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Environmental Risk Assessment and Mitigation Protocols in Ready-Mix Concrete Plants

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Abstract
Ready-mix concrete (RMC) plants play a vital role in modern infrastructure development, yet their operations pose significant environmental risks that require systematic evaluation and control. This project focuses on identifying, assessing, and mitigating the environmental impacts associated with RMC production processes. Risk factors examined include particulate emissions from material handling, noise pollution from batching operations, contamination of soil and water through improper disposal of slurry and aggregates, and increased carbon footprint due to high energy consumption and cement usage. Using established Environmental Risk Assessment (ERA) frameworks, the study evaluates the likelihood and severity of these hazards through qualitative and quantitative methods, including site surveys, process flow analysis, pollution measurements, and stakeholder interviews. The project further proposes a comprehensive set of mitigation protocols tailored for RMC plants, such as dust suppression systems, closed-loop water recycling, optimized material storage, noise-reducing engineering controls, and adoption of energy-efficient practices. Additionally, the study emphasizes the importance of regulatory compliance, continuous monitoring, and the implementation of Environmental Management Systems (EMS) such as ISO 14001 to ensure long-term sustainability. Integrating risk assessment findings with practical mitigation strategies, the project aims to support RMC operators and policymakers in improving environmental performance, reducing ecological impacts, and promoting responsible industrial growth. Ultimately, this research contributes to developing safer, cleaner, and more sustainable ready-mix concrete production practices.
Keywords: *Environmental Risk Assessment, Ready-Mix Concrete (RMC), Pollution Control, Dust Mitigation, Wastewater Management, Sustainability, Environmental Management Systems, Industrial Safety, Carbon Footprint, Mitigation Protocols.*

1. Introduction
Ready-Mix Concrete (RMC) plants are a vital component of modern infrastructure development, supplying consistent and quality-controlled concrete for residential, commercial, and industrial construction projects. With rapid urbanization and increased demand for construction materials, the number and scale of RMC plants have expanded significantly. However, alongside their economic and operational benefits, RMC plant operations pose considerable environmental risks that require systematic evaluation and control. Activities such as raw material handling, batching, mixing, transportation, and equipment cleaning can generate air pollutants, wastewater, solid waste, excessive noise, and high energy consumption, all of which may adversely affect the surrounding environment and local communities if not properly managed. Environmental Risk Assessment (ERA) provides a structured and scientific approach to identifying, analyzing, and prioritizing these environmental hazards based on their likelihood and potential severity. Integrating ERA with well-defined mitigation protocols, RMC plants can minimize environmental impacts while ensuring regulatory compliance and sustainable operations. Mitigation protocols focus on preventive and control measures

such as dust suppression systems, wastewater recycling, noise reduction techniques, spill prevention, and efficient resource utilization. This study on Environmental Risk Assessment and Mitigation Protocols in Ready-Mix Concrete Plants aims to systematically assess environmental risks associated with RMC operations and propose practical, cost-effective mitigation strategies. The adoption of such protocols supports sustainable development, protects environmental quality, and promotes responsible industrial practices in the construction sector.

2. Literature Review

Recent studies highlight growing efforts to improve the environmental sustainability of ready-mix concrete (RMC) production through waste utilization, performance optimization, and life-cycle assessment. V. R. Kowshika et al. (2025) investigated the utilization of RMC waste as recycled aggregates, demonstrating that such practices significantly reduce dependence on virgin aggregates and landfill disposal. Although recycled aggregates exhibit higher water absorption and slightly reduced compressive strength, the performance remains acceptable for many applications, offering clear environmental and economic benefits while supporting a circular economy. Focusing on fresh concrete performance, João Pacheco et al. (2025) examined the workability of RMC incorporating industrial recycled aggregates. Their findings reveal that while mixed demolition waste aggregates are unsuitable, recycled concrete aggregates can be safely used up to 10–20% replacement, provided workability loss is carefully controlled at plant level. From a systems perspective, Hassanean S. H. Jassim et al. (2025) proposed an optimization framework integrating environmental impact, cost, and time across the RMC supply chain, identifying transportation distance as a dominant emission factor. Material performance and durability were addressed by Nayeemuddin Mohammed et al. (2025), who emphasized the influence of curing methods and internal concrete zones on strength and water absorption. Saud Anjum Mahevi et al. (2024) demonstrated that partial replacement of cement with Fly Ash and GGBS significantly reduces ecological footprint without compromising strength. Complementing these studies, Jonathan Michael Broyles et al. (2023) provided an extensive Environmental Product Declaration dataset, enabling data-driven life-cycle assessments of RMC mixtures. Collectively, these works underline the importance of integrated environmental risk assessment and mitigation protocols in RMC plants.

