A SYSTEMATIC REVIEW ON ENVIRONMENTAL IMPACT ASSESSMENT IN MANUFACTURING INDUSTRIES

[1]M.KAVINASH, [2]Mr.G.RAJESH,

[1]PG SCHOLAR, [2]ASSISTANT PROFESSOR,
[1]DEPARTEMENT OF MECHANICAL ENGINEERING,
[1]SRM VALLIAMMAI ENGINEERING COLLEGE, KATTANKULATHUR, INDIA

Abstract : Environmental Impact Assessment (EIA) has emerged as a critical decision-making tool for identifying, predicting, and mitigating the adverse effects of industrial activities on the natural environment. Manufacturing industries, being major contributors to air pollution, water pollution, solid waste generation, noise pollution, and greenhouse gas emissions, are under increasing regulatory pressure to adopt systematic environmental management practices. The assessment covers six major environmental aspects: (i) ambient air quality monitoring, (ii) wastewater generation and treatment efficiency, (iii) solid and hazardous waste characterization, (iv) noise environment monitoring, (v) energy consumption and greenhouse gas (GHG) emissions, and (vi) ecological and social baseline profiling. A total of 100 survey respondents from different departments participated in a structured questionnaire study to assess the perceived environmental awareness, risk cognition, and EMP compliance levels.

1.INTRODUCTION

1.1 Background and Context

The industrial sector is the cornerstone of economic development in rapidly growing nations. However, the accelerated pace of industrialization comes at a significant environmental cost. Manufacturing industries are among the largest contributors to environmental degradation globally, accounting for approximately 30% of global energy consumption, 20% of total freshwater withdrawal, and over 25% of greenhouse gas (GHG) emissions according to the United Nations Industrial Development Organization (UNIDO, 2020).

Environmental Impact Assessment (EIA) is a systematic, iterative, and participatory process designed to identify, predict, evaluate, and mitigate the biophysical, social, and other relevant effects of development proposals before major decisions are made and commitments are undertaken. First introduced as a formal legislative mechanism in the United States through the National Environmental Policy Act (NEPA) in 1969, EIA has since been adopted by over 190 countries and has become the most widely used environmental management instrument in the world. This project was conducted at a medium-scale automotive component manufacturing company in Chennai, which produces precision-machined components, fabricated assemblies, and painted sub-systems for OEM customers. The company employs approximately 320 workers across production, quality, maintenance, and support functions, and operates two production shifts per day. The environmental study was conducted over a continuous 12-month period to capture seasonal variability in environmental parameters.

1.2 Problem Statement

Despite the regulatory requirement for EIA in large industrial projects, medium-scale manufacturing industries in India often operate with limited systematic environmental monitoring, fragmented data management, and reactive compliance approaches rather than proactive environmental management. The following specific problems were identified at the study facility and in the broader literature:

- Absence of a comprehensive baseline environmental study integrating air, water, land, noise, and climate parameters in a unified assessment framework.
- Lack of a quantitative Environmental Impact Score (EIS) model that combines pollution indices, risk scores, and regulatory compliance metrics.

These gaps form the central motivation for this research, which seeks to develop and demonstrate an integrated, reproducible EIA framework applicable to medium-scale manufacturing industries.

1.3 Objectives of the Study

The primary and secondary objectives of this study are as follows:

Primary Objectives:

1. To conduct a systematic review of existing EIA literature for manufacturing industries using PRISMA methodology.

2. To perform a comprehensive baseline environmental study at the study facility covering air quality, wastewater, solid waste, noise, and energy parameters.
3. To develop an integrated Environmental Impact Score (EIS) model as a novel multi-criteria evaluation tool.

Secondary Objectives:

To assess worker and management awareness of environmental impacts through structured questionnaire surveys.
To map the regulatory compliance status of the facility against applicable Indian environmental laws and standards.
To identify technology upgradation opportunities for pollution prevention and resource efficiency.

1.4 Scope of the Study

The scope of this study is defined as follows:

- Geographic Scope: The study is confined to the manufacturing facility premises and a 1 km buffer zone for air quality and noise monitoring.
- Temporal Scope: Primary data collection was conducted over 12 months (January–December 2023) to capture seasonal variability.

1.5 Structure of the Report

This report is organized into eight chapters. Chapter 1 presents the background, problem statement, objectives, and scope. Chapter 2 provides a systematic literature review. Chapter 3 describes the industry profile and methodology. Chapter 4 presents the baseline environmental study with measured data. Chapter 5 details the environmental impact analysis including risk assessment and the EIS model. Chapter 6 presents survey analysis results. Chapter 7 presents the Environmental Management Plan. Chapter 8 provides conclusions and recommendations for future work. References and appendices follow.

2.LITERATURE REVIEW

2.1 Historical Development of EIA

Environmental Impact Assessment as a formalized policy instrument originated with the United States National Environmental Policy Act (NEPA) of 1969. The Council on Environmental Quality (CEQ) subsequently issued implementing regulations in 1978 that established the foundational concepts of screening, scoping, prediction, mitigation, monitoring, and public participation that continue to define EIA practice globally.

The United Nations Conference on the Human Environment (Stockholm, 1972) triggered a global wave of environmental legislation, with most OECD countries adopting EIA frameworks during the 1970s and 1980s. The EU Directive 85/337/EEC (1985) harmonized EIA requirements across member states and introduced the concept of Environmental Statements. Subsequent amendments (1997, 2003, 2009) expanded the scope and strengthened public participation requirements.

In developing countries, EIA frameworks developed more slowly. The World Bank made EIA a prerequisite for project financing in 1989, creating significant momentum for adoption in Asia, Africa, and Latin America. The Rio Declaration (1992) Principle 17 established EIA as a key environmental policy instrument at the international level.

2.2 EIA in Indian Manufacturing Industries

India's EIA framework has evolved through several generations. The Environment Protection Act (EPA) 1986 established the legal foundation, followed by the EIA Notification 1994 that imposed mandatory environmental clearance requirements on 29 categories of projects. The revised EIA Notification 2006 substantially overhauled the process, introducing a four-stage clearance process: screening, scoping, public consultation, and appraisal.

Several studies have examined EIA implementation in Indian manufacturing. Rajesh and Anand (2012) analyzed 45 EIA reports from Tamil Nadu and found that baseline data quality, impact prediction accuracy, and EMP implementation were the weakest components of the process. Singh et al. (2014) documented systematic deficiencies in cumulative impact assessment and alternatives analysis in Indian EIAs, attributing these to capacity constraints among project proponents and consulting agencies.

Bana and Rajput (2016) conducted a meta-analysis of 120 EIA reports from Indian manufacturing industries and found that 68% of EIAs focused exclusively on regulatory compliance without forward-looking environmental management planning. Only 23% of reviewed EIAs included quantitative environmental performance indicators (EPIs) linked to management actions.

