and personal resources. Perceived health, family functioning, resilience, gratitude, and acceptance were the most important factors that contributed both to personal growth and to purpose in life. Increasing personal resources among older adults holds the key to a greater improvement in psychological well-being.

Prado-Gasco et al. (2020) studied Stay at Home and Teach: A Comparative Study of Psychosocial Risks between Spain and Mexico During the Pandemic. The COVID-19 pandemic has struck very deep into the very core of life and business in the world today, be it education or many other sectors that present psychosocial hazards. The current research compares perceptions

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maintained by Spanish and Mexican non-university teachers regarding COVID-19 and its linked psychosocial risks during the first months of the pandemic. Data obtained from 421 teachers showed that inequity and work overload were the most relevant risks. Teachers were satisfied to a moderate degree with the information on COVID-19 and the measures adopted; they expressed less satisfaction with the available resources. Mexican teachers developed better perceptions of the information, measures, and resources than their Spanish counterparts did, who suffered from an intense impact produced by the health emergency. These findings confirm the important role of perception in the management of psychosocial risks and in maintaining teacher well-being and effectiveness.

Kamaruzaman and Surat (2021) conducted Teachers Psychological Well Being During Covid-19 Pandemic. Not only healthcare workers, but teachers have been the front liners in learning as they scramble to make sure learning doesn't stop. Therefore, the aims of this study were to explore how teachers have been affected by the Lockdown with respect to their psychological well-being level and the difference between gender. In this regard, the present research has designed an online survey to quantify data from 361 teachers in Kuala Lumpur using Ryff's Psychological Well-being scale during the second MCO. In analysis, data collected is treated as follows: Mean, SD, and t-test. From the results obtained, the level of psychological well-being among teachers was high, and it has shown no significant difference between genders. These findings are important for further studies by psychologists, counsellors, educationists, and policy makers, among others.

Villani et al. (2021) examined Impact of the COVID-19 pandemic on psychological well-being of students in an Italian university: a web-based cross-sectional survey. Italy was the first European country to impose a national lockdown due to covid-19 and citizens of Italy are among those who have been most mentally affected. The psychological condition of university students in Italy during and after the first lockdown. The questionnaires were distributed on the personal websites of the students, and out of 501 students, 35.33% reported anxiety with 72.93% symptoms of depression. Though the level of understanding of the preventive measures was very high, most of the participants were distressed by not being able to see friends and partners at an alarming rate of over 70%. Increased anxiety was significantly associated with female sex, studying in Rome, missed university attendance, and not seeing one's partner, while regular physical activity contributed to reducing anxiety. The findings highlight the necessity for effective interventions along with the need for psychological services that address the long-term mental health consequences among university students.

Xiong et al. (2020) analysed Impact of COVID-19 pandemic on mental health in the general population: A systematic review. There has undoubtedly been a devastating effect of the COVID-19 pandemic on mental health worldwide, beyond that affecting patients and healthcare workers. The following systematic review undertakes to summarize the studies related to psychological

effects due to the pandemic and their associated risk factors. It analyzed data from several databases for up to May 2020 and showed high rates: anxiety, which ranged from 6.33% to 50.9%; depression, 14.6% to 48.3%; PTSD, 7% to 53.8%; psychological distress, 34.43% to 38%; and stress, 8.1% to 81.9%, in Covid-19 pandemic in China, Spain, Italy, Iran, the US, Turkey, Nepal, and Denmark. The risk factors are female gender, younger age ≤ 40 years, chronic or psychiatric conditions, unemployment, student status, and high media exposure. This review underlines the need for international public health efforts to address these major mental health challenges.

3. RATIONALE OF THE STUDY

The impact of the pandemic on family environment and psychological well-being are important in guiding targeted mental health interventions. Educators, healthcare workers, and older adults, among other populations, suffered varied psychological effects because of the different roles and responsibilities each had during the pandemic. This research study intends to bridge the gaps in the existing literature and further provide helpful insight for policymakers, mental health professionals, and researchers who are working in efforts toward mitigating the psychological effects of the pandemic.

4. STATEMENT OF THE PROBLEM

Hence, the current problem is stated as *“The Impact of COVID-19 on Family Environment and Psychological Well-Being: A Systematic Review”*.

5. OBJECTIVES

- a) To review the literature systematically on the impact of COVID-19 on psychological wellbeing between the period of 2020-2022.
- b) To highlight those key dimensions of psychological well-being that have been affected by the pandemic.
- c) To address the gaps in the present literature and make suggestions for future research.

6. RESEARCH QUESTIONS

- a) What are the reported impacts of COVID-19 on psychological well-being across different populations?
- b) How do these impacts vary according to demographic factors such as occupation, age, and geographic location?
- c) Which dimensions of psychological well-being have been most impacted during the pandemic, and what does this mean for future research?

7. HYPOTHESES

Based on the three objectives or three components, the following hypothesis was examined:

The impact of COVID-19 on psychological wellbeing between the period of 2020-2022, Dimensions of psychological well-being that have been affected by

the pandemic and Gaps in the present literature and make suggestions for future research would be.

8. DELIMITATIONS

This review is thus limited to quantitative studies published between the years 2020 and 2022 and centering on the direct impacts of COVID-19 on psychological wellbeing. The excluded studies are those that have estimated the psychological wellbeing only as a secondary outcome or focus on interventions rather than direct impacts of COVID-19.

9. DEFINITION OF KEY TERMS

- ❖ **COVID-19:** A new coronavirus disease at the root of the current global pandemic, having caused a respiratory illness, along with widespread social and health effects.
- ❖ **Psychological Well-Being:** Non-unidimensional in nature; hedonic happiness and eudaimonic happiness are included, together with resilience or coping and emotion regulation (Tang et al., 2019).
- ❖ **Hedonic Happiness:** Well-being of pleasure and enjoyment.
- ❖ **Eudaimonic Happiness:** Well-being as meaningfulness, purpose, and personal growth.
- ❖ **Resilience:** The ability to cope with stress and adversity, including emotion regulation and problem-solving skills.

10. METHODOLOGY

10.1. Study Design

The systematic review was done based on PRISMA guidelines. The necessity to minimize a comprehensive and reproducible searching and selection process guides the review of the study.

10.2. Search Strategy

A combination of search strategies was utilized:

Database Search: MEDLINE/PubMed.

Some keywords used were "psychological well-being" and "COVID-19," and the search was confined to 2021-2022.

10.3. Screening and Selection

Inclusion:

- ❖ To focus on the impact of COVID-19 on family environment and psychological well-being.
- ❖ A study that reported original research.
- ❖ Research whose keywords appeared in either the title or the abstract.

Exclusion:

- ❖ Studies in which psychological wellbeing was a secondary outcome.
- ❖ Intervention studies.

Duplicates were removed and the reference lists from the reviewed articles were screened to ensure comprehensiveness.

10.4. Population

- a) Educational Settings: The studies reviewed will aim at teachers, lecturers, and students specifically.
- b) Health Care Workers: Those that work in the health care environment.
- c) Older Adults: People who are aged 65 years and above.

10.5. Samples

- a) Teachers: 2029 participants,
- b) Students, 3186 participants,
- c) Health Care Workers: 1432 participants,
- d) Older Adults: 878 participants.

10.6. Tools

The quantitative tools applied in the research have been identified as;

- a) Patient Health Engagement Scale, which measures engagement in health management
- b) Self-Rating Anxiety Scale, SAS and Self-Rating Depression Scale, SDS, depression and anxiety
- c) DASS-21 Depression, anxiety and stress assessment
- d) Mental Health Test-MHT on various mental health dimensions.
- e) Child Revised Impact of Events Scale (CRIES).
- f) Behaviour Intervention Monitoring Assessment System (BIMAS-2)
- g) Ryff's Psychological Well-being Scale: Assesses various aspects of well-being.
- h) Family APGAR: Measures family functioning.
- i) Brief Resilient Coping Scale (BRCS): Quantifies resilience.
- j) Acceptance and Action Questionnaire
- k) General Health Questionnaire (GHQ-28): Assesses general mental health.

10.7. Quality Assessment of the Studies

Evaluation of internal validity regarding the potential for biases and confounding variables affecting this study was made. No evaluation of external validity was done since studies were of convenience samples.

10.8. Data Collection and Analysis

Data from characteristics of studies, populations, measurement tools, and results were extracted on a Microsoft Excel spreadsheet. A qualitative synthesis was done to look for patterns and gaps in the research.

11. RESULTS

The initial search identified 77,571 studies, which were limited to 60 by including the search terms in the title or abstract, followed by the application of

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the inclusion and exclusion criteria, which further systematised the results to 8 studies (Fig. 1). The studies were developed primarily in Europe (n = 6), Asia (n = 1) and North America (n = 1). The populations predominantly included teachers (n = 2,029), students (n = 3186), health care workers (n = 1432), and older adults (n = 878) with a total of 7,525 individuals; every study was quantitative and relied on survey data (Table 1).

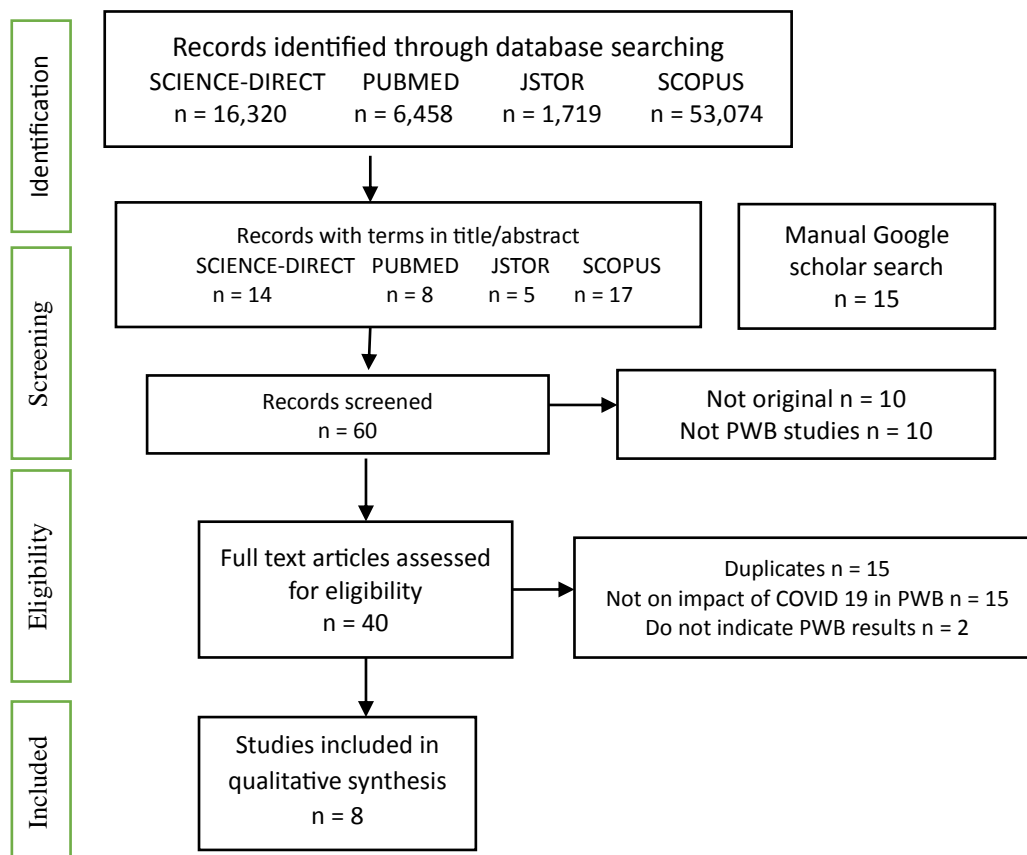


Figure 1 Flow diagram of study selection

The objectives mentioned in the various studies generally point to two patterns. The first pattern intends to demonstrate the impact of COVID-19 on the psychological well-being of individuals during the COVID-19 pandemic, that is, the mental state associated with the individual during lockdown. The other pattern intends to demonstrate the impact of COVID-19 on the psychological well-being of individuals after the reopening of lockdown (Table 1).