3. Problem Identification

Ready-mix concrete (RMC) plants play a critical role in supporting modern infrastructure development; however, their production processes generate multiple environmental challenges that are often inadequately identified and managed. A key problem is the absence of a structured and systematic environmental risk assessment framework in many RMC facilities, leading to uncontrolled emissions, inefficient resource use, and unsafe environmental conditions. Dust emissions from cement silos, aggregate handling, and transit mixer loading significantly degrade ambient air quality and pose occupational health risks to workers as well as nearby communities. In addition, wastewater and slurry generated from mixer washing and yard cleaning are frequently discharged without adequate treatment, resulting in soil contamination and pollution of surface and groundwater resources. Noise pollution from batching operations, mechanical equipment, and heavy vehicle movement further contributes to environmental stress, particularly in urban and semi-urban locations. High consumption of energy, fuel, and raw materials increases the overall carbon footprint of RMC operations, while poor material storage and housekeeping practices exacerbate environmental hazards. Many plants lack essential pollution control systems such as dust collectors, enclosures, and wastewater recycling units. Furthermore, non-compliance with environmental regulations is common due to insufficient monitoring, documentation, and awareness among plant personnel. Environmental management is often reactive rather than preventive, with no plant-specific mitigation protocols in place. This situation highlights the urgent need for comprehensive environmental risk assessment and effective mitigation strategies to ensure sustainable, compliant,

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and environmentally responsible operation of RMC plants.

4. Methodology

The methodology of this study was designed to systematically assess and mitigate the environmental impacts associated with ready-mix concrete (RMC) production. The first step involved the selection of the study area and RMC plant, ensuring that the chosen facilities were representative of typical operational conditions and production capacities. Criteria for selection included plant size, production volume, accessibility, and willingness to participate in site assessments. Following the selection, process mapping and site observation were conducted to gain a comprehensive understanding of the production workflow.

Selection of Study Area / RMC Plant
↓
Process Mapping and Site Observation
↓
Environmental Risk Identification
↓
Risk Assessment
↓
Development of Mitigation Protocols
↓
Validation and Expert Review
↓
Implementation Plan and Monitoring Framework
↓
Documentation and Reporting

Figure 1 Methodology

4.1. Selection of Study Area / RMC Plant

The selection of an appropriate study area and Ready-Mix Concrete (RMC) plant is a critical step in conducting an effective Environmental Risk Assessment (ERA), as it directly influences the reliability, relevance, and applicability of the research outcomes. RMC plants vary widely in terms of production capacity, technology level, layout design, and environmental management practices. Therefore, a systematic and well-defined selection approach is essential to ensure that the chosen plant realistically represents typical industry operations and associated environmental challenges. RMC production involves multiple stages such as aggregate handling, cement storage, batching, mixing, transportation, and equipment cleaning. Each stage generates distinct environmental stressors including dust emissions, wastewater, noise, and energy consumption. Selecting a plant that exhibits these common operational characteristics ensures that the environmental risks identified are practical and relevant to real-world conditions. The chosen study area must reflect operational complexity and sufficient production activity to allow meaningful monitoring and data collection.

- Criteria for Selecting the RMC Plant : Key criteria adopted for plant selection include production capacity, geographic location, accessibility, willingness of management to participate, and representativeness of typical RMC operations. Medium-to-high capacity plants were preferred, as higher throughput intensifies environmental interactions and allows assessment under peak conditions. Geographic location and proximity to sensitive receptors such as residential areas and water bodies were also considered to evaluate off-site environmental impacts. Management cooperation was essential to enable access to operational data, site observations, and environmental measurements.
- Collection of Background Information : Once selected, detailed background information was collected on plant layout, production processes, raw materials, utilities, waste streams, and equipment condition. This baseline data supported accurate identification of environmental risk sources and informed the development of targeted mitigation strategies.
- Relevance to Environmental Risk Assessment : The selected RMC plant reflected standard industry practices, conventional equipment usage, and observable environmental stressors. This ensured that the findings of the study are transferable to similar RMC facilities, strengthening the practical value and industry-wide applicability of the proposed

environmental risk mitigation protocols.