Table 2.1: Summary of Key Literature Reviewed (Selected Papers)

S.No.	Author & Year	Study Focus	Methodology	Key Finding
1	Rajesh & Anand (2012)	EIA quality in Tamil Nadu industries	Content analysis of 45 EIA reports	Baseline data quality is the weakest component
2	Singh et al. (2014)	Cumulative impact assessment gaps	Systematic review, 120 EIAs	68% reports lacked cumulative impact analysis
3	Bana & Rajput (2016)	EMP implementation effectiveness	Longitudinal field study	Only 23% had quantitative EPIs linked to actions
4	Moorthy & Krishnan	Air quality in auto	Field monitoring, 18	SPM exceeds limits near grinding

	(2017)	component industry	months	operations
5	Venkat & Suresh (2018)	ISO 14001 & EIA integration	Case study, 3 manufacturers	EMS integration improves EMP compliance by 42%
6	Patel et al. (2019)	EIA in small/medium enterprises	Survey study, 200 SMEs	Awareness gap is the primary implementation barrier
7	Ramachandran (2020)	Wastewater impacts in machining industry	Water quality monitoring	Cutting fluid effluents are high COD risk source
8	Narayanan et al. (2021)	GHG emissions in Indian manufacturing	LCA-based study, 15 facilities	21% reduction possible through energy efficiency
9	Kumar & Devi (2022)	Noise impacts in industrial zones	Acoustic monitoring, 6 facilities	Production floor noise 92–102 dB exceeds OSHA limits
10	Sharma et al. (2023)	EIS composite index development	Multi-criteria analysis	Weighted EIS model improves decision transparency

2.3 Environmental Aspects of Manufacturing

Manufacturing processes generate a wide range of environmental pressures. The following sub-sections review literature on the major environmental aspects relevant to this study:

2.3.1 Air Quality Impacts

Machining, welding, grinding, and surface coating operations generate particulate matter (PM2.5 and PM10), metal fumes, volatile organic compounds (VOCs), and acid gases (SO_2, HCl). Moorthy and Krishnan (2017) found that grinding and deburring stations generate SPM concentrations of 380–520 mg/m³ depending on abrasive type and ventilation efficiency. Ventilation engineering controls and dust extraction systems are the primary mitigation measures recommended.

2.3.2 Water Pollution

Industrial effluents from manufacturing include cooling water blowdown, cutting fluid wastewater, plating bath rinse water, and sanitary wastewater. Ramachandran (2020) documented BOD values of 500–750 mg/L and COD values of 1200–1800 mg/L in raw effluents from machining operations. Effective Effluent Treatment Plants (ETPs) incorporating primary clarification, biological treatment, and tertiary polishing can achieve discharge-compliant effluent quality.

2.3.3 Solid and Hazardous Waste

Metal swarf, rejected components, spent cutting fluids, paint sludge, filter cartridges, and fluorescent lamps constitute the primary solid and hazardous waste streams in metalworking industries. The Hazardous Waste (Management, Handling and Transboundary Movement) Rules 2016 require authorized treatment, storage, and disposal facilities (TSDFs) for scheduled hazardous wastes. Waste minimization hierarchy (prevention > reuse > recycling > recovery > disposal) is the recommended management approach.

2.3.4 Noise Pollution

Presses, compressors, grinders, and material handling equipment are major noise sources in manufacturing facilities. Kumar and Devi (2022) found production floor noise levels of 92–102 dB in multi-operation manufacturing facilities, significantly exceeding the OSHA permissible exposure limit of 90 dB for an 8-hour TWA. Engineering controls (enclosures, vibration isolation), administrative controls, and PPE are the recommended control hierarchy.

2.4 Previous EIA Methodologies Reviewed

Several methodologies have been used for industrial EIA in manufacturing contexts:

Table 2.2: EIA Methodologies Comparison

Methodology	Type	Advantages	Limitations
Leopold Matrix	Checklist/Matrix	Visual, systematic, covers interactions	Qualitative, no weightage
Network Analysis	Cause-Effect	Captures indirect impacts	Complex, time-consuming
AHP (Delphi+AHP)	Multi-Criteria	Quantitative weights, expert input	Subjectivity in judgements
Rapid EIA	Simplified	Quick, low-cost	Less rigorous, misses long-term impacts
EIS Model (This Study)	Hybrid Composite	Integrates quantitative + qualitative + regulatory	Requires comprehensive data inputs

2.5 Research Gap Identification

The systematic literature review revealed the following significant research gaps that this study addresses:

- No prior study has developed an Integrated Environmental Impact Score (EIS) model combining quantitative monitoring data, stakeholder perception indices, and regulatory compliance scores for medium-scale Indian manufacturing EIAs.
- Studies addressing automotive component manufacturing EIAs in Tamil Nadu are very limited, with most available research focused on large Category A projects.
- Previous EIAs rarely integrate a 12-month continuous monitoring programme covering all six environmental media simultaneously with seasonal analysis.
- The application of PRISMA systematic review methodology to structure the literature review in Indian industrial EIA practice is novel and adds methodological rigour absent in most project-level EIAs.
- Linkage between survey-based worker environmental awareness scores and on-ground EMP compliance rates has not been studied in the Indian manufacturing context.

These gaps justify the objectives and methodological approach adopted in this study, establishing its originality and contribution to knowledge.

3. INDUSTRY PROFILE AND METHODOLOGY

3.1 Industry Profile

is a medium-scale Tier-2 automotive component manufacturer established in 2002 and located in the Ambattur Industrial Estate, Chennai, Tamil Nadu. The company specializes in precision machining, fabrication, sub-assembly, and powder-coat painting of structural and moving components for passenger car and light commercial vehicle OEMs. Key operational details are presented in Table 3.1.

Table 3.1: Company Profile Summary

Parameter	Details
Company Type	Private Limited, Tier-2 Automotive OEM Supplier
Location	Ambattur Industrial Estate, Chennai – 600 058, Tamil Nadu
Year of Establishment	2002
Plot Area	12,500 sq.m (Total); 7,800 sq.m (Built-up)
No. of Employees	320 (Permanent: 285; Contract: 35)
Working Hours	Two shifts × 8 hours; 300 working days/year
Product Range	Machined housings, brackets, shafts, fabricated assemblies
Annual Turnover	Approx. ₹85 Crores (FY 2022–23)
Key Processes	CNC Machining, MIG/TIG Welding, Grinding, Surface Treatment, Painting
Pollution Category	Orange Category (TNPCB Classification)
Environmental Clearance	Under SEIAA, Tamil Nadu (Valid till 2027)
Water Source	CMWSSB Municipal Supply + 2 Borewells
Power Source	TANGEDCO Grid (1000 kVA connection) + 750 kVA DG set (backup)
Waste Disposal	Authorized TSDF (Vellore), TNPCB-licensed recyclers

3.2 Manufacturing Process Description

The manufacturing process flow is described sequentially as follows:

1. Raw Material Receipt: Hot-rolled steel sheets, MS tubes, aluminium billets, and castings are received by road and stored in a covered warehouse.
2. CNC Machining: Components are precision-machined on CNC turning centres, machining centres, and VMCs using water-based cutting fluids.
3. MIG/TIG Welding: Sub-assemblies are welded using CO_2/Ar MIG welding and TIG welding, generating fume and UV radiation.
4. Grinding & Deburring: Surface finishing by angle grinders, bench grinders, and vibratory de-burring, generating metal dust/SPM.
5. Surface Treatment: Shot-blasting, phosphating, and passivation surface treatment prior to painting.
6. Powder Coat Painting: Components are painted in an enclosed spray booth with electrostatic powder guns and cured in conveyor oven at 180°C.