Table 1 Description of Studies According to Year, Country, Objective and Study Population

<i>Author</i>	<i>Year</i>	<i>Location</i>	<i>Objective</i>	<i>Population</i>
Lopez et al.	2020	Spain	assess the association between age and psychological well-being (personal growth and purpose in life)	878 older adults
Villani, et al.	2021	Italy	Investigate the impact of the COVID-19 pandemic on psychological well-being in a cohort of Italian university students.	501 undergraduate students
Ozamiz-Etxebarria, Santxo, Mondragon, & Santamaria	2021	Spain	measure the symptomatology shown by teaching staff in the Basque Autonomous Community at the time	1,633 teachers

				when schools were reopened	
Scheer & Laubenstein	2021	Germany	investigate teachers' perceptions of changes in students' emotional and behavioural disorders (E/BD)	173 students	
Schwartz, Exner-Cortens, & Canfield	2021	Canada	gather responses from students regarding their feelings about COVID-19 and related health and protective behaviours, their stress related to COVID-19, and their self-reported mental health	2,310 students	
Kamaruzaman & Surat	2021	Malaysia	explore how teachers have been affected by the lockdown with respect to their psychological well-being level and the difference between gender	361 teachers	
Sipeki, Vissi, & Turi	2022	Hungary	examine the mental health of special educator-students compared to their lecturers and inspectors	19 lecturers, 16 instructors and 202 students	
Canal-Rivero, et al.	2022	Spain	explore the impact of COVID-19 as well as possible gender differences on mental health status and suicidality in a cohort of HCW	1432 Health Care Workers	

In the eight quantitative studies, tools primarily consisted of surveys with Likert type questions such as Patient-Health-Engagement-Scale, Self-Rating-Anxiety-Scale, and Self-Rating-Depression-Scale (Villani, et al., 2021); the DASS-21scale (Ozamiz - Etxebarria, Santxo, Mondragon, & Santamaria, 2021); Hungarian language Mental Health Test (MHT) (Sipeki, Vissi, & Turi, 2022); standardized teacher-report form for emotional and behavioral problems and competencies, as well as perceptions of inclusion (Scheer & Laubenstein, 2021); Remote learning experience, COVID-19 health and protection behaviors, Child Revised Impact of Events Scale (CRIES), Behavior Intervention Monitoring Assessment System (BIMAS-2) (Schwartz, Exner - Cortens, & Canfield, 2021); Ryff's Psychological Well-being scale (Kamaruzaman & Surat, 2021; Lopez, et al., 2020); the Family APGAR, Brief Resilient Coping Scale (BRCS), and the Acceptance and Action Questionnaire - II (AAQ-II) (López, et al., 2020); and General Health Questionnaire 28 (GHQ-28) (Canal-Rivero, et al., 2022).

12. DISCUSSION

The discussion puts into perspective the findings from the systematic review in relation to a wider perspective on psychological well-being in the COVID-19 pandemic.

12.1. Psychological Impact of COVID-19

The COVID-19 pandemic has caused significant disturbance in the psychological well-being of diverse population groups:

- a) **Educational Settings:** There was a huge amount of stress and burnout among the teaching fraternity about instant shifts to online teaching, increased workload issues, and health and safety matters. In educators, stress and anxiety were greatly heightened during this time, as can be noted in such studies as Ozamiz-Etxebarria et al. (2021) and Scheer & Laubenstein (2021). Similarly, students reported heightened states of

anxiety and stress with regard to challenges in learning remotely and uncertainties about their future.

- a) **Medical Staff:** The pandemic put great pressure on health care workers; hence, entailing a high level of stress and burnout. In support, Canal-Rivero et al. (2022) found that among health care workers, there was a major psychological impact emanating from the heavy workload and the fear of catching or spreading the virus. Both the emotional and physical demands linked to their job roles made the stress higher.
- b) **Older Adults:** Whereas many indeed suffered from increased anxiety and depression because of the feeling of isolation and poor health, Lopez et al. (2020) mention that personal resources, including family and coping mechanisms, served as a buffer against these influences. The psychological well-being in older adults was firmly linked with their ability to cope with stress and maintain a feeling of self-directedness within the course of the pandemic.

12.2. Gaps in Current Research

It is in the review that a number of gaps in the literature were identified, including:

- a) **Comprehensive coverage:** Whereas most studies focused on very small populations, even as specific as educators or healthcare workers, not as many covered the relationships between groups or analyzed the holistic view of psychological well-being across different demographics. There is, therefore, a need for research that applies to a greater variation of populations and takes into consideration the interaction of factors that influence the state of well-being.
- b) **Long-term Effects:** Most of the reviewed studies assessed short-term effects, and only a few studies reported the long-term psychological effects of the pandemic. Future studies should focus on the long-term consequences of the pandemic on mental health and investigate changes in psychological well-being over time.
- c) **Holistic measures:** Most of the literature has focused on very narrow measures of psychological well-being, namely, stress or anxiety scales. Moving toward a more holistic approach that captures different dimensions of psychological well-being, including resilience, personal growth, and life satisfaction, would provide a full understanding of the impact of the pandemic.

In other words, despite some light shed by the above-reviewed studies on the psychological impact of COVID-19, there is definitely a need for research to be more nuanced and comprehensive and oriented toward long-term perspectives regarding the impact on mental health due to the pandemic and construction of effective interventions.

13. CONCLUSION

The literature review concerning COVID-19 impacts on psychological well-being provides several leads to conclusions and prospects for further research. The place that the pandemic occupies in the minds of educators, students, health caregivers, and older adults has brought about a profound and multi-faceted effect on the mental health of these populations. These manifest as increased levels of stress, anxiety, depression, and burnout-an indication of the pandemic causing disruption across wide parameters.

Key Findings:

- a) **Educational Sector:** The abrupt transition to virtual classes, workload, and uncertainty regarding the future have resulted in serious psychological stress for teachers as well as students. Though educators cited increased levels of stress, as witnessed in Ozamiz-Etxebarria et al. (2021) and Scheer & Laubenstein (2021), and anxiety in students, as reflected in Villani et al. (2021), immediate mental health interventions within educational settings appear called for.
- b) **Health Care Workers:** Health workers have been under psychological pressure never experienced before, with many reporting high levels of stress and burnout. Canal-Rivero et al. explain that highly demanding tasks and further responsibility burden stemming from the pandemic create adverse effects on mental health. This work points out the need for increasing mental health resources and support structures among health care workers.
- c) **Older Adults:** The pandemic has brought older adults both complex and nuanced impacts. While some manifested increased psychological distress, others were able to show resilience provided personal and social resources. Lopez et al. (2020) therefore present individual coping strategies and support systems as some factors that buffer the negative impact of the pandemic on the mental health of older adults.

13.1. Gaps in Research and Further Studies:

Although the reviewed studies have provided further insights, there are a number of gaps:

- a) **Comprehensive and Longitudinal:** Long-term impacts on psychological well-being-involving integration across demographic groups-are needed. Longitudinal studies would better provide insight with respect to the temporal development of mental health associated with the pandemic.
- b) **More Comprehensive Holistic Measures of Psychological Well-being:** This is to be addressed by future studies using comprehensive measures that include, but are not limited to, stress and anxiety, such as resilience, life satisfaction, and personal growth. In this regard, nuances into the effects of this pandemic would be more fully realized.
- c) **Intervention Development:** The findings from this review emphasize the need for targeted psychosocial interventions that might be developed and

implemented on mental health across diverse populations, having components specific to older adults, health care workers, educators and students.

The need for solid support systems and awareness of psychological well-being has never been in stronger focus than in the time of the COVID-19 pandemic. Thus, to cope with the psychological fallouts of the pandemic, one needs to approach the problem from a multidimensional angle through ongoing research, comprehensive measurement tools, and targeted interventions. This way, the world would be in a better position to understand and improve the psychological consequences brought about by future global calamities.

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ARTFUL ATTIRE: THE CROSSROADS OF INDIAN GREAT MASTERS AND FASHION CULTURE

Ms. Tarandeep Kaur¹, Dr. Tikendra Kumar Sahu²

¹PG Department of Fashion Designing, Kanya Maha Vidyalaya, Jalandhar,
Punjab, India

²School of Design and Visual Arts, Apeejay Stya University, Gurugram,
Haryana, India

Abstract - This research paper examines the complex relationship that exists between the ever-changing world of fashion and the prestigious history of Indian art. By examining the works of esteemed Indian artists, this research delves into the complex correlations that exist between classical artistry and contemporary sartorial expressions.

The principal objective of this study is to investigate the profound impact that paintings by Indian Great Masters have had on contemporary fashion culture. By conducting an in-depth examination of particular works of art and applying a comparative perspective, this paper investigates the ways in which cultural themes, color, and composition reverberate within the dynamic fabric of modern clothing. This exemplifies the reciprocal association between fashion and classical Indian art, demonstrating how enduring aesthetics persistently influence notions of sophistication, cultural allure, and style.