4.2. Process Mapping and Site Observation

Process mapping and site observation are fundamental components of an effective Environmental Risk Assessment (ERA) in Ready-Mix Concrete (RMC) plants. RMC operations involve a sequence of interlinked activities raw material handling, batching, mixing, transportation, and waste management each contributing distinct environmental pressures. Process mapping provides a systematic visualization of these activities, enabling clear identification of material flows, energy use, and pollution sources. Site observation complements this approach by validating mapped processes under real operating conditions, capturing actual work practices, equipment performance, and on-site environmental behavior. Together, these methods ensure that the assessment is evidence-based and reflects real industrial conditions rather than theoretical assumptions.

- **Methodological Approach:** The process mapping exercise followed a structured methodology consisting of defining operational boundaries, mapping material and energy flows, identifying environmental interaction points, and verifying findings through direct site observation. Core processes such as aggregate handling, cement transfer, batching, mixing, loading, dispatch, and washout were mapped in detail, along with peripheral activities including generator operation and maintenance. Environmental interaction points dust emission zones, wastewater generation areas, noise-intensive equipment, and fuel combustion sources were systematically identified and verified through repeated observations during peak and non-peak operations.
- **Mapping of Key Operational Stages** :Detailed mapping revealed that aggregate handling and storage generate significant fugitive dust and noise due to loader movement and open stockpiles. Cement and fly ash transfer from silos were identified as major sources of fine particulate emissions, particularly when filter maintenance was inadequate. Batching and mixing operations contributed to combined impacts of dust leakage, mechanical noise, and high energy consumption. Transportation and dispatch activities emerged as key contributors to carbon emissions and traffic-related noise, while equipment cleaning and washout procedures posed serious risks of soil and water contamination due to highly alkaline slurry.
- **Integration with Environmental Risk Assessment:** Integrating process mapping with site observation enabled the identification of critical environmental hotspots and their root causes. This integrated understanding formed the basis for prioritizing risks and developing targeted, practical mitigation protocols. Overall, process mapping and site observation established a strong analytical foundation for accurate environmental risk identification and effective mitigation planning in RMC plant operations.

Table 1 **Criteria For Selection Of Study Area / Ready-Mix Concrete (Rmc) Plant**

Selection Criterion	Description Of Criterion	Purpose / Rationale	Data Required	How It Supports Environmental Risk Assessment (Era)
1. Production Capacity	The Plant's Hourly Concrete Output (E.G., 30–150 M³/Hr).	Ensures The Selected Plant Reflects Realistic Industrial-Scale Operations; Higher Output Increases Environmental Impact Visibility.	Production Logs, Batching Rates, Operational Hours.	Determines Volume Of Emissions, Waste, And Resource Usage; Higher Capacity Reveals Worst-Case Environmental Scenarios.
2. Geographic Location	Physical Placement Of The	Location Affects Environmental	Gps Coordinates,	Helps Assess Environmental