7. Quality Inspection: Dimensional, surface, and functional inspection per customer specifications.
8. Dispatch: Final packed components dispatched to OEM plants.

3.3 Research Design and Framework

This study adopts a mixed-methods sequential explanatory research design combining quantitative environmental monitoring data with qualitative stakeholder surveys. The EIA framework follows the Bureau of Indian Standards IS 15500:2004 guidelines for EIA preparation, supplemented by MoEFCC's General Conditions for Environmental Clearance (2006).

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework was applied to the literature review component to ensure systematic, reproducible, and bias-minimized source selection. The database search strategy, inclusion/exclusion criteria, and quality assessment protocols are documented in Appendix A.

The Environmental Impact Score (EIS) model — the novel methodological contribution of this study — assigns weighted scores across three dimensions: (i) Pollution Index (PI) from measured monitoring data; (ii) Regulatory Compliance Index (RCI) from applicable standards; and (iii) Stakeholder Perception Index (SPI) from survey data. The composite $EIS = 0.50 \times PI + 0.30 \times RCI + 0.20 \times SPI$, with scores normalized on a 0–100 scale.

3.4 Data Collection Methods

3.4.1 Ambient Air Quality Monitoring

Air quality monitoring was conducted at four locations: (1) Upwind (background), (2) Production area, (3) Boundary wall (leeward), and (4) Nearest habitation (500 m downwind). Parameters monitored include: Suspended Particulate Matter (SPM), Respirable Suspended Particulate Matter (RSPM/PM10), SO_2, NO_x, and CO. Monitoring frequency: 24-hourly samples, twice per month per location, using High Volume Samplers (HVS) for SPM and Respirable Dust Samplers (RDS) for RSPM, calibrated per CPCB standards.

3.4.2 Wastewater Monitoring

Effluent samples were collected from the ETP inlet, ETP outlet, and storm water drain at monthly intervals. Parameters analysed: pH, BOD_5 at 20°C, COD, TSS, TDS, oil & grease, heavy metals (Cr, Ni, Zn, Cu). Analysis was performed by a NABL-accredited external laboratory as per Standard Methods for Examination of Water and Wastewater (SMEWW, 23rd Edition).

3.4.3 Solid Waste Monitoring

Solid waste was characterized and quantified at monthly intervals through direct weighing of waste streams at generation points. Hazardous waste manifests were obtained from the authorized TSDF. Waste composition (by category) was documented using Form 3 registers as required under HW Rules 2016.

3.4.4 Noise Monitoring

Noise monitoring was conducted at 8 locations using a calibrated Sound Level Meter (Type 2, IEC 61672:2002) with A-weighting. Day time (6 AM – 10 PM) and night time (10 PM – 6 AM) equivalent noise levels (Leq) were measured at each location for 15-minute sampling periods. Individual worker exposure was assessed using personal dosimeters for high-risk operations.

3.4.5 Survey Methodology

A structured questionnaire comprising 35 questions in 5 sections (environmental awareness, risk perception, EMP compliance, training effectiveness, and improvement suggestions) was administered to 100 employees selected using stratified random sampling across 5 departments. Responses were recorded on a 5-point Likert scale. The questionnaire was validated by a panel of three environmental management experts and pilot-tested on 10 respondents before full administration.

3.5 Monitoring Parameters and Standards

Table 3.2: Monitoring Parameters and Applicable Standards

S.No.	Parameter	Medium	Standard/Limit	Applicable Regulation
1	SPM	Ambient Air	500 µg/m³ (Industrial)	CPCB Ambient Air Quality Standards
2	RSPM (PM10)	Ambient Air	200 µg/m³ (Industrial)	CPCB NAAQS 2009
3	SO_2	Ambient Air	80 µg/m³ (Industrial)	CPCB NAAQS 2009
4	NO_x	Ambient Air	80 µg/m³ (Industrial)	CPCB NAAQS 2009
5	CO	Ambient Air	10 mg/m³ (8hr avg)	CPCB NAAQS 2009
6	pH	Wastewater	6.5 – 8.5	Environment Protection Rules 1986, Sched VI
7	BOD	Wastewater	30 mg/L	EP Rules 1986
8	COD	Wastewater	250 mg/L	EP Rules 1986
9	TSS	Wastewater	100 mg/L	EP Rules 1986

10	Oil & Grease	Wastewater	10 mg/L	EP Rules 1986
11	Day Noise (Leq)	Noise	75 dB(A) (Industrial)	EP Rules 1986; Noise Pollution Rules 2000
12	Night Noise (Leq)	Noise	70 dB(A) (Industrial)	Noise Pollution Rules 2000

4. BASELINE ENVIRONMENTAL STUDY

4.1 Ambient Air Quality

Air quality monitoring was conducted over 12 months at four monitoring locations. The annual average values of key parameters at the production area monitoring location (most critical receptor) are presented in Table 4.1 below, alongside applicable CPCB National Ambient Air Quality Standards (NAAQS) for industrial areas.

Table 4.1: Annual Average Ambient Air Quality – Production Area Monitoring Station

S.No.	Parameter	Unit	Measured(Annual Avg)	PermissibleLimit	Status
1	SPM	µg/m³	**420**	500	**Within Limit**
2	RSPM (PM10)	µg/m³	**185**	200	**Within Limit**
3	SO_2	µg/m³	**88**	80	**⚠ Slightly Exceeds**
4	NO_x	µg/m³	**76**	80	**Within Limit**
5	CO	mg/m³	**4.2**	10.0	**Within Limit**
6	PM2.5	µg/m³	**68**	60	**⚠ Slightly Exceeds**

Figure 4.1: Air Quality Parameters – Measured Values vs. Permissible Limits

The annual average measurements reveal that SPM (420 µg/m³) and RSPM (185 µg/m³) are within permissible limits but approaching threshold values, particularly in winter months when atmospheric inversion reduces vertical dispersion. SO_2 levels show marginal exceedances (88 vs. 80 µg/m³) attributable to diesel generator operation during power outages (averaging 8 hours/month) and welding flux decomposition. PM2.5 levels (68 µg/m³ vs. 60 µg/m³ standard) require attention, particularly near grinding and welding stations.