Thematic areas of interest encompass the examination of how iconic artworks serve as catalysts for modern fashion trends, the development of beauty standards within the framework of Indian art, the symbolic connections that exist between modern fashion and traditional art, and the expression of cultural elements in avant-garde apparel. The study places this analysis in the wider cultural and historical frameworks, underscoring the importance of classical Indian art in influencing the discourse surrounding modern fashion as an expression of changes in society and cultural devotion.

By employing visual analysis, comparative studies, historical research, and expert insights, this paper endeavors to provide significant contributions to the ongoing discourse surrounding the dynamic language of contemporary style and the brushstrokes of Indian Great Masters. Through an exploration of this juncture, the study aims to enhance our comprehension of the enduring impact and inspiration that classical Indian art maintains on the dynamic realm of fashion culture.

Keywords: Contemporary Fashion, Indian Art Heritage, Great Masters' Paintings, Cultural Influences, Sartorial Expressions.

1 INTRODUCTION

The intersection of great Indian master painters and fashion culture involves the incorporation of traditional painting styles, motifs, and themes into contemporary fashion. India has a rich art tradition, with master painters who have left an indelible mark on the artistic landscape. Their works often serve as

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inspiration for modern designers, leading to a fusion of artistic heritage and fashion. When art meets fashion it's a match made in heaven. For decades, fashion designers have been inspired by artists and used art to inspire their designs. The correlation between fashion and art has been present since ancient times.

In the past, art and fashion were often seen as conflicting concepts, causing concern over the potential loss of artistic significance and the inappropriate appropriation of fashion. Art is often associated with being timeless and eternal, only perceptible through visual observation. In contrast, fashion exists solely when it is worn and assessed as a temporary trend that leaves an impact only during that specific period. Nevertheless, it is evident from historical records that the trajectories of these two terms have intersected and even amalgamated in a contradictory manner.

Artists and designers are distinct. The artist enjoys absolute freedom during the creative process, and the result of their work is an aesthetically pleasing entity. Nevertheless, designers lack the artistic freedom enjoyed by artists. However, the plans created by designers are driven by aesthetic emotions, and the resulting design product is primarily focused on functionality, while also having the potential to be aesthetically pleasing. Furthermore, a notable similarity between art and design is that both disciplines yield tangible outcomes resulting from deliberate effort and strategic decision-making. This definition encompasses all forms of art and design products that are widely acknowledged and accepted.

Indian art has a profound and storied history, characterized by its intricate designs, vibrant colors, and symbolic depth. Renowned Indian masters, such as Raja Ravi Varma, Jamini Roy, S.H. Raza, Amrita Sher-Gil, and M.F. Hussain have left an indelible mark on the cultural landscape [1]. Their works, often rooted in mythology, folklore, and everyday life, offer a treasure trove of inspiration for contemporary fashion designers. This paper examines the symbiotic relationship between Indian art and fashion, illustrating how traditional motifs and aesthetics are revitalized in modern attire, thereby bridging the past and present. The present work focuses on the exploration of the historical and artistic concepts involved in Indian art and how these concepts are cleverly integrated into the fashion domain to form a perfect culmination of tradition and contemporariness.

2 REVIEW OF LITERATURE

Contributions of Indian Great Masters artist and their influence on fashion culture:

2.1 Raja Ravi Varma (1848–1906):

Raja Ravi Varma was a famous Indian painter and artist of the Indian Renaissance. Raja Ravi Varma can be credited as one of the most famous painters in the history of art in India; he has achieved what no other painter had achieved until then by painting mythological and historical themes in a

realistic manner [2]. This is perhaps seen in the way he uses color and the amount of concern that he devotes to each of his creations.

He is most famous for his realistic style in his artwork which was achieved through emphasizing aspects such as texture, facial features and bones, use of oils and linear perspective, and chiaroscuro. These mythological themes are quite appropriate in Varma's work as he paints Hindu gods and deities as well as legends from the epics in bright and dramatic style. Regarding the paintings of Indian royalty, his work is believed to be realistic, and the nature of the subjects has been depicted in an appropriate manner. He also painted Indian women with dignity and sensuality, dressed in Indian costumes highlighting their charm and their inner feelings [2]. The combination of the Indian cultural essence with Western techniques made Varma's work unique and appealing to many. Furthermore, his use of oleographs for the purpose of mass production made art affordable to the public and put him in the category of the artists who played a significant role in the process of the democratization of art in India.

Fashion Influence: Some of the traditional Indian clothes as painted by Raja Ravi Varma have been borrowed by modern fashion designers. The royal and luxurious costumes of the subjects depicted in his paintings are often used as a guide for bridal and festive wear.

Raja Ravi Varma's influence extended to jewelers and weavers of his era, who incorporated his motifs, patterns, and even the design of jewelry and the draping style of sarees worn by his subjects. Hermès, as an early adopter, drew inspiration from Varma's painting of an esteemed Nair woman and crafted a dress drape with a Parisian influence using Kerala's traditional gold-and-white sari over ten years ago. Designers and brands are showing renewed interest this year due to the 175th birth anniversary of the artist, whose cultural legacy remains enduring [3].

Anju Modi, a renowned fashion designer and advocate for India's cultural heritage, made a significant impact on Sustainable Fashion Day at Lakme Fashion Week [4]. She showcased her designer clothing collection, which drew inspiration from Raja Ravi Varma's beloved muse. Named "Damayanti," her assortment includes saris, lehenga-cholis, jackets, and pre-stitched saris with designs that evoke the style of the renowned artist's paintings. These garments were crafted using a specialized fiber made from wood chips/pulp, giving the fabric a biodegradable characteristic.



Fig. 1 Anju Modi showcased her collection, which drew inspiration from the paintings of Raja Ravi Varma, at the FDCI x Lakmé Fashion Week 2022 held at the Jio World Convention Centre in Mumbai.

Modi's appearance in the show was influenced by the artworks of Raja Ravi Varma, who frequently depicted Damayanti. His look showcased the Western techniques and styles that were innovated by the artist. The saris were intricately decorated with embroidery and adorned with various traditional styles. They were brightly colored and had artistically designed shimmering borders that accurately replicated the appearance of Varma's artworks.

Modi greatly admired Raja Ravi Varma's artwork and had always aspired to integrate his style into her designs. The source of inspiration for her poem titled "Ode to Raja Ravi Varma" is Damayanti, whom she perceives as the favored muse of the artist. "The couturier asserts that he was fascinated by her grace and elegance." "A painting of a beautiful woman sitting by a pillar, staring at a swan, playing the sitar, or wandering in a forest is found in many Indian households. There may be variations, but the essence remains the same—the beauty in her expressions, even the dreamy backgrounds, colors, etc."

She transformed the artist's vision into tangible female characters that depicted Damayanti. The models walked confidently with their bare feet adorned with intricately designed payals and their soles dyed with henna, evoking a sense of India's historical heritage. The ensemble consisted of saris, cholis, and jackets adorned with asymmetrical drapes on one side and complementary shawls on the other, effectively capturing the essence of affluent Indian women flaunting their jewellery.

"It is my way of honoring Raja Ravi Varma," declares Modi [4].

Gaurang Shah's "Chitravali" collection was a tribute to the celebrated artist Raja Ravi Varma. In this collection, she came up with handwoven sarees that depicted scenes from Varma's paintings. Employing basic weaving practices and natural colors, Shah was able to replicate the details and colors of Varma's artistry on fabric. The collection blended art and fashion flawlessly, thus, preserving the timeless beauty of Varma's works

Santati was Shah's most challenging project, and the work was unveiled at the National Gallery of Modern Art (NGMA) in Mumbai to commemorate the 150th birth anniversary of Mahatma Gandhi [3]. The exhibition showcased the

replication of Varma's paintings on the sari by twenty artists through the jamdani weave. The process of weaving each sari demanded a time span that could vary from six months to two years.



Fig. 2 Gaurang Shah has created a sari that incorporates a woven Raja Ravi Varma painting in the pallu.

Shah chose the paintings, which the artist had painted less frequently. Of 54 oleographs, he and his team could produce 33 saris with paintings by Varma on the pallu [3]. These saris were produced with special weaves of khadi material and natural colors. The paintings were selected based on three distinct categories: concerning women in Varma's works, images of gods and goddesses, and stories.

Gaurang Shah who is the designer adds that some of the saris took a period of three months to be made while those with painting took more than 10 months to be designed. Before starting the work, the designer undertook a background search for more than six months. This involved supervising the production of 600 distinct shades of colors and dyeing over 200 kilograms of yarn. The purpose of this meticulous process was to accurately replicate the paintings using khadi fabric and faithfully recreate the original colors on the woven pallus. According to Shah, the use of the Srikakulam jamdani technique allowed us to design the entire pattern without any repetition.

The team had to surmount distinct obstacles. Initially, they noticed that Varma's paintings consisted of curved brush strokes, and it proved to be a monumental challenge to teach the weavers how to recreate his masterpieces. In order to accurately depict the intricate details, color variations, texture, and patterns, even a small painting had to be enlarged to nearly 40 inches. Additionally, it proved challenging to locate a suitable group of weavers proficient in on-paper jamdani, a technique involving the printing of a six-meter paper pattern that is then placed beneath the warp for reference during weaving. They successfully identified and enlisted 20 families for the task.

In addition to utilizing 150 units of high-quality khadi fabric, another obstacle was the task of procuring suitable dyes and ensuring their compatibility with the saris [3]. Upon examining certain saris, they discovered that the artwork became apparent on the reverse side. Occasionally, the color combinations were not successful. Consequently, they were compelled to

modify their approach, blueprint, and weaving configuration in order to achieve the most accurate replica.

Producing various hues of yarn color using natural dyes required meticulous effort, as the colors spanned from radiant to soft pastel pinks. The most significant challenge was to accurately reproduce the draping of the clothing and the facial expressions of each character in the paintings using jamdani weaves. However, Shah demonstrated determination and achieved success, much like he did for an arts and culture exhibition in Delhi (and later in Hyderabad and Ahmedabad) that honored Gandhi's philosophy. The complexity and grandeur of Indian weaving are clearly displayed in these saris, just as the lasting impact of a renowned 19th-century painter on a versatile 21st-century designer is apparent.

Sabyasachi Mukherjee is well-known for his deep appreciation of Indian art and culture. His collections often reflect the rich heritage and intricate detailing characteristic of traditional Indian art. For example, one of his collections took inspiration from Raja Ravi Varma's paintings, incorporating the painter's regal and mythological themes into luxurious textiles, rich embroidery, and classical silhouettes. Mukherjee's work captures the opulence and elegance of Varma's art, translating it into modern couture.