	Plant (Urban, Industrial, Rural, Coastal).	Sensitivity And Regulatory Oversight.	Zoning Classification, Proximity To Communities Or Water Bodies.	Sensitivity, Potential Off-Site Impact, And Pollution Dispersion.
3. Accessibility For Research Team	Ease Of Site Access For Repeated Visits And Equipment Setup.	Ensures Feasibility Of Continuous Monitoring And Data Collection.	Travel Routes, Permission Status, Safety Requirements.	Enables Accurate Monitoring Of Emissions, Noise, Wastewater, And Operational Variations Over Time.
4. Willingness To Participate	Cooperation From Plant Managers And Staff.	Essential For Gaining Access To Records, Operational Areas, And Conducting Interviews.	Formal Consent Letters, Meeting Records.	Facilitates Transparent Data Collection And Ensures Availability Of Operational And Environmental Data.
5. Representativeness Of Typical Rmc Operations	Common Batching Systems, Cement Silos, Aggregate Handling, And Mixer Operations.	Ensures Applicability Of Findings Across Other Rmc Plants.	Equipment Inventory, Layout Drawings, Equipment Specifications.	Provides A Realistic Baseline For Environmental Risk Comparison Across The Industry.
6. Proximity To Sensitive Receptors	Distance To Residential Areas, Schools, Agricultural Land, Rivers, Etc.	Sensitive Receptors Increase Environmental Risk Significance And Require Stricter Mitigation.	Gis Maps, Environmental Regulation Boundaries.	Determines Risks Related To Dust, Noise, Wastewater Runoff, And Community Health.
7. Availability Of Background Information	Existing Documents Such As Layout Plans, Material Flow Charts, Compliance Reports.	Strengthens Baseline Understanding Of Plant Operations.	Process Maps, Maintenance Logs, Environmental Audit Records.	Improves Accuracy Of Hazard Identification And Risk Quantification.
8. Type Of Raw Materials Used	Cement Type, Aggregates, Admixtures, Fly Ash, Ggbs, Recycled Materials.	Material Characteristics Influence Dust Generation, Emissions, And Wastewater Composition.	Material Safety Data Sheets (Msds), Purchase Records.	Essential For Identifying Chemical Risks, Dust Hazards, And Waste Classification.
9. Machinery And Equipment Condition	Age, Maintenance Frequency, And Emission Controls.	Older Or Poorly Maintained Equipment May Cause Greater Environmental Impacts.	Maintenance Logs, Equipment Inspection Reports.	Supports Assessment Of Noise Levels, Dust Emissions, And Fuel Usage Impacts.
10. Compliance	Past	A Plant With Previous	Regulatory	Helps Assess Whether

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History	Environmental Violations Or Audits.	Issues Offers Insights Into Risk Patterns.	Reports, Environmental Licenses, Fines.	Risks Are Systemic Or Linked To Poor Compliance.
11. Waste Management System	Handling Of Slurry, Wash Water, Solid Waste, Aggregates.	Critical For Evaluating Pollution Risks And Recycling Opportunities.	Waste Disposal Records, Recycling Logs.	Clarifies Wastewater, Solid Waste, And Sludge-Related Risks.
12. Energy Consumption Profile	Electricity And Fuel Sources For Batching, Mixing, Transport.	Energy Use Directly Affects Carbon Footprint.	Utility Bills, Generator Logs, Fuel Consumption Records.	Supports Calculation Of Co_2 Emissions Associated With Plant Operations.
13. Volume Of Truck Movement	Number Of Transit Mixers Entering And Leaving The Plant Daily.	Transportation Increases Co_2, Noise, And Dust Emissions.	Dispatch Logs, Gps Data, Transport Schedules.	Enables Assessment Of Off-Site Environmental Impacts.
14. Environmental Features Of Surroundings	Soil Type, Groundwater Depth, Local Biodiversity.	Influences Risk Pathways For Contamination.	Soil Tests, Hydrological Maps, Ecological Surveys.	Helps Evaluate Likelihood Of Environmental Degradation.
15. Safety And Operational Culture	Worker Awareness, Training, Ppe Usage.	Reflects The Plant's Readiness To Adopt Mitigation Protocols.	Training Records, Safety Audits.	Supports Evaluation Of Human-Related Risk Factors And Operational Discipline.

Table 2 Background Information Collected For Selected RMC Plant

Category	Specific Information Collected	Purpose
Plant Layout	Aggregate stockpiles, silos, batching tower, mixer area, truck washout zone	Mapping high-risk emission and contamination zones
Process Flow	Material delivery → Storage → Weigh batching → Mixing → Dispatch → Waste handling	Supports environmental path analysis
Raw Materials	Cement, sand, gravel, admixtures, water source, supplementary cementitious materials	Evaluating dust, chemical hazards, carbon footprint
Utilities	Electrical consumption, generator usage, fuel consumption	Calculating energy-related emissions
Waste Streams	Slurry, sediment, wash water, solid aggregate waste	Identifying pollution pathways
Operations	Working hours, shift patterns, peak production times	Determining temporal variations in environmental impacts
Emission Points	Silo vents, conveyor transfer points, vehicle movement areas	Designing monitoring protocols

Existing Controls	Bag filters, water sprinklers, noise barriers, recycling pits	Assessing mitigation effectiveness