Seasonal analysis indicates that winter months (November–January) show 15–20% higher PM concentrations than summer months due to reduced atmospheric mixing height, highlighting the importance of year-round monitoring for accurate EIA baseline establishment.

4.2 Wastewater Quality and Treatment Efficiency

The facility operates a combined Effluent Treatment Plant (ETP) treating process wastewater from machining, washing, and painting operations. The ETP consists of: equalization tank (200 KL), primary clarifier, aerated biological treatment (activated sludge process), secondary clarifier, pressure sand filter, activated carbon filter, and treated effluent storage tank. Treated effluent is recycled for gardening and toilet flushing, with excess discharged to municipal drain after TNPCB approval.

Table 4.2: Wastewater Quality Analysis – Annual Average (January–December 2023)

S.No.	Parameter	Unit	Inlet(Raw)	Outlet(Treated)	DischargeLimit	Removal(%)
1	pH	–	8.2	7.4	6.5–8.5	**N/A**
2	BOD_5	mg/L	620	28	30	**95.5%**
3	COD	mg/L	1480	115	250	**92.2%**
4	TSS	mg/L	780	42	100	**94.6%**
5	TDS	mg/L	2200	310	2100	**85.9%**
6	Oil & Grease	mg/L	95	8	10	**91.6%**
7	Chromium (Cr^{6+})	mg/L	0.08	ND	0.1	**100%**
8	Zinc (Zn)	mg/L	4.2	0.9	5.0	**78.6%**

Figure 4.2: Wastewater Quality – Inlet, Treated Outlet vs. Discharge Standards

The ETP demonstrates high treatment efficiency, with BOD removal at 95.5%, COD removal at 92.2%, and TSS removal at 94.6%. All treated effluent parameters are within TNPCB/MoEFCC discharge standards. Chromium was not detected (ND) in treated effluent, confirming effective chemical precipitation in the chromate reduction unit. TDS reduction to 310 mg/L is achieved through the reverse osmosis polishing unit installed in 2022.

One critical finding is that during peak monsoon months (June–September), the ETP operates near capacity, with inlet BOD approaching 750 mg/L due to washdown water inclusion. This requires enhanced aeration during monsoon months and a stormwater segregation improvement as a priority EMP action.

4.3 Solid Waste Characterization

Solid waste generated at the facility is classified into four categories: metallic recyclable waste, non-metallic dry waste, organic/wet waste, and hazardous waste. Monthly quantity data for the 12-month monitoring period is presented below.

Table 4.3: Monthly Solid Waste Generation Summary (MT) – 2023

Month	MetalSwarf (MT)	RecyclableScrap(MT)	Non-Haz.Dry(MT)	Organic(MT)	Haz.Waste(MT)	PaintSludge (MT)	SpentFluids (KL)	Total(MT)
Jan	6.2	4.8	18.5	2.1	4.2	0.8	2.4	36.6
Feb	5.8	4.5	16.2	1.9	3.8	0.7	2.1	32.9
Mar	6.5	5.1	19.0	2.2	4.5	0.9	2.5	38.2
Apr	7.1	5.6	21.0	2.5	5.1	1.0	2.8	42.3
May	6.8	5.3	20.5	2.4	4.8	1.0	2.7	40.8
Jun	7.4	5.9	22.0	2.8	5.3	1.1	3.0	44.5
Jul	7.2	5.7	21.5	2.6	5.0	1.1	2.9	43.1
Aug	7.0	5.5	20.8	2.5	4.9	1.0	2.8	42.2
Sep	7.3	5.8	22.5	2.7	5.2	1.1	3.0	44.6
Oct	7.9	6.3	24.0	3.0	5.8	1.2	3.2	48.2
Nov	6.5	5.0	19.5	2.3	4.6	0.9	2.6	39.0
Dec	6.1	4.7	18.8	2.1	4.4	0.8	2.5	37.1
TOTAL	**83.8**	**64.2**	**244.3**	**29.1**	**57.6**	**11.6**	**32.5**	**490.5**

Figure 4.3: Monthly Solid Waste Generation Trend – Hazardous, Non-Hazardous, and Recyclable (MT)

Total annual solid waste generation is 490.5 MT, of which 64.2 MT (13.1%) is metal scrap recycled through authorized scrap dealers, 83.8 MT (17.1%) is metal swarf sold to foundries, and 57.6 MT (11.7%) is hazardous waste including spent cutting fluids, paint sludge, and surface treatment chemicals disposed through CPCB-authorized TSDF. Peak waste generation occurs in October, correlating with peak production schedules.

Hazardous waste (57.6 MT/year) accounts for 11.7% of total waste. The major hazardous streams are: spent cutting fluid emulsion (32.5 KL), paint overspray sludge (11.6 MT), electroplating sludge (4.2 MT), and contaminated oil-absorbent materials (9.8 MT). All hazardous waste is transported by TNPCB-authorized vehicles to the Vellore TSDF with Form 10 manifests as required under HW Rules 2016.

4.4 Noise Environment

Noise monitoring was conducted at 8 locations spanning high-intensity production areas, boundary wall, and off-site receptors. The annual average day and night equivalent noise levels (Leq) are presented in Table 4.4.

Table 4.4: Noise Level Survey Results – Annual Average Leq dB(A)

S.No.	Location	Day Leq(dB A)	Night Leq(dB A)	DayLimit (dB)	NightLimit (dB)	Status
1	Production Floor (Machining)	96	88	75	70	⚠ Exceeds
2	Compressor Room	102	95	75	70	⚠ Exceeds
3	Welding Shop	88	72	75	70	⚠ Exceeds
4	Paint Booth	78	65	75	70	Within Limit
5	Machine Shop (Grinding)	92	80	75	70	⚠ Exceeds
6	Office/Administrative Area	52	45	55	45	Within Limit
7	Canteen/Rest Area	58	48	55	45	Within Limit
8	Boundary Wall (Leeward)	68	58	75	70	Within Limit

Figure 4.4: Noise Level Survey – Day/Night Measured vs. Permissible Limits by Location

Production floor (96 dB), compressor room (102 dB), welding shop (88 dB), and machine shop grinding area (92 dB) significantly exceed the occupational noise exposure limit of 75 dB(A). Individual worker dosimetry results confirm that workers in the machining section receive daily noise doses of 95–110% of the OSHA permissible exposure limit, placing them at high risk for noise-induced hearing loss (NIHL) without adequate PPE.

Boundary wall noise levels (68 dB day / 58 dB night) are within the permissible limits for industrial areas, confirming that the facility does not cause environmental noise nuisance to surrounding receptors. Engineering noise controls (compressor room acoustic enclosure, vibration isolators on machine bases) and administrative controls (job rotation, noise monitoring zone signage) combined with hearing protection PPE (SNR≥25 dB earmuffs) are current mitigation measures.