2.2 Amrita Sher-Gil (1913–1941):

The painting style adopted by Amrita Sher-Gil is a unique blend of the Western as well as the Indian style of paintings. Originally trained in Paris, early paintings of her shows Post-Impressionism, a European modern art style that is evident in the choice of colors and strokes used. But after going back to India she started adopting elements of Indian miniature paintings and frescoes that can be seen in her works and thus created a style that is quite characteristic of her [5]. She uses bright and saturated colors, which bring emotions and a story to her paintings; she composes them in a precise manner, depicting the everyday life and experiences of the people of India, especially women. Sher-Gil's paintings are autobiographical and ethnographic in a sense, as her paintings focus on subjects such as femininity, identity, and synthesis of cultures which are depicted in the rural Indian scenes.

Fashion Influence: Sher-Gil's personal life and art were rebellious and free-spirited, and this has influenced designers. Her work with colors and shapes can still be seen today as a reference for contemporary fashion looks. Several contemporary fashion designers have drawn inspiration from Amrita Sher-Gil's paintings, creating collections that reflect her unique artistic vision.

Suneet Varma, the designer, has a strong interest in Amrita Sher-Gil and has chosen to devote his Fall-Winter collection to her. Suneet Varma's collection for the season aimed to depict the various stages of the painter's short life and the unconventional era she resided in. He named his collection **Amrita Sher-Gil: A Life Extraordinary**.

Suneet Verma divided his collection into six distinct sections. The show commenced with Hungarian Memories; a line characterized by prominent

1920s Art Deco patterns. The models on the runway showcased a variety of colors, including porcelain pink, ivory, and black. However, the main focus of the collection was on tunics, both long and short, which were paired with wide pants. The second line, known as The Paris Years, featured a color palette consisting of deep burgundy, emerald, antique gold, fuchsia pink, and flaming orange. Tailored dresses and elegant evening gowns captured attention.

The influence of Sher-Gil's stay in southern India is evident in Varma's third work, titled "Search For Roots." This discussion focused exclusively on saris and long kurtas. The painter's affinity for ivory and Banarasi textiles served as the inspiration for the fourth line, which was crafted in a combination of white and gold. The fifth- and sixth-lines celebrated femininity using a primary pastel color scheme.

What makes Amrita Sher-Gil particularly significant to Varma? He expresses his long-standing admiration for her elegance and acknowledges that her fashion sense has served as a source of inspiration for him.

Fashion designer Bibhu Mohapatra has scorched the New York Fashion Week with his Spring/Summer 2021 (SS 21) collection. Inspired by the Hungarian Indian revolutionary avant-garde painter, Amrita Sher-Gil, the New York-based designer unveiled his 26-piece collection. Bibhu Mohapatra's latest collection is inspired by Amrita Sher-Gil, a pioneering artist known for challenging societal norms. The collection showcases Sher-Gil's defiant nature through the use of vibrant hues, specifically chartreuse, incorporated into fabrics such as tulle, Chantilly lace, and crepe [6]. Bibhu is renowned for his striking evening wear and enchanting design style. His collection features a combination of formal and semi-formal garments, including a chartreuse twist drape dress, a pale-blue crepe cape dress, and a white denim tailored blazer adorned with crystal paisley embroidery.

The collection also introduces versatile separates for at-home wear and virtual meetings, incorporating embroidery and handiwork for added sophistication.



Fig. 3 Designer Bibhu Mohapatra's collection is inspired by the great artist Amrita Sher-Gil: lockdown series. Images courtesy of JD Urban

Sanjay Garg's collection inspired by Amrita Sher-Gil is a tribute to her revolutionary spirit and artistic legacy. Through the use of Indian fabrics and embroideries and the incorporation of modern Western fashion into the designs, Garg captures the same sense of hybridity that lies at the core of Sher-Gil's art. In this case, paying tribute to Sher-Gil through fashion is not only a tribute but also an introduction to her colorful and innovative spirit to a new generation.

Tarun Tahiliani's collection which was based on Amrita Sher-Gil is a very moving tribute to the artist. Tahiliani succeeded in incorporating the coloration, painting style, and cultural elements of Sher-Gil's paintings into his fashion creations thus paying homage to the artist as well as connecting art and fashion. This blend makes the collection classic yet trendy at the same time, which will be appreciated by Indian people with their roots and taste for modern fashion.

Sabyasachi Mukherjee is a prominent fashion designer in India associated with luxurious and elaborate creations inspired by the art and traditions of India. He has mentioned that some of his collections are inspired by Amrita Sher-Gil. It is not a secret that Sabyasachi draws inspiration from vibrant colors, intricate patterns, and traditional Indian motifs, and with this collection, he pays tribute to Sher-Gil's style.

A prominent Indian fashion designer is Ritu Kumar who has been involved in the revival of traditional fabrics and art forms. She has also been influenced by Amrita Sher-Gil in her paintings by using bright colors in her paintings and merging Indian motifs with modernist style. It is not uncommon for her collections to depict the cultural amalgamation that Sher-Gil's paintings portray.

Manish Arora always finds inspiration in the world of art. He effortlessly translates the aesthetics of contemporary art into his fashion collection, creating pieces that are visual treat [1]. The choice of fabrics, cuts, and patterns in Manish Arora's creations are brave, different, and colorful like the paintings of Amrita Sher-Gil. Most of his designs are a blend of Indian motifs and modern fashion trends which shows that Sher-Gil has the ability to fuse different cultures.

Anita Dongre, who is famous for her detailed work and Indian aesthetics in her creations, has also taken her inspiration from the artistic brilliance of Amrita Sher-Gil. Dongre's collection has the theme of Indian heritage, which is similar to Sher-Gil's Indian identity theme.

The designer Payal Khandwala is an artist turned designer and her collection is inspired by Indian artists [1]. Payal's create collection inspired from Amrita Sher Gil's art in particular. Her style is characterized by powerful color saturation and geometrical forms of dresses, which echo the powerful and passionate character of Sher-Gil's paintings.

Some of these designers include among others; the way Amrita Sher-Gil fused the two worlds, the Indian and the Western in her paintings, the use of bright colors, and the themes of culture and femininity. Many of their

collections are similarly a mix of the traditional and the contemporary as they celebrate the spirit of Sher-Gil as a pioneer artist in the world of art and fashion.

2.3 Jamini Roy (1887–1972):

Artistic Style: Jamini Roy was a famous Indian artist who was famous for his work of art which was a blend of traditional folk arts of India with a touch of modernity. His painting style is vibrant and aggressive with black bold lines, flat colors, and more or less simplified forms and resembles the Kalighat Pat paintings of Bengal. Kalighat pat influenced Roy a lot, these were religious and narrative scrolls which were created by folk artists of Bengal. He adopted some of these earlier styles, including the thick black outlines and bright coloration, but adapted them into his own unique style [7]. This is one of the ways that define Roy's style, the colors are earthy, gotten from natural pigments such as lamp black, Indian red, yellow ochre, and chalk. He preferred to paint on handmade paper, cloth, or wooden board which gave his paintings a naïve and folklike look. The subjects that Roy depicted were mostly scenes from Indian mythology, rural lifestyle, and the routine activities that took place in the villages. He painted figures simplified in form and gesture, even when depicting the human face and body, he was more concerned with the image than likeness.

Fashion Influence: Fashion designers use the simplicity and the daring nature of Jamini Roy's work in apparel. Folk motifs and earthy colors are seen in contemporary fashion due to the impact of his unique sense of style.

This is probably why Anamika Khanna's 2018 couture collection was inspired by Jamini Roy's folk art style. The collection included such elements as the integral lines, the earthy colors, and the traditional ornaments that are characteristic of Roy's art, so he was able to convey his vision in the language of modern fashion. This collection was presented at the India Couture Week 2018 in which the models looked gorgeous dressed up in creations that were inspired by the legendary actress Roy.

Today's well-known fashion designer Sabyasachi Mukherjee has incorporated the artwork of Jamini Roy in his creations. Sabyasachi has had a deep passion for the art and culture of India and some elements of painting by Jamini Roy have been incorporated into his creations.

Jamini Roy, one of the most famous artists of the new generation for his daring simplicity and use of bright colors got inspiration from the traditional folk art of India, particularly the Kalighat pat style. Like these aspects, the works of Sabyasachi also bear such elements as heavy lines, rich and vibrant color combinations, and motifs inspired by the folk and tribal arts that Roy brought to the fore. Therefore, Sabyasachi uses these artistic elements in his clothing line and creates clothing items that not only embody the Indian culture but also fit into the modern context, for instance, Jamini Roy's paintings. This combination of styles not only honors Roy's heritage but also applies his creative concept to contemporary luxury fashion.

Manish Arora has always found inspiration in the world of art [1]. Manish Arora tried to capture the essence of Jamini Roy's folk art style through his collection by making it as bright and daring as possible. The fashion show included bright and saturated colors, the simplicity of the shapes, and the ornamentation of the garments that reflected Roy's individual vision. Through the application of bright and daring patterns, Arora successfully introduced a contemporary aspect to Roy's folklore motifs, making the showcased clothing line visually appealing as well as culturally diverse.

Ayushman Mitra, a contemporary fashion designer and artist of fashion and art, has made collections based on the paintings of an Indian painter Jamini Roy. From the works of Jamini Roy, who had a unique style that was very close to the traditional folk art of Bengal, Mitra was encouraged to merge similar aspects into his fashion creations. The works in Mitra's collections are reminiscent of Roy's powerful lines, energetic and bright color palettes, and clear but eloquent shapes.

Here, one can observe the embodiment of Roy's vision in the fabric art. Many of the pieces depict the themes of rural life, mythological characters, and aboriginal symbols seen in Roy's paintings. Mitra's choice of earthy colors and bright primary colors is reminiscent of the original artworks by Roy and adds a sense of authenticity to the project.

Through the incorporation of these artistic aspects, Ayushman Mitra pays tribute to Jamini Roy while also creating a connection between traditional Bengali art and modern-day fashion. These combinations produce items that are both culturally meaningful and aesthetically appealing, so the audience can appreciate Roy's artistic vision in the contemporary world.

2.4 S.H. Raza (1922–2016):

The painting style of S. H. Raza is characterized by the bright and active brush and the combination of Indian spiritual essence with abstract and geometric art. His choice to paint in bright and intense tones – deep reds, blues, yellows, oranges – has an impact of conveying an incredible force and turning his creations into a symbolical expression of Indian philosophy and cosmology. Geometry and other shapes and forms such as circles, squares, triangles, lines, and space are the most important elements in his compositions although these are used to represent spiritual and philosophical ideas, the dot or Bindu being the point of creation of the universe. The symbols that can be observed in Raza's paintings include Kundalini, Mahabhuta, and Mandala, which make the paintings deeper in terms of spirituality [8]. His paintings are actively constructed through the use of color, shape, and texture that make them look like they are in motion; this makes one slow down and think. Texture is also important here and the layering of colors and different techniques used to produce the image add depth to it. In terms of style, Raza's work is a combination of both Indian and Western motifs, notably derived from Abstract Expressionism which is a reflection of East meets West.