Table 3 Process Mapping and Site Observation of RMC Plant

Process Stage	Major Equipment Used	Material Handled	Throughput / Capacity	Operating Time (hrs/ day)	Observed Emission / Impact Source	Measured / Observed Value	Risk Level
Raw Material Receipt	Tipper trucks, loaders	Aggregates, sand	350 tonnes/ day	2.5	Fugitive dust, vehicle emissions	PM_{10}: 210 µg/m³	High
Aggregate Storage	Open storage yard	Coarse & fine aggregates	2,000 tonnes	Continuous	Wind-blown dust	Visible dust dispersion up to 25 m	High
Cement Storage	Cement silos (300 t)	OPC/PPC cement	240 tonnes/ Day	1.5	Silo vent dust	$PM_{2.5}$: 95 µg/m³	Medium
Aggregate Weigh Batching	Hopper & conveyor system	Aggregates	240 m³/day	3.0	Dust at transfer points	PM_{10}: 185 µg/m³	High
Cement Weigh Batching	Screw conveyor	Cement	96 tonnes/ Day	2.0	Fine particulate release	$PM_{2.5}$: 82 µg/m³	Medium
Water Dosing	Automated water dosing unit	Fresh & recycled water	45 m³/day	3.0	Wastewater spillage	Spillage rate: 2–3%	Low
Admixture Dosing	Dosing pumps	Chemical admixtures	1.8 tonnes/ month	1.0	Chemical leakage	Minor leakage observed	Low
Mixing Operation	Twin shaft mixer	Concrete mix	180 m³/day	4.0	Noise, vibration	Noise: 88 dB(A)	High
Transit Mixer Loading	Loading chute	Wet concrete	180 m³/day	4.0	Noise, slurry drip	Slurry loss: 0.5 m³/day	Medium
Vehicle Movement	Transit mixers (12 nos.)	Concrete	~65 trips/day	Continuous	Exhaust emissions, noise	Noise: 82 dB(A)	Medium
Washing of Mixers	High-pressure wash system	Concrete residue	6.5 m³ slurry/day	1.5	Alkaline wastewater	pH: 11.2	High
Slurry Collection	Slurry pit	Cement slurry	6.5 m³/day	Continuous	Soil & water contamination	Overflow observed	High
Wastewater Recycling	Reclaimer system	Process water	65% recycled	2.0	Suspended solids	TSS: 1,200 mg/L	Medium
Power Generation	DG set (backup)	Diesel	90 litres/day	1.0	Gaseous emissions	CO_2: 2.6 kg/litre	Medium

Table 4 Equipment Utilization

Equipment	Rated Capacity	Actual Utilization (%)	Energy Consumption	Noise Level dB(A)	Observation Remarks
Batching Plant	30 m³/hr	75	520 kWh/day	84	Efficient but noisy
Aggregate Conveyor	120 tph	82	180 kWh/day	80	Dust at belt joints
Cement Screw Conveyor	25 tph	70	95 kWh/day	76	Fine dust leakage
Concrete Mixer	1.5 m³/batch	78	240 kWh/day	88	High vibration
Air Compressor	10 bar	65	115 kWh/day	79	Periodic leakage
DG Set	250 kVA	40	90 L diesel/day	90	Used during outages

Table 5 Observed Environmental Hotspots

Observation Area	Primary Impact	Measured Value	Permissible Limit	Compliance Status
Aggregate Yard	Dust	PM_{10} = 210 µg/m³	100 µg/m³	Non-compliant
Mixing Zone	Noise	88 dB(A)	75 dB(A)	Non-compliant
Washing Area	Wastewater	pH = 11.2	6.5–8.5	Non-compliant
Vehicle Pathways	Noise	82 dB(A)	75 dB(A)	Marginal
Cement Silo Vent	Fine dust	$PM_{2.5}$ = 95 µg/m³	60 µg/m³	Non-compliant

Environmental monitoring at the RMC plant revealed several critical environmental hotspots requiring immediate attention. The aggregate yard recorded high dust levels, with PM_{10} concentration of 210 µg/m³, exceeding the permissible limit of 100 µg/m³, indicating non-compliance due to uncontrolled material handling. The mixing zone exhibited excessive noise levels of 88 dB(A) against the allowable limit of 75 dB(A), posing occupational and community noise concerns. Wastewater analysis at the washing area showed a highly alkaline pH of 11.2, far above the acceptable range of 6.5–8.5, confirming improper slurry management. Vehicle pathways recorded marginally high noise levels of 82 dB(A), mainly due to heavy vehicle movement. Additionally, fine dust emissions from the cement silo vent showed $PM_{2.5}$ levels of 95 µg/m³, exceeding regulatory limits. These findings highlight priority areas for targeted mitigation and continuous environmental monitoring.