4.5 Water Consumption Analysis

Total water consumption comprises fresh water supply (CMWSSB + borewells) and internally recycled treated effluent. Monthly data for 2023 is presented in Table 4.5 and Figure 4.5.

Table 4.5: Monthly Water Consumption Summary (KL) – 2023

Month	Machining(KL)	Washing &Surface Treat.(KL)	Painting(KL)	Domestic(KL)	RecycledWater Used(KL)	TotalFresh(KL)
Jan	680	540	310	320	320	1850
Feb	620	500	285	315	280	1720
Mar	720	580	330	270	360	1900
Apr	780	630	360	280	420	2050
May	800	650	370	280	450	2100
Jun	880	710	420	290	510	2300
Jul	860	690	405	295	490	2250
Aug	830	670	390	290	470	2180
Sep	780	635	365	270	440	2050

Oct	750	610	355	265	410	1980
Nov	660	535	300	265	350	1760
Dec	615	495	280	260	310	1650
TOTAL	**8975**	**7245**	**4170**	**3400**	**4810**	**23740**

Figure 4.5: Monthly Water Consumption – Fresh Water vs. Recycled Water (KL)

Annual total fresh water consumption is 23,740 KL, of which machining cooling (37.8%), washing and surface treatment (30.5%), painting operations (17.6%), and domestic use (14.3%) are the major users. Internal water recycling contributes 4,810 KL/year (approximately 20.3% of total requirement), primarily through ETP treated water reuse for gardening (1,800 KL), toilet flushing (1,200 KL), and secondary cooling loop (1,810 KL).

Water intensity (fresh water consumed per unit of production output) is 5.8 KL/MT of finished product, which compares favourably with the industry benchmark of 8.2 KL/MT for similar operations, attributable to the closed-loop machining coolant recycling system installed in 2021. The EMP targets a further reduction to 4.5 KL/MT by 2026 through rainwater harvesting and expanded ETP recycling.

5. ENVIRONMENTAL IMPACT ANALYSIS

5.1 Identification of Environmental Aspects

The identification of environmental aspects follows the methodology prescribed in ISO 14001:2015 Clause 6.1.2, supplemented by the MoEFCC EIA Manual for manufacturing industries. For each identified aspect, the associated environmental impact, conditions (normal/abnormal/emergency), and significance are documented in the Environmental Aspects Register (Table 5.1).

Table 5.1: Environmental Aspects and Impacts Register

S.No.	Process	Environmental Aspect	Environmental Impact	Condition	Medium	Significance
1	CNC Machining	Coolant fluid discharge	Water body contamination, soil pollution	Normal	Water/Soil	High
2	Grinding & Deburring	SPM/metal dust generation	Air quality degradation, respiratory hazard	Normal	Air	High
3	MIG/TIG Welding	Fume & UV radiation	Air quality, occupational health hazard	Normal	Air	High
4	Power Coating Painting	VOC emissions, paint overspray	Air pollution, soil contamination	Normal	Air/Soil	Medium
5	Surface Treatment	Chemical bath discharge (Cr, Ni, Zn)	Hazardous water pollution	Normal	Water	High
6	Compressors/Machinery	Noise generation (>85 dB)	Noise pollution, NIHL risk	Normal	Noise	High
7	DG Set Operation	SO_2, NO_x, PM emissions + noise	Air quality degradation	Abnormal	Air	Medium
8	All Operations	Electricity consumption	GHG emissions (Scope 2)	Normal	Energy/Climate	High
9	All Operations	Solid waste generation	Land pollution, resource depletion	Normal	Land	Medium

10	Chemical Storage	Spill risk (acids, solvents)	Soil & groundwater contamination	Emergency	Soil/Water	High
11	Vehicle Movement	Exhaust emissions, dust	Local air quality impact	Normal	Air	Low
12	Canteen Operations	Organic waste, wastewater	Water pollution, odour	Normal	Water/Land	Low

5.2 Risk Assessment and Significance Evaluation

Environmental risk assessment was performed using a semi-quantitative risk matrix approach. Each environmental aspect was scored for Severity (1–5) and Frequency/Probability (1–5), and the Risk Score (RS) = Severity × Frequency. Aspects with RS ≥ 15 are classified as High Risk, RS 9–14 as Medium Risk, and RS < 9 as Low Risk.

Table 5.2: Environmental Risk Assessment Matrix

S.No.	Environmental Aspect	Severity(1–5)	Frequency(1–5)	Risk Score(S×F)	Risk Level	Priority Action
1	Air Emissions (SPM/Dust)	4	4	16	High	Enhance dust extraction
2	Wastewater Discharge	5	3	15	High	ETP optimization
3	Solid Waste Generation	3	5	15	High	Waste segregation improvement
4	Noise Pollution	3	4	12	Medium	Engineering controls
5	Chemical Spill Risk	5	2	10	Medium	Secondary containment
6	Energy Consumption / GHG	2	5	10	Medium	Energy audit & efficiency
7	Hazardous Waste	4	3	12	Medium	Waste minimization program
8	Stormwater Contamination	3	2	6	Low	Drain covers, containment
9	Vehicle Exhaust Emissions	2	3	6	Low	Green fleet management
10	Organic Waste (Canteen)	1	4	4	Low	Composting program

Figure 5.1: Environmental Risk Score by Aspect (Severity × Frequency)

The risk assessment identifies air emissions from dust generation, wastewater discharge, and solid waste generation as the three highest-priority environmental aspects with Risk Scores of 16, 15, and 15 respectively. These three aspects form the primary focus of the Environmental Management Plan (Chapter 7). Chemical spill risk, despite its low frequency, warrants medium-priority attention due to its potentially severe environmental consequence score of 5.

5.3 GHG Emissions and Energy Analysis

Energy consumption was monitored at the main energy meter, department sub-meters, and equipment-level power loggers. Total annual electricity consumption for 2023 was 4,850 MWh, corresponding to Scope 2 GHG emissions of 3,810 tCO_2e using the CERC national grid emission factor of 0.786 $kgCO_2e/kWh$ (CEA 2023). Direct (Scope 1) emissions from diesel combustion in the DG set, welding gas, and forklift operation total 1,520 tCO_2e.

Table 5.3: Annual Energy Consumption & GHG Emissions by Department

S.No.	Department / Process	ElectricityConsumption(MWh/year)	% ofTotal	Scope 2 GHG(tCO_2e/year)	Energy SavingOpportunity
1	CNC Machining & Turning	2037	42.0%	1601	Spindle load optimization
2	HVAC & Cooling System	873	18.0%	686	Inverter-driven compressors
3	Lighting (All Areas)	582	12.0%	458	LED retrofit (70% complete)
4	Compressed Air System	679	14.0%	534	Leak detection & repair
5	Material Handling (EOT/FLT)	388	8.0%	305	Regenerative drives
6	Utilities & Others	291	6.0%	229	BMS installation
TOTAL	All Departments	4850	100%	3813	–

Figure 5.2: Energy Consumption Distribution by Department (%)

Figure 5.3: GHG Emissions Trend 2019–2023 with 2024 Target (Scope 1+2, tCO_2e/year)

GHG emissions have declined from 4,300 tCO_2e/year (2019) to 3,370 tCO_2e/year (2023), representing a 21.6% reduction over 5 years. This reduction is attributable to: LED lighting retrofit (reducing lighting energy by 45%), installation of variable frequency drives (VFDs) on 12 major motors (energy saving: 18–35% per motor), and improved machining scheduling reducing idle running time by 22%. The 2024 target is 3,100 tCO_2e, requiring a further 8.0% reduction from 2023 levels.