Fashion Influence: The geometric patterns and spiritual themes depicted in Raza’s art have inspired fashion designers who use abstract designs and symbols in their apparel designs. The decision to use shapes and colors is unresolved and goes to the core of his concept.

Satya Paul, a leading fashion designer from India, is very famous for using art, cultural, and natural designs and patterns. Among the sources of inspiration, one of the most memorable is the works of Sayed Haider Raza – an eminent Indian painter, and an abstract and expressionist artist. The characteristics of Raza’s art include the use of bright colors geometric patterns and symbolic figures and shapes such as the Bindu or the point that is the source of creation.

If Satya Paul made a collection based on S. H. Raza, Satya Paul would probably incorporate the main idea of Raza’s art which is the intensity of colors. One should expect to see tones like reds, blues, yellows, and oranges predominate in the garments as reflective of the energetic color palette of Raza’s paintings. These colors are not only bright and powerful but also convey the force and the essence behind the art of Raza.



Fig. 4 Great artist S. H. Raza’s paintings were used by fashion designers Satya Paul, Mini Sondhi, and Shanti Banaras for their creative fashion collections.

Geometry would be an important aspect of this collection with circles, triangles, and lines which Raza used in his work being incorporated into the fabric patterns as they are an art form in their own right. The application of such shapes would further extend the aspect of modern and abstract in the traditional Indian wear thus making the garments look unique.

There would also be the appearance of geometric shapes as it is typical of Raza to incorporate circles, triangles, and lines into his work they can easily be included in the fabric patterns to create the perfect fusion of art and fashion. The incorporation of such shapes would introduce a modern and unconventional form in the traditional Indian attire, and the look of the clothes would be different.

Some of the most probable characteristics of the collection would be in the use of symbolism, especially the Bindu motif. The “Bindu” is a symbol for

the creation point and the cosmos, and if the symbol is printed on the garments, the outfits would gain a deeper meaning. The combination of the spirit of the church with the spirit of fashion would create designs that not only looked good but also had a meaning behind them that would affect the souls of the people who wore them.

Also, the collection would probably include such materials as silk and satin alluding to the texture of Raza's work and embroidering and beading as the reflection of the luxurious aspect of the artist's paintings, The combination of fine fabrics with artistic prints would make it a luxurious ethnically touched collection.

Satya Paul would have created the contemporary version of the artworks of S. H. Raza that would have been a tribute to India. The collection would also be in memory of Raza's artwork and at the same time create a new art of art and fashion features. Therefore, integrating Raza's concepts of abstraction and expressionism into the fashion domain, Satya Paul would design a visually appealing and conceptually provocative line that would celebrate Indian art and heritage.

Shanti Banaras collection based on S.H. Raza's paintings is a perfect blend of the aesthetics of Banarasi weaving tradition and the abstract and spiritual nature of Raza's artworks. This collection is a rich palette of colors, geometry, and symbolism inherent in Raza's paintings. All the works in the series are inspired by the history and traditions of Varanasi, but they have Raza's iconic symbols, such as the Bindu and geometric shapes. The outcome is an exquisite blend of artistry and style, where Banarasi weaves enrich the traditional fabrics with modernism inspired by S. H. Raza's abstract paintings on the clothes.

Mini Sondi's clothing line based on S. H. Raza's paintings is a tremendous example of fashion integrated with the abstract art of Raza. Her collection is based on Raza's colors, geometrical forms, and religious motifs and it is transformed into contemporary wear. Each of them echoes the profound and complex nature and emotional message of Raza's painting, with the 'Bindu' (dot) and other geometric shapes. By incorporating these aspects in her design, Mini Sondi is able to capture Raza's work and at the same time bring a new and fresh appeal to the modern fashion-savvy people.

2.5 MF Husain (1915–2011):

This article focuses on the artworks of Maqbool Fida Husain commonly known as M F Husain who is considered as one of the most famous and productive painters of India. Thus, during several decades he created his highly individual and dynamic painting manner. He employs strong and active strokes for the delineation of figures and masses in motion in his paintings. In his paintings, Husain used a wide palette, deep browns, and black, and bright reds and blues, and gave his paintings the feel of vibrant passion [9]. His works are often vibrant and harmonious, so people pay attention to his art due to the invigorating layout and structure of his pieces.

According to Husain, he got his inspiration from Indian culture, legends, and reality by painting scenes from Indian epics and using motifs that symbolize Indian culture. Most of his works contain some didactic elements and are often full of narrative and allegorical meaning [9]. He tried out different styles and different media and this is perhaps one of the reasons why he has been hailed as an influential artist of the modern period. From oil painting to watercolor and to all the other forms of painting, he got to discover various aspects of his creativity.

It is possible to state that in addition to his contributions to the sphere of art, M. F. Husain is famous for his passion for the Indian spirit and for his contribution to the development of contemporary art in India and in the world. The artworks he has created still raise questions and evoke emotions, testifying to the significance of his role in the art world and his influence on artists of the future.

Fashion Influence: The vibrant colors and the fluid line of Husain's art have influenced fashion designers to be innovative and come up with new prints. It is in this regard that he brings out the Indian cultural symbols in most of the contemporary wears. Yes, Satya Paul, a famous Indian fashion designer, has come out with sarees that have prints of artwork of M. F. Husain. Satya Paul is well known for its artistic and inventive style of clothing which has been inspired by different art forms. Satya Paul's collaboration with the legendary artist M. F. Husain is one of the most prominent instances of fashion and fine art coming together in perfect harmony.



Fig. 5. Dresses designed by Mini Sondhi inspired by the paintings of MF Hussain

These sarees have prints that resemble Husain's style with strong lines, clear colors, and movements on the fabric surface. Satya Paul has done a great job in incorporating Husain's motifs into his saree collection not only as fashion wear but also as a form of art that respects Indian culture and artistry. The blend of art and fashion gives society an artistic fashion that enables people to wear a portion of Husain's artistic vision in their day-to-day outfits.

Mini Sondhi has created an inspired collection that is influenced by the colorful and spirited paintings of M. F. Husain, and embodying them in modern clothing. Sondhi's collection is inspired by Husain's work as the latter's painting style is characterized by the dynamic use of lines and bright colors; every dress

created by Sondi reflects this principle. The series effectively presents the aspect of Husain as a storyteller through pictures, with motifs from Indian culture and mythology that were characteristic of his work. Through his understanding of the craft, Sondi has paid tribute to Husain in a way that the works produced are steeped in cultural depth but also contemporary design. Thus, in this project of utilizing Husain's artwork to create fashion pieces, Mini Sondi not only celebrates the artist's work but also allows people to enjoy Husain's themes and energy in the context of their clothing.

3 RESULTS AND DISCUSSION

The hybridization of ancient Indian art and modern fashion has created a creative and vibrant synergy that has revolutionized modern fashion significantly. This research proves how the great masters of India like Jamini Roy; Amrita Sher-Gil; Raja Ravi Varma; S. H. Raza; and M.F. Husain are still influencing contemporary fashion and present a fusion of tradition and modernity & modern aesthetics.

3.1 Results:

The material evidence indicates that modern fashion designers have borrowed from the thematic density, colors, and composition of these masters of painting. For instance, Raja Ravi Varma's painting style of royalty and naturalism has been imbibed in bridal wear that mirrors the magnificence of his work. This bohemian style and the bright color palette have been reflected in the contemporary clothes that represent the spirit of the artist as a rebel. True to its rawness and simplicity, Jamini Roy's palette of earthy colors and folk motifs has been incorporated into contemporary designs that embrace rural India. S. H. Raza's stylistic painting and the symbolism of geometric shapes led designers to integrate evocative and dynamic patterns into their designs. Finally, the paintings by M. F. Husain have been adopted to produce beautiful and unique apparel that have a clear meaning of Indian culture as enhanced by the dynamic and radiant lines of the paintings.

3.2 Discussion:

This artistic and fashionable blend is proof of the modern Indian Great Masters' influence on today's aesthetic. Therefore, fashion designers not only continue the artists' works while using the motifs and artistic components in their creations but also help to transfer the Indian culture to the future generation. This combination allows for an exchange of dialogue between the past and the present to enjoy the artistic values of India and still align with the present trends.

The study also demonstrates how this congruence is beneficial for the broader cultural discourse as it maintains consistency and appreciation for the pre-existing forms of art. The use of these elements in the clothing that people wear to work and other everyday activities makes it possible for people to engage and even declare their culture. Besides, this has provided an identity to

Indian fashion on the global stage where there is a shift towards the originality and the heritage aspect of fashion. Furthermore, the conclusions drawn in the study suggest that art is not only ornamental but also semiotic, containing a higher meaning of culture and philosophy. For example, the use of mythological motifs and narrative characteristics in the fashion based on the paintings of M. F. Husain demonstrates the importance of the narrative in Indian art and the possibility of the art telling more than one layer of social and cultural context.

4 CONCLUSION

Therefore, one can speak about the interesting symbiosis of the great Indian master painters and fashion culture, which is a part of art history and the contemporary trends in clothing. Some of the famous painters of India are Jamini Roy, Amrita Sher-Gil, Raja Ravi Varma, M. F. Husain, S. H. Raza, and many more painters have left their strong impact on Indian art and fashion because their paintings are very realistic, full of bright colors and very energetic brush.

This is evident in the integration of conventional patterns, brightness, and meaning into current wear. Designers replicate these great artists by taking their unique styles and themes and incorporating them into current collections, thus marrying the vintage and contemporary.

Starting with bridal wear in a style of Varma's royal art to the modernist creations referring to Sher-Gil's gypsy soul, the folk prints in Roy's earthy palette to abstract prints in Raza's dynamic paintings, the dynamic prints in Husain's paintings to wearable art of his visionary creations, these master's have greatly influenced fashion culture.

Therefore, the compatibility between art and fashion in India proves that these masters' work remains timeless and influential. They are remembered and their works are still being used by modern designers thus ensuring that the Indian artistic culture is still alive and dynamic in the fashion world today.