4.3.Environmental Risk Identification

Environmental risk identification is a critical and foundational step in the Environmental Risk Assessment (ERA) process, particularly for resource-intensive and emission-prone industries such as ready-mix concrete (RMC) plants. This stage focuses on the systematic recognition of all potential environmental hazards arising from routine operations, auxiliary activities, material handling, equipment usage, waste generation, and abnormal or accidental conditions. Effective identification ensures that environmental impacts are not addressed in isolation but are understood as outcomes of

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interconnected operational processes. In RMC plants, environmental risks are present across the entire production lifecycle from raw material unloading and storage to batching, mixing, transportation, equipment cleaning, and waste management. These risks manifest in various forms, including particulate air emissions, alkaline wastewater discharge, soil contamination from spills and slurry seepage, excessive noise from heavy machinery, high energy consumption, and greenhouse gas emissions. If not properly identified at an early stage, such risks can lead to regulatory non-compliance, environmental degradation, occupational health issues, and conflicts with surrounding communities. This study adopts a structured environmental risk identification framework aligned with internationally recognized management and assessment approaches, including ISO 14001, Hazard Identification and Risk Assessment (HIRA), Failure Mode and Effects Analysis (FMEA), and Environmental Impact Assessment (EIA) principles. The identification process integrates findings from detailed process mapping, direct site observation, operational data review, and stakeholder consultations. Both routine risks (such as dust generation during aggregate handling) and episodic risks (such as wastewater overflow during heavy rainfall or silo over-pressurization) are considered to ensure comprehensive coverage. Environmental risks identified were further classified based on their source, mode of release, affected environmental receptors, and potential consequences. This holistic approach enables the clear prioritization of risks according to their likelihood and severity. By establishing a thorough and evidence-based understanding of environmental hazards, this chapter provides the analytical foundation for subsequent risk evaluation, ranking, and the development of targeted mitigation protocols aimed at improving environmental performance and sustainability in RMC plant operations

Table 6 Air Quality Data (PM10, PM2.5, TSP, Cement Dust) Daily Average Values Measured During 30-Day Monitoring Period

Location	PM10 (µg/m³)	PM2.5 (µg/m³)	TSP (µg/m³)	Cement Dust Concentration (mg/m³)	Regulatory Limit (PM10 / PM2.5)	Compliance
Cement Silo Vent	298	138	512	22.4	150 / 75	✗Exceeded
Batching Unit	254	121	411	18.9	150 / 75	✗Exceeded
Aggregate Stockpile	219	101	375	16.2	150 / 75	✗Exceeded
Loading/Unloading Area	176	88	324	12.7	150 / 75	✗Slightly Exceeded
Main Gate	112	54	201	4.1	150 / 75	✔ Within Limits
Office Boundary	79	33	145	2.8	150 / 75	✔ Within Limits

Air quality measurements at the RMC plant revealed elevated particulate matter concentrations in key operational areas. PM10, PM2.5, total suspended particles (TSP), and cement dust levels were recorded and compared against regulatory limits (PM10: 150 µg/m³; PM2.5: 75 µg/m³).

- Cement Silo Vent: PM10 at 298 µg/m³ and PM2.5 at 138 µg/m³ far exceeded limits, with cement dust concentration of 22.4 mg/m³, indicating critical emission sources.
- Batching Unit: PM10 and PM2.5 values of 254 µg/m³ and 121 µg/m³, respectively,

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highlight significant dust generation during material handling.

- Aggregate Stockpile: PM10 at 219 µg/m³ and PM2.5 at 101 µg/m³ indicate fugitive dust emissions from stockpile activity.
- Loading/Unloading Area: Slight exceedance observed with PM10 at 176 µg/m³ and PM2.5 at 88 µg/m³.
- Main Gate & Office Boundary: Values were within regulatory limits, showing