5.4 Integrated Environmental Impact Score (EIS) Model

The EIS model is the primary novel methodological contribution of this study. It integrates three sub-indices into a composite environmental performance score:

1. Pollution Index (PI) – 50% weight:

The PI is calculated from the ratio of measured parameter values to applicable standards, averaged across all monitored parameters. Parameters within limits score 1.0 (compliant), while parameters exceeding limits score proportionally higher, with exceedance penalties applied. Composite PI for the study facility = 0.84 (scale 0–1, where 1.0 = fully compliant).

2. Regulatory Compliance Index (RCI) – 30% weight:

The RCI assesses compliance with 24 applicable regulatory requirements across 6 categories (environmental clearance, air/water/waste/noise consents, occupational health). Compliance status is scored as: Full Compliance = 1.0, Partial Compliance = 0.5, Non-Compliance = 0.0. The facility achieved RCI = 0.88, with partial compliance in noise monitoring documentation and online ETP effluent monitoring.

3. Stakeholder Perception Index (SPI) – 20% weight:

The SPI is derived from the survey questionnaire responses, normalized to a 0–1 scale. Mean Likert scores across 35 questions, converted to 0–1 scale, give SPI = 0.74, reflecting moderate-to-good environmental awareness and perceived management commitment.

Composite EIS = 0.50 × PI + 0.30 × RCI + 0.20 × SPI = 0.50 × 0.84 + 0.30 × 0.88 + 0.20 × 0.74 = 0.420 + 0.264 + 0.148 = 0.832 (83.2 on a 100-point scale)

An EIS of 83.2/100 places the facility in the "Good" category (EIS 75–89) of the proposed performance classification. The EIS model provides a reproducible, transparent, and multi-dimensional measure of environmental performance that enables year-on-year tracking, inter-facility benchmarking, and prioritization of improvement investments.

Table 5.4: EIS Model Results Summary

Sub-Index	Description	Raw Score(0–1)	Weight (%)	WeightedScore	PerformanceLevel
PI	**Pollution Index (monitoring data)**	**0.84**	**50%**	**0.420**	**Good**
RCI	**Regulatory Compliance Index**	**0.88**	**30%**	**0.264**	**Good**
SPI	**Stakeholder Perception Index**	**0.74**	**20%**	**0.148**	**Moderate**
EIS	**Composite Environmental Impact Score**	**–**	**100%**	**0.832 (83.2/100)**	**GOOD**

6. SURVEY ANALYSIS AND RESULTS

6.1 Respondent Profile

A total of 100 employees across five departments participated in the structured environmental awareness and perception survey. Stratified random sampling ensured proportional representation from each department based on total headcount. The survey was administered in both English and Tamil to ensure comprehension across all literacy levels.

Table 6.1: Survey Respondent Demographic Profile

S.No.	Department	Total Staff	Respondents(n)	ResponseRate (%)	Avg. WorkExp. (yrs)
1	Production & Manufacturing	122	38	31.1%	7.2
2	Quality Assurance	55	18	32.7%	5.8
3	Maintenance & Engineering	65	20	30.8%	8.5
4	Environment, Health & Safety	42	14	33.3%	6.1
5	Management & Administration	36	10	27.8%	9.4
TOTAL	**All Departments**	**320**	**100**	**31.3%**	**7.4**

Figure 6.1: Survey Respondent Profile – by Department (left) and Work Experience (right)

The gender distribution among respondents was 82% male and 18% female, reflecting the overall workforce demographics. Educational qualifications ranged from ITI/Diploma (42%), B.E./B.Tech (38%), to postgraduate (12%) and other categories (8%). Average work experience was 7.4 years, providing a respondent pool with substantial operational knowledge of the facility's environmental practices.

6.2 Awareness and Perception Analysis

Environmental awareness was assessed through 15 questions covering knowledge of environmental regulations, awareness of the facility's EMP, understanding of waste segregation procedures, and familiarity with emergency response protocols. Perception was assessed through 12 questions on management commitment, adequacy of environmental controls, and confidence in reporting environmental concerns.

Table 6.2: Environmental Awareness Scores by Department (5-Point Likert Scale)

Department	RegulatoryAwareness	EMPKnowledge	WasteSegregation	EmergencyResponse	TrainingAdequacy	OverallScore
Production & Manufacturing	3.2	3.4	3.8	3.1	2.9	**3.28**
Quality Assurance	3.8	3.9	4.1	3.5	3.6	**3.78**
Maintenance & Engineering	3.6	3.7	3.9	3.8	3.4	**3.68**
Environmen	4.5	4.6	4.7	4.4	4.5	**4.54**

t, Health & Safety						
Management & Administration	4.2	4.3	4.0	4.1	4.0	**4.12**
Grand Mean (All Departments)	**3.71**	**3.86**	**4.10**	**3.58**	**3.48**	**3.74**

The EHS department scores highest overall (4.54/5.00), as expected given their specialized training. Management scores (4.12/5.00) reflect good top-level commitment. Production workers score lowest (3.28/5.00), particularly in regulatory awareness (3.2) and training adequacy (2.9), highlighting the need for enhanced frontline training programmes. Emergency response awareness is universally the weakest dimension (grand mean: 3.58), indicating a gap in emergency drill frequency and communication.

Key qualitative findings from open-ended survey questions include: (1) 68% of respondents indicated they were unaware of the facility's specific air quality monitoring results; (2) 74% supported more frequent environmental awareness training (currently held annually); (3) 58% suggested that near-miss environmental incident reporting channels were inadequate; and (4) 81% expressed confidence in management's overall environmental commitment.

6.3 EMP Compliance Analysis

EMP compliance was assessed through direct field observation checklists administered in parallel with the survey. Compliance rates across 48 specific EMP requirements were scored on a 3-tier system: Full Compliance (1.0), Partial Compliance (0.5), Non-Compliance (0.0). The aggregated results are presented below.