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**DESIGN AND DEVELOPMENT OF AN ENVIRONMENTAL AIR PARAMETER
MONITORING SYSTEM USING IOT FACILITY**

Dr. Shamkumar B. Chavan

Department of Technology, Shivaji University, Kolhapur, Maharashtra, India

Abstract - Monitoring the atmospheric air parameters is very crucial in many applications. Use of Internet of Things is becoming popular for monitoring or controlling the parameters remotely. Considering this, the presented work deals with design and development of an air parameter monitoring system in which the atmospheric parameters like temperature, humidity and pressure are monitored and send to cloud. The remotely located monitoring system can observe the data at any instant of time by accessing the channel of the cloud. The presented systems uses DHT11 sensor module for sensing the temperature and humidity, the BMP180 sensor module is used to sense the atmospheric pressure. The low cost Node MCU ESP 8266 microcontroller is used to sense the data given by above mentioned sensor modules. The Node MCU records this data and send it to the pre-created channel on the Thing Speak cloud platform. The main advantage of this system is the accessibility from any remote place. Further the software tools needed for this project are freely available and more user friendly.

The advantages of the system are scalability, connectivity, accurate sensing and monitoring of the parameters, active engagement and use of compact devices. The system can be upgraded as per need. Further it can be used for monitoring the air pollution by connecting appropriate sensors. The AI algorithms can be incorporated in it. The system can be used for industrial parameter monitoring by minor changes and by adding suitable sensors. Connectivity ensures the guaranteed accessibility of the data from any place and at any time. This avoids the travelling cost and use of human intervention. The well proven sensors are used which are small in size and calibrated. Hence the accuracy of the system is increases and is trustworthy. The user can see the required data any time and from any place. Due to use of sensor modules, the system is very compact and handy. There is less dependence of the designers on the printed circuit boards. The focus is on connective the components to each other. Since the IoT technology is used, there could be issues related to security and privacy however they are controlled and such threats may happen due to the negligence of the user or person who are using it. If proper security precautions are taken then more security and privacy can be obtained. The system can be upgraded as per need and can deployed in the pollution creating industries, highways etc. for monitoring the pollution levels.

Keywords: Environmental parameter monitoring system, pollution monitoring system, IoT based pollution monitoring, IoT based atmospheric parameter monitoring.

1. INTRODUCTION

Environmental parameter monitoring is very important to track the changes in the environment. It is essential to monitor and record the parameters to know the changes in the parameter for adaptability of human being. Considering this researchers have developed many schemes and methodologies for monitoring environmental parameters. Reference [1] describes the design and implementation of embedded web server for measuring and showing the environmental parameters. In this temperature and humidity sensor is used to monitor and sense the temperature and humidity. The microcontroller continuously monitors the sensor output and sends the data to the embedded web server. The environmental parameters of the remote location where the station is deployed can be continuously monitored from remote place. Similar kind of system is developed in ref. [2] in which SHT 11 sensor module is used to monitor the temperature and humidity. The data is send to the web server continuously and can be seen from remote place. A system is designed and developed [3] using microcontroller which continuously measures the temperature and humidity, also records the time and date and stores in SD card. This is a data logger systems in which parameters are stored. Such a system can be used for studying the changes in environmental parameters. A system is presented for remote monitoring and control of the parameters for industrial applications through embedded web server [4], here the parameters can be monitored and for special applications the parameters can be controlled remotely. A system for monitoring the environmental parameters in developed [5] which is useful in underwater archeological sites. It supports SPI internet interface, MicroCD card slot, CAN bus controller, RTC and EZO module. The parameters can be monitored and the readings can be stored in microSD card. For mushroom plant an electronic system is developed to monitor and control the temperature and humidity conditions [6], in this application , first communication with sensor is established by the controller, then the air-condition relays for controlling application are set. Based on the existing environmental parameters the necessary conditions are set. An IoT based system is developed to monitor the parameters of remote location [7], this system have facility of data logging. The system based on ESP 32 S board is presented for monitoring the environmental parameters [8], it uses sensor modules like DHT-22, BMP- 180, MQ135. The data can be seen on the ThinkSpeak could platform remotely. Reference 9 describes the system of monitoring the environmental parameters accelerator's room of electron beam. Here an IoT based system is developed for remote monitoring.

The technological advancements in Internet of Things technology have brought lot of revolutions in the remote monitoring and control applications. Nowadays it is very easy to design the electronic systems to monitor the parameters. Figure 1 shows the typical trend of IoT based technology in monitoring and controlling the remote parameters. Designers have used the sensor modules to sense various parameters. The modules are directly

interfaced with the Node MCU ESP 8266 microcontroller which supports various communication protocol, I/O pins and on chip modules.

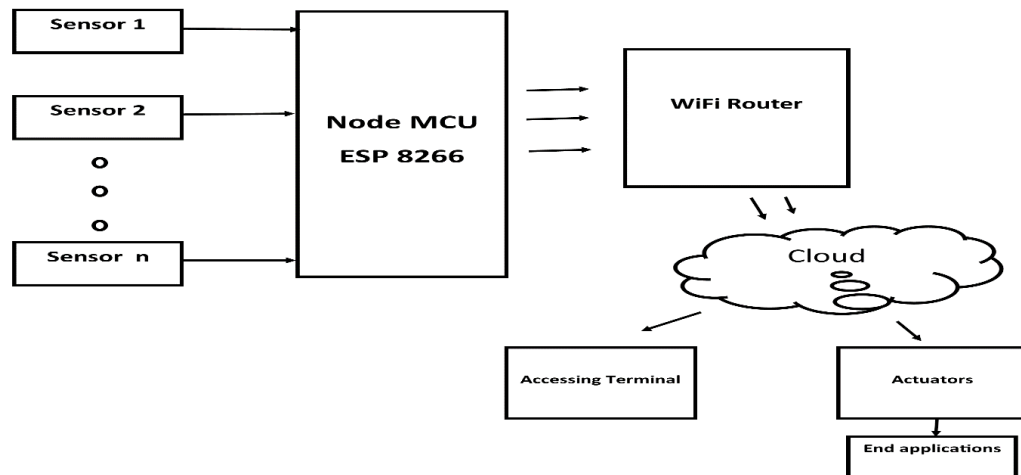


Figure 1 Typical system block diagram of IoT based systems for monitoring the parameters

The accessing terminal can access the parameters through cloud channel which are sensed by sensors located at remote places. Further the end application can be controlled using actuators through the commands given by accessing terminals. In some cases instead of using the IoT, web servers are used for monitoring and controlling the applications.

2. SYSTEM BLOCK DIAGRAM

Figure 2 shows the system block diagram for developing the parameter monitoring station which can be placed at remote locations.

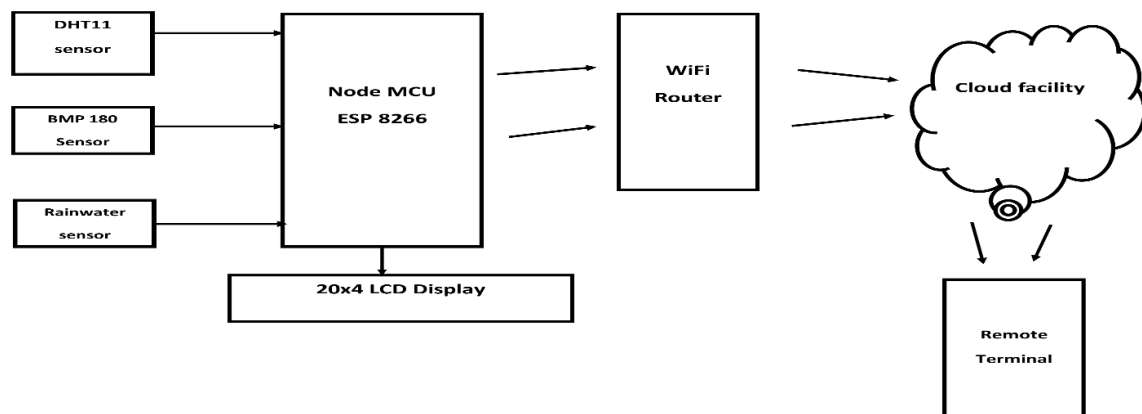


Figure 2 System block diagram

For monitoring the temperature and the humidity, DHT 11 sensor is used, for monitoring the pressure BMP 180 sensor is used. For monitoring the rain water, the rain water gauge is used. The program for calculating the magnitudes of these parameters is fed in the Node MCU ESP 8266 microcontroller. The Node MCU continuously monitors the environmental parameters, records it and send to cloud after pre-set interval of 15 seconds to the cloud. The ThingSpeak cloud platform is used here. It is essential to create

the channel on the ThingSpeak platform. The NodeMCU sends the data to cloud through WiFi router or through the Mobile hotspot.

3. TECHNOLOGICAL REQUIREMENTS

Following electronics components/modules are required for system implementation.

- i) **DHT11:-** For measuring temperature and humidity.
- ii) **BMP180:-** For measuring atmospheric pressure.
- iii) **NodeMCU (ESP8266):-** For controlling the sensors and sending data to the cloud.
- iv) **ThingSpeak Cloud:-** IoT platform to store and visualize sensor data.
- v) **Mobile Terminal:-** To monitor and interact with data.

The libraries required for programming are

- i) DHT sensor library (DHT.h)
- ii) Adafruit BMP085 Unified library (for BMP180 sensor)
- iii) ESP8266WiFi.h (for WiFi)
- iv) ThingSpeak.h (for ThingSpeak interaction)

The Arduino open source IDE is available which can be used for system implementation.

The advantages of the system are facility of remote monitoring, scalability i.e. system can be upscale or downscale as per requirement. It is a low cost system. The disadvantages of the system are its dependence on the internet connection. The power limitations are also there due to the use of battery. Due to power consumption limitations some additional circuits are needed to use it for high power applications.

4. CONCLUSION

This system offers the advantages like remote monitoring of the parameters, lower cost, security, scalability etc. It can be used for monitoring the parameters in agriculture, industry, farm houses, indoor parameters etc. The integration of artificial intelligence technology is possible for prediction of the environmental parameters. Advantages of Internet of Things technology can be taken in this application.

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STUDY ON AIRBORNE INTELLIGENCE: AI-ENABLED SUPPLY CHAIN STRATEGIES FOR THE INDIAN AIR FORCE

Gagan Bhayana

Research Scholar, Department of Science & Technology, Jayoti Vidyapeeth
Women's University Jaipur (Rajasthan), India

Dr. Prof. Sourabh Kumar Jain

Professor, Jayoti Vidyapeeth Women's University, Jaipur (Rajasthan), India

Abstract - This study explores the role of AI-enabled strategies in optimizing the supply chain operations of the Indian Air Force (IAF). By utilizing hypothetical data, the paper investigates how AI can enhance demand forecasting, inventory management, and maintenance operations within military logistics. The analysis highlights potential improvements in operational efficiency, cost reduction, and resource allocation through AI-driven solutions. The findings suggest that AI can significantly strengthen the IAF's logistical capabilities, providing strategic advantages in responsiveness and readiness.

Keywords: AI-enabled supply chain, Indian Air Force, military logistics, predictive analytics, autonomous systems.

1. INTRODUCTION

1.1 Background

The modern military landscape is increasingly reliant on complex logistical operations that ensure the seamless supply of resources to support both peacetime activities and combat readiness. For air forces around the world, including the Indian Air Force (IAF), supply chain efficiency is critical in maintaining operational capability. With the rapid development of advanced technologies, traditional supply chain management strategies are being replaced by more sophisticated, technology-driven solutions. Among these, Artificial Intelligence (AI) has emerged as a transformative force, offering the potential to automate and optimize various facets of supply chain operations.

Airborne intelligence, powered by AI, has the ability to provide real-time insights and predictive capabilities that can greatly enhance decision-making processes. The IAF's logistics and supply chain operations, dealing with a wide array of resources from fuel and spare parts to highly sensitive electronic equipment, could benefit from AI-enabled strategies. By streamlining logistics, reducing bottlenecks, and predicting future needs, AI could revolutionize the way the IAF manages its supply chain.

1.2 Role of AI in Supply Chain Management

AI has rapidly become a vital component in supply chain management, capable of analyzing large datasets, identifying patterns, and making intelligent predictions. In commercial sectors, AI applications have proven effective in demand forecasting, inventory optimization, and autonomous delivery systems.

Transferring these capabilities to military logistics, especially in the context of the Indian Air Force, could significantly enhance the efficiency and reliability of supply chains.

The adoption of AI technologies can help overcome traditional supply chain challenges such as human errors, delays in communication, and inefficiencies in resource allocation. AI's ability to provide predictive analytics allows for proactive management of the supply chain, ensuring that critical resources are always available and that maintenance needs are predicted before they become critical issues. Autonomous systems, powered by AI, also hold the promise of enhancing transportation and logistics, enabling faster and more secure delivery of materials in both combat and non-combat scenarios.

2. LITERATURE REVIEW

2.1 AI in Military Supply Chains

The role of Artificial Intelligence in military logistics has gained significant attention in recent years, as defense forces seek ways to enhance operational efficiency and preparedness. Military supply chains are inherently complex, involving the management of vast resources, equipment, personnel, and sensitive data. The use of AI in optimizing logistics operations has proven particularly beneficial in improving decision-making, resource allocation, and supply chain resilience in unpredictable environments.

Numerous studies have examined the application of AI in military logistics. For example, the U.S. Department of Defense has invested in AI technologies to enhance supply chain automation, using predictive analytics to anticipate resource demands and allocate supplies more effectively during combat situations. AI's ability to process large volumes of real-time data allows for continuous monitoring and forecasting of logistical needs, ensuring that critical resources are available when and where they are needed. In countries like Israel and the United Kingdom, AI-driven systems are already employed to optimize transportation routes, minimize fuel consumption, and streamline maintenance operations.

While the global defense sector has recognized AI's potential, India's military, including the Indian Air Force (IAF), is still in the early stages of integrating these technologies into its logistics operations. As the IAF modernizes its fleet and infrastructure, AI could become a critical component in transforming its supply chain strategies.

2.2 AI-Driven Predictive Analytics in Supply Chain Optimization

Predictive analytics is one of the most promising AI applications in supply chain management, leveraging data from various sources to forecast future events and trends. In military supply chains, predictive analytics has been used to improve demand forecasting, inventory management, and risk mitigation. AI-driven predictive models can identify patterns in historical data and anticipate potential disruptions, allowing organizations to take preventive measures before problems arise.

In the context of military logistics, predictive analytics can enhance supply chain agility by predicting the demand for spare parts, fuel, ammunition, and other critical resources. Studies have shown that AI-based predictive systems can reduce excess inventory, lower costs, and improve the overall responsiveness of supply chains. For example, research conducted on NATO's logistics operations demonstrates how AI-based systems predicted shortages and enabled faster resupply operations.

The Indian Air Force, with its diverse range of aircraft and equipment, could benefit from adopting AI-driven predictive analytics. By forecasting equipment failures, AI can streamline maintenance schedules and prevent unscheduled downtime. Additionally, AI's ability to analyze data from multiple sources, including weather conditions and flight patterns, could optimize the timing of supply shipments, reducing operational risks.

2.3 Autonomous Systems in Military Logistics

AI-powered autonomous systems have gained traction as a key innovation in military logistics. Autonomous vehicles, including drones and self-driving trucks, are being developed and deployed by various militaries worldwide for the transportation of supplies, especially in high-risk or hard-to-reach areas. These systems are designed to operate without human intervention, reducing the risk to personnel and enabling faster and more reliable delivery of goods.

Autonomous drones, in particular, have shown promise in resupplying forward operating bases and conducting reconnaissance missions. AI algorithms allow these drones to navigate complex environments, avoid obstacles, and adjust their routes based on real-time data. In 2020, the U.S. Army successfully tested autonomous drones to deliver supplies during combat simulations, demonstrating the potential for such systems to enhance battlefield logistics.

The Indian Air Force could adopt autonomous systems to streamline supply deliveries, especially in remote and high-altitude regions where traditional transportation methods are slow or impractical. AI-driven drones could carry essential materials, such as spare parts or medical supplies, to forward bases, improving the IAF's ability to maintain operational readiness in isolated areas.

2.4 AI in Maintenance Operations

AI's role in predictive maintenance is critical for the operational efficiency of any air force. Predictive maintenance involves using AI algorithms to analyze equipment data and predict when maintenance is required, minimizing downtime and extending the lifespan of assets. By continuously monitoring aircraft systems and components, AI can detect anomalies early and provide real-time alerts for maintenance crews.

Numerous studies have highlighted the benefits of AI in predictive maintenance for aviation. AI systems can predict equipment failures before they occur, allowing for timely repairs and reducing the need for unscheduled

maintenance. For example, in the commercial aviation sector, companies such as Boeing and Airbus have adopted AI-driven predictive maintenance systems to monitor their aircraft fleets, reducing maintenance costs and improving aircraft availability.

The Indian Air Force, with its diverse fleet of aircraft, could significantly enhance its maintenance operations by adopting AI-powered predictive systems. These systems would enable the IAF to anticipate and address potential failures before they affect mission readiness, ensuring that aircraft are always available for deployment.

2.5 Challenges and Opportunities in AI Adoption for Military Supply Chains

Despite the significant potential of AI, there are challenges associated with its adoption in military supply chains, particularly in a country like India. One of the main obstacles is the integration of AI with existing logistics infrastructure. Military supply chains involve a wide range of legacy systems, and transitioning to AI-driven operations requires careful planning, substantial investment, and skilled personnel. Furthermore, data security is a critical concern when implementing AI in military operations, as cyber-attacks on AI systems could compromise sensitive information or disrupt logistical operations.

However, the opportunities offered by AI-enabled supply chain management for the IAF far outweigh these challenges. With India's push toward modernization and technological advancements in its defense sector, AI could be a game-changer in optimizing supply chain operations, improving efficiency, and reducing costs.

3. AI-ENABLED SUPPLY CHAIN STRATEGIES FOR IAF

The Indian Air Force (IAF) faces complex logistical challenges due to its wide-ranging operations, involving the management of diverse equipment, personnel, and resources. As the IAF modernizes its fleet and expands its mission scope, efficient supply chain management becomes critical for maintaining operational readiness and sustainability. AI can offer powerful solutions to these logistical challenges by enhancing demand forecasting, optimizing inventory management, and automating maintenance operations. In this section, several AI-enabled strategies are proposed to address the unique supply chain needs of the IAF.

3.1 Supply Chain Challenges in the IAF

The IAF operates in a demanding environment where rapid deployment, resource availability, and mission-critical equipment maintenance are essential for success. Some of the key challenges faced by the IAF in supply chain management include:

- **Unpredictable Demand:** The IAF's demand for spare parts, fuel, and other resources can fluctuate due to the dynamic nature of military operations.

- **Inventory Management:** Managing large inventories across multiple airbases and forward operating locations can lead to inefficiencies, delays, and stockouts or overstocking of materials.
- **Maintenance Operations:** Aircraft and equipment maintenance is a key aspect of IAF operations, but unscheduled maintenance or supply shortages can lead to operational downtime.
- **Resource Allocation:** Allocating resources efficiently between bases and combat zones is crucial for maintaining operational readiness, but logistical delays can impact mission effectiveness.

AI-enabled supply chain strategies can address these challenges by providing predictive insights and automating several key aspects of the IAF's logistics operations.

3.2 AI for Demand Forecasting

One of the most significant challenges in military logistics is predicting the demand for materials and resources. The IAF's operations vary in scale and location, making it difficult to forecast the exact quantities of supplies needed at any given time. AI can be leveraged to predict demand more accurately by analyzing historical data, mission patterns, and environmental factors.

- **AI-Driven Predictive Models:** Machine learning algorithms can be trained on historical data from IAF operations to predict future demand for spare parts, fuel, ammunition, and other essential supplies. These models can take into account variables such as aircraft usage rates, maintenance histories, and mission requirements.
- **Real-Time Data Integration:** AI systems can integrate real-time data from sensors on aircraft and equipment to adjust demand forecasts dynamically. For example, if an aircraft shows signs of mechanical stress, the system can predict the need for specific parts and trigger early resupply orders.
- **Proactive Resource Planning:** By predicting demand well in advance, AI enables the IAF to plan more proactively, ensuring that resources are available when and where they are needed, thus minimizing supply chain disruptions during critical missions.

3.3 Automated Inventory Management

Inventory management is one of the most resource-intensive tasks in military logistics. With bases spread across vast geographical areas, the IAF requires a system that can efficiently track, manage, and optimize inventory levels in real-time. AI can provide automated solutions for managing inventory, ensuring that the right amount of stock is available at the right time.

- **AI-Powered Inventory Monitoring:** AI systems can continuously monitor inventory levels, predict stock shortages, and automatically reorder supplies when necessary. These systems can use real-time data from IAF warehouses and bases to maintain optimal inventory levels across locations.
- **Inventory Optimization:** AI algorithms can analyze historical consumption patterns to determine the ideal stock levels for each base, reducing the risk

of overstocking or under stocking. AI can also optimize supply distribution by identifying the most efficient routes and methods for transporting materials.

- **Supply Chain Transparency:** AI systems can provide real-time visibility into the entire supply chain, allowing logistics managers to track supplies from procurement to delivery. This improves accountability and ensures that critical supplies are always available.