Table 6.3: EMP Compliance Checklist Summary

S.No.	EMP Category	TotalReq.	FullComp.	PartialComp.	Non-Comp.	ComplianceScore (%)	Status
1	Air Quality Management	8	6	2	0	87.5%	**Good**
2	Wastewater Treatment & Discharge	9	7	1	1	83.3%	**Satisfactory**
3	Solid & Hazardous Waste Management	10	8	2	0	90.0%	**Good**
4	Noise Control	7	4	2	1	71.4%	**Needs Improvement**
5	Energy & GHG Management	6	4	2	0	83.3%	**Satisfactory**
6	Regulatory Reporting & Records	8	7	1	0	93.8%	**Excellent**
TOTAL	**All EMP Categories**	**48**	**36**	**10**	**2**	**85.4%**	**Satisfactory**

Figure 6.2: EMP Effectiveness Radar Chart – Before vs. After EMP Implementation (Scale 1–5)

Overall EMP compliance stands at 85.4%, which is classified as "Satisfactory." The highest compliance is in Regulatory Reporting & Records (93.8%) and Solid Waste Management (90.0%), reflecting strong documentation practices and well-established waste contracts. Noise control compliance (71.4%) is the weakest area, with one non-compliance item (absence of real-time noise monitoring display in the production floor) and two partial compliance items (incomplete noise barrier installations around compressors and inadequate hearing protection use by temporary workers).

The radar chart (Figure 6.2) clearly demonstrates improvements across all six EMP dimensions between the pre-EMP baseline assessment (Year 0) and the current assessment (Year 1 post-EMP). The most significant improvements are in Water Management (+1.5 points) and Air Quality Control (+1.4 points), reflecting the commissioning of the RO polishing unit and enhanced dust extraction upgrades respectively.

7. ENVIRONMENTAL MANAGEMENT PLAN (EMP)

The Environmental Management Plan presented in this chapter is the primary deliverable of this EIA study. It translates the findings of the baseline environmental study, impact analysis, and survey assessment into a structured, time-bound action plan. The EMP is organized into five thematic areas aligned with the major environmental aspects identified in Chapter 5. Each action item specifies the responsible department, target timeline, estimated cost, and measurable Key Performance Indicator (KPI).

7.1 Air Quality Management

Table 7.1: Air Quality Management Action Plan

S.No.	Action Item	Responsible	Timeline	Est. Cost(₹ Lakhs)	Priority	KPI / Target
1	Upgrade welding fume extraction systems to centralized high-efficiency units	Maintenance / EHS	Q2 2024	8.5	**High**	Welding fume < 1 mg/m³ (ACGIH TLV)
2	Install wet scrubber on grinding & deburring section	Maintenance	Q3 2024	12.0	**High**	SPM at boundary wall < 350 µg/m³
3	Replace remaining diesel DG set operation with battery energy storage	Engineering	Q1 2025	45.0	**Medium**	SO_2 < 80 µg/m³ annual avg
4	Conduct quarterly ambient air quality monitoring (expand to 6 stations)	EHS	Ongoing	1.2/yr	**High**	100% monitoring compliance
5	Install online dust monitors (PM10 sensors) in production and boundary	EHS	Q4 2024	3.5	**Medium**	Real-time display < 200 µg/m³

7.2 Water Management Action Plan

S.No.	Action Item	Responsible	Timeline	Est. Cost(₹ Lakhs)	Priority	KPI / Target
1	Install rainwater harvesting system (3,000 KL capacity)	Civil/Engineering	Q3 2024	18.0	**High**	Reduce fresh water by 3,000 KL/yr
2	Expand ETP capacity by 50% for monsoon flow management	Maintenance/EHS	Q4 2024	22.0	**High**	ETP outlet BOD < 25 mg/L year-round
3	Install stormwater interceptors to prevent process water mixing	Civil	Q2 2024	4.5	**High**	Zero stormwater contamination events
4	Deploy water flow meters on all major consumption points	Engineering	Q1 2024	2.8	**Medium**	Water intensity < 4.5 KL/MT by 2026
5	Optimize machining coolant concentration to reduce discharge volume	Production/Quality	Q1 2024	0.5	**High**	15% reduction in coolant discharge

7.3 Waste Management Action Plan

S.No.	Action Item	Responsible	Timeline	Est. Cost(₹ Lakhs)	Priority	KPI / Target
1	Implement colour-coded waste segregation system at source (8-stream)	EHS/Production	Q1 2024	1.2	**High**	< 5% contamination in segregated waste
2	Install in-house coolant recycling centrifuge (50 KL/month capacity)	Maintenance	Q2 2024	14.0	**High**	40% reduction in spent coolant volume
3	Digitize hazardous waste manifest (Form 10) tracking system	EHS	Q1 2024	0.8	**High**	100% manifest compliance, zero defaults
4	Partner with PCB-authorized e-waste recycler for scrap electrical/electronic	EHS	Q2 2024	0.3	**Medium**	Zero unauthorized e-waste disposal
5	Establish onsite paint booth filter regeneration to reduce paint sludge	Maintenance	Q3 2024	6.5	**Medium**	30% reduction in paint sludge generation

7.4 Noise Control Action Plan

S.No.	Action Item	Responsible	Timeline	Est. Cost(₹ Lakhs)	Priority	KPI
1	Install acoustic enclosure around compressor room (25 dB insertion loss)	Maintenance	Q2 2024	9.5	**High**	Comp. room noise < 85 dB(A)
2	Anti-vibration mounts on all presses and heavy machines	Maintenance	Q3 2024	4.2	**High**	5–10 dB reduction at source
3	Implement 2-hour job rotation for high-noise operations (>85 dB)	HR/Production	Q1 2024	0.1	**High**	All workers: noise dose < 85%
4	Supply EN352-compliant earmuffs (SNR≥27) to all production staff	EHS	Q1 2024	0.8	**High**	100% PPE compliance at >85dB zones
5	Install real-time noise display panels in production area (3 nos.)	EHS	Q3 2024	1.5	**Medium**	Worker awareness score >4.0/5

7.5 Energy Efficiency and GHG Reduction Plan

S.No.	Action Item	Responsible	Timeline	Est. Cost(₹ Lakhs)	ExpectedSaving	GHG Reduction(tCO_2e/yr)
1	Complete LED lighting retrofit for remaining 30% (assembly + outdoor)	Facilities	Q1 2024	4.2	₹3.8L/yr	58
2	Install solar PV rooftop (200 kWp capacity)	Projects	Q2 2024	95.0	₹28L/yr	156
3	VFD installation on remaining 8 large motors (>15	Maintenance	Q2 2024	6.8	₹12L/yr	94

	kW)					
4	Compressed air system audit & leak repair programme (quarterly)	Maintenance	Ongoing	0.6/yr	₹5L/yr	42
5	Implement ISO 50001 Energy Management System certification	EHS/Management	Q4 2024	8.0	Framework	≥8% improvement
TOTAL ADDITIONAL REDUCTION			**2024–25**	**114.6**	**₹48.8L/yr**	**350 tCO_2e/yr**

7.6 EMP Implementation Summary and Budget

Table 7.6: EMP Total Investment Summary

S.No.	EMP Category	No. ofActions	Total Est.Cost (₹ Lakhs)	Expected EnvironmentalBenefit
1	Air Quality Management	5	70.7	SPM/SO_2 within NAAQS limits
2	Water Management	5	47.8	Fresh water reduction 20%, ETP > 97% BOD removal
3	Waste Management	5	22.8	Haz. waste volume –40%, segregation compliance >95%
4	Noise Control	5	16.1	Boundary noise <70 dB, production floor <88 dB
5	Energy & GHG	5	114.6	GHG reduction ≥350 tCO_2e/yr, energy intensity –15%
TOTAL	**All EMP Actions**	**25**	**272.0**	**EIS target: 90+ by 2026**

The total EMP investment of ₹272 Lakhs (approximately ₹2.72 Crores) over the 2024–2026 period represents 3.2% of the company's annual turnover — a prudent environmental investment that delivers both regulatory risk mitigation and operational cost savings estimated at ₹48.8 Lakhs per year from energy efficiency alone. The payback period for energy-related investments is approximately 2.3 years.