3.4 AI-Optimized Maintenance Operations

Maintenance is a critical component of the IAF's operations, as aircraft and equipment must be kept in peak condition to ensure mission readiness. AI-enabled predictive maintenance systems can greatly enhance the IAF's ability to maintain its assets efficiently by predicting potential failures before they occur.

- **Predictive Maintenance Models:** AI algorithms can analyze data from aircraft systems and components to predict when maintenance is required. This includes monitoring flight hours, engine performance, and environmental conditions to detect early signs of wear and tear. Predictive maintenance models can then recommend optimal times for repairs or replacements, reducing the need for unscheduled maintenance.
- **Minimizing Downtime:** By predicting maintenance needs, AI systems can minimize aircraft downtime and ensure that equipment is always operational. This is particularly valuable in high-stakes scenarios where aircraft availability is crucial for mission success.
- **Automated Maintenance Scheduling:** AI can automate the scheduling of maintenance operations, ensuring that all necessary personnel, parts, and tools are available when maintenance is required. This reduces delays and improves the efficiency of the IAF's maintenance teams.

3.5 Autonomous Transportation and Drones

AI-powered autonomous transportation systems, including drones, can play a pivotal role in the IAF's supply chain, particularly in delivering supplies to remote or high-risk areas. Autonomous systems can provide faster, more reliable, and secure delivery of materials, reducing the need for human intervention in dangerous environments.

- **Autonomous Drones for Delivery:** AI-enabled drones can be used to transport spare parts, fuel, medical supplies, and other critical resources to forward operating bases or isolated locations. These drones can navigate autonomously, avoiding obstacles and choosing the most efficient routes based on real-time data.
- **Reduced Risk to Personnel:** By using autonomous systems, the IAF can reduce the risk to personnel involved in supply delivery missions, especially in combat zones or difficult terrains. AI-driven drones can operate in hazardous environments, ensuring that supplies reach their destination without endangering human lives.

- **Improved Response Time:** Autonomous transportation systems can significantly reduce the time it takes to deliver supplies, enabling faster resupply missions and improving the IAF's operational agility.

3.6 AI-Enhanced Supply Chain Security

The security of supply chain operations is critical in military logistics, particularly when dealing with sensitive equipment and materials. AI can be used to enhance supply chain security by detecting anomalies, preventing cyber-attacks, and ensuring the integrity of supply routes.

- **Anomaly Detection:** AI systems can monitor supply chain operations for unusual patterns or activities that may indicate a security threat. For example, AI can detect unauthorized access to supply depots or unusual delays in shipments, triggering alerts for further investigation.
- **Cybersecurity in Supply Chains:** AI can be used to safeguard supply chain operations from cyber-attacks, which could disrupt the flow of critical resources. AI algorithms can continuously monitor for potential cyber threats and implement protective measures to prevent unauthorized access to supply chain data.

4. IMPLICATIONS FOR THE INDIAN AIR FORCE

The integration of AI-enabled supply chain strategies presents significant implications for the Indian Air Force (IAF), affecting not only its logistics and operational efficiency but also its overall defense capabilities. As the IAF continues to modernize and adopt cutting-edge technologies, AI-driven supply chain management offers the potential to enhance operational readiness, reduce costs, and provide a strategic advantage in combat and peacetime operations.

4.1 Enhanced Operational Readiness

AI's predictive capabilities have a profound impact on maintaining operational readiness across all facets of the IAF's supply chain. Predictive analytics, when applied to demand forecasting, maintenance scheduling, and resource management, allow the IAF to be better prepared for both routine and emergency situations.

- **Minimized Downtime:** AI-enabled predictive maintenance significantly reduces unplanned aircraft downtime, ensuring that the IAF's fleet is ready for deployment at all times. By predicting potential equipment failures before they happen, AI can ensure continuous operational availability, which is critical for mission success.
- **Real-Time Adaptability:** AI systems can adapt to changing operational demands in real-time, enabling the IAF to respond quickly to unanticipated needs. Whether it's an immediate requirement for supplies in a forward base or the sudden redeployment of aircraft, AI systems can recalibrate supply chain processes to ensure a swift response.

- **Mission Flexibility:** AI-driven logistics systems allow for greater flexibility in mission planning. With AI providing continuous insights into resource availability, maintenance needs, and transportation logistics, the IAF can execute more complex and diverse missions with confidence.

4.2 Cost Reduction and Resource Optimization

Efficient resource management and cost reduction are among the most significant benefits of AI in supply chain management. For the IAF, where operational costs can be high, AI-enabled systems offer opportunities for considerable savings and better allocation of resources.

- **Reduced Inventory Costs:** By leveraging AI-driven inventory optimization, the IAF can maintain optimal stock levels, avoiding the costs associated with overstocking and stockouts. This ensures that materials and spare parts are available when needed, without excessive inventory buildup.
- **Streamlined Maintenance Operations:** Predictive maintenance reduces the frequency of costly, unscheduled repairs and increases the lifespan of aircraft and equipment. This contributes to lower maintenance costs and improved asset utilization over time.
- **Fuel Efficiency:** AI-optimized transportation routes, including those managed by autonomous vehicles and drones, can significantly reduce fuel consumption. AI can calculate the most efficient paths for transporting supplies, thus minimizing travel time, fuel usage, and operational costs.

4.3 Strategic Advantage in Combat Situations

AI-enabled supply chain systems can provide the IAF with a strategic advantage in combat scenarios by improving the speed and reliability of logistical operations. In modern warfare, logistics plays a critical role in determining the success of military operations, and AI-enhanced supply chains can ensure that the IAF remains agile and responsive in battlefield conditions.

- **Rapid Resupply:** The use of AI-driven autonomous systems, such as drones, for supply delivery can ensure faster resupply missions, even in high-risk or remote areas. This capability can be a game-changer in combat situations, where timely delivery of critical supplies can influence the outcome of a mission.
- **Combat Sustainability:** AI's ability to forecast resource demands ensures that the IAF remains well-stocked with essential supplies, such as fuel, ammunition, and spare parts, during extended combat operations. This sustainability allows the IAF to operate for longer periods without interruption.
- **Improved Tactical Decision-Making:** AI can assist commanders in making real-time, data-driven decisions during combat. By providing up-to-the-minute insights into resource availability and logistical constraints, AI enables military leaders to adapt their strategies on the fly, optimizing outcomes in dynamic battlefield environments.

4.4 Enhanced Human Resource Efficiency

AI-enabled supply chain management allows the IAF to make more efficient use of its personnel by automating time-consuming and repetitive logistical tasks. This frees up human resources for higher-level decision-making, strategic planning, and combat operations.

- **Automation of Routine Tasks:** AI can automate routine tasks such as inventory tracking, maintenance scheduling, and supply reordering, allowing logistics personnel to focus on more complex and strategic functions. This not only improves efficiency but also reduces the potential for human error in critical processes.
- **Support for Logistics Personnel:** AI systems can act as decision-support tools for logistics personnel, providing them with accurate forecasts and actionable insights. This enhances their ability to make informed decisions, further improving the efficiency and effectiveness of supply chain management.
- **Training and Skill Development:** As AI systems become more integrated into IAF logistics, there will be a growing need for personnel to acquire new skills in AI management, data analysis, and autonomous systems operation. This opens opportunities for training programs and the development of specialized roles within the IAF.

4.5 Cybersecurity and Data Protection Concerns

The implementation of AI in supply chain management comes with its own set of risks, particularly in terms of cybersecurity and data protection. Since military logistics involve sensitive data, ensuring the security of AI systems is crucial to preventing potential cyber threats.

- **Vulnerability to Cyber-Attacks:** AI-driven systems, especially those handling critical logistical operations, are vulnerable to cyber-attacks that could disrupt supply chains or compromise sensitive data. The IAF must invest in robust cybersecurity protocols to protect its AI systems from malicious actors.
- **Data Integrity and Reliability:** AI systems rely heavily on data for decision-making. Therefore, ensuring the integrity and accuracy of data is essential to avoid flawed predictions or disruptions in supply chain operations. The IAF will need to implement rigorous data validation processes to safeguard the reliability of AI-driven logistics.

4.6 Long-Term Strategic Development

The adoption of AI-enabled supply chain strategies by the IAF represents a long-term investment in both technology and infrastructure. The implications for strategic development include the modernization of logistical frameworks and the potential integration of AI into broader defense systems.

- **Modernization of Logistics Infrastructure:** The IAF will need to invest in upgrading its logistics infrastructure to fully leverage AI technologies. This includes integrating AI systems with legacy logistics platforms, expanding

data collection capabilities, and developing a unified logistics management system.

- **AI Integration Across Defense Operations:** AI's potential goes beyond logistics, offering opportunities for integration across various defense operations, including mission planning, intelligence gathering, and combat strategy. The lessons learned from AI in supply chain management could serve as a foundation for broader AI adoption within the IAF and other branches of the Indian armed forces.
- **Partnerships and Collaboration:** The IAF may need to collaborate with AI technology developers, private sector partners, and research institutions to fully develop and implement AI-driven supply chain strategies. Such partnerships will be essential for ensuring the successful integration of AI into the IAF's logistics framework.

5. CONCLUSION

The study of AI-enabled supply chain strategies for the Indian Air Force (IAF) reveals the transformative potential of artificial intelligence in revolutionizing military logistics. As the IAF continues to modernize and face increasingly complex operational challenges, AI offers a range of solutions that enhance efficiency, reduce costs, and improve operational readiness. By leveraging AI for demand forecasting, inventory management, predictive maintenance, and autonomous logistics, the IAF can ensure that its supply chain remains agile, responsive, and robust in both peacetime and combat scenarios.

AI's predictive capabilities allow the IAF to plan proactively, minimize downtime, and optimize the allocation of critical resources. Automated inventory management systems ensure that materials are available when needed, while AI-driven predictive maintenance reduces unscheduled repairs, leading to improved fleet availability. The use of autonomous transportation systems, such as drones, enhances the speed and safety of resupply missions, particularly in remote or high-risk environments.

However, the adoption of AI in supply chain management also presents certain challenges, particularly in terms of cybersecurity and data integrity. The IAF must invest in protecting its AI systems from cyber threats and ensure the reliability of the data that drives these systems. Additionally, the integration of AI into existing logistical frameworks requires infrastructure upgrades and the development of new skill sets among personnel.

In the long term, AI-enabled supply chain strategies will provide the IAF with a significant strategic advantage, allowing it to respond more effectively to dynamic operational demands. The insights gained from AI-driven logistics could also pave the way for broader applications of AI in other aspects of defense operations. Ultimately, the integration of AI into the IAF's supply chain is a critical step toward building a more resilient, adaptive, and technologically advanced air force, ready to meet the challenges of the future.

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