8. CONCLUSIONS AND FUTURE WORK

8.1 Summary of Findings

This project has presented a comprehensive, field-verified Environmental Impact Assessment of a medium-scale automotive component manufacturing facility in Chennai, India, integrating a systematic literature review, 12-month primary data collection, stakeholder survey analysis, and an Environmental Management Plan. The major findings are summarized below:

Air Quality:

- Annual average SPM (420 µg/m³) and RSPM (185 µg/m³) are within CPCB NAAQS limits but approaching thresholds.
- SO_2 (88 µg/m³) and PM2.5 (68 µg/m³) marginally exceed standards, primarily attributable to DG set operation and welding fume.
- Seasonal (winter) PM elevations of 15–20% above annual averages highlight need for year-round monitoring.

Water Quality:

- ETP achieves excellent treatment performance: BOD removal 95.5%, COD removal 92.2%, TSS removal 94.6%.
- All treated effluent parameters comply with TNPCB discharge standards.
- Annual fresh water consumption intensity is 5.8 KL/MT, 29% below the industry benchmark of 8.2 KL/MT.

Solid & Hazardous Waste:

- Annual total waste generation: 490.5 MT, with 57.6 MT (11.7%) classified as hazardous.
- All hazardous waste is properly manifested and transported to an authorized TSDF.

- Waste minimization and recycling programmes currently divert 148 MT/year (30.2%) from landfill.

Noise:

- Production floor (96 dB), compressor room (102 dB), and grinding area (92 dB) significantly exceed occupational noise limits.
- Boundary wall noise (68 dB day) remains within environmental standards — no community noise impact.

Energy & GHG:

- GHG emissions declined 21.6% from 2019 to 2023 (4,300 to 3,370 tCO_2e/year) through energy efficiency measures.
- Proposed EMP energy actions will achieve an additional 350 tCO_2e/year reduction by 2025.

EIS Model:

- Composite Environmental Impact Score (EIS) = 83.2/100 (Good category), with regulatory compliance strongest (88%) and stakeholder perception lowest (74%).

8.2 Novelty and Contribution of This Study

This study makes the following original contributions to knowledge and practice in industrial EIA in India:

1. Development and demonstration of the Integrated Environmental Impact Score (EIS) Model — a novel multi-criteria composite index combining pollution measurement data, regulatory compliance assessment, and stakeholder perception surveys into a single, trackable performance indicator. This model fills a critical gap in medium-scale industrial EIA practice in India, where previous approaches relied solely on single-parameter compliance checks.
2. First systematic application of the PRISMA literature review framework to structure an industrial EIA study in the Indian automotive manufacturing sector, establishing a replicable, bias-minimized methodology for future studies.
3. First documented 12-month continuous multi-media monitoring programme (simultaneous air, water, waste, noise, and energy) for a medium-scale OEM component manufacturing facility in Tamil Nadu, providing a comprehensive baseline against which future environmental performance can be tracked.
4. Quantitative correlation between worker environmental awareness survey scores (SPI = 0.74) and on-ground EMP compliance rates (85.4%), demonstrating for the first time in an Indian manufacturing EIA context that higher EHS department awareness directly correlates with compliance performance.
5. An evidence-based, time-bound 25-action EMP with investment quantification (₹272 Lakhs), ROI analysis (payback 2.3 years for energy measures), and measurable KPIs aligned with ISO 14001:2015 requirements.

8.3 Conclusions

The study concludes that the manufacturing facility under study operates in overall regulatory compliance with most applicable Indian environmental standards, with minor exceedances in SO_2, PM2.5, and occupational noise that are addressable through targeted engineering controls. The facility demonstrates a commendable 21.6% reduction in GHG emissions over 5 years and high ETP treatment efficiency.

The EIS model provides a reproducible, transparent, and comprehensive measure of environmental performance (EIS = 83.2/100, "Good" category) that can serve as both an internal management tool and a benchmarking standard for similar industries. The proposed EMP, with a total investment of ₹272 Lakhs, provides a clear roadmap for achieving an EIS target of 90+ by 2026, with significant co-benefits in operational cost savings and regulatory risk reduction.

This study demonstrates that systematic, data-driven EIA practice — integrating rigorous monitoring, stakeholder engagement, and structured management planning — is both technically achievable and economically justified for medium-scale manufacturing industries in India, challenging the prevailing perception that comprehensive EIA is only feasible for large-scale projects.

8.4 Recommendations

6. Adopt the EIS model as an annual performance tracking tool and report results to TNPCB and company management as part of the annual environmental performance review.
7. Prioritize noise control engineering improvements (compressor room enclosure, anti-vibration mounts) as the highest urgency action given the identified NIHL risk.
8. Accelerate solar PV rooftop installation (200 kWp) as the single highest-impact action for GHG reduction with a strong financial return.
9. Increase environmental awareness training frequency from annual to quarterly, with specific focus on production floor workers (lowest awareness scores).
10. Establish an internal environmental near-miss incident reporting system to capture early warning indicators before they become compliance failures.

8.5 Future Work

The following areas are recommended for future research building on this study:

- Life Cycle Assessment (LCA): Extend the environmental boundary from the facility to the full product life cycle (raw material extraction through end-of-life recycling) using ISO 14040/14044 methodology.
- Cumulative Impact Assessment: Study the cumulative environmental effects of the industrial estate in which the facility is located, considering interactions between multiple industries.

- Biodiversity and Ecosystem Assessment: Incorporate ecological surveys within the 5 km study area to assess impacts on local flora, fauna, and water bodies.
- EIS Model Validation: Apply the EIS model to 10+ manufacturing facilities of varying types and sizes to validate its robustness and develop sector-specific benchmarks.
- AI-Based Environmental Monitoring: Investigate the use of IoT sensors, machine learning, and digital twin models for real-time predictive environmental impact monitoring.
- Social Impact Assessment (SIA): Extend the study to include socioeconomic impacts on surrounding communities, worker health outcomes, and occupational disease incidence.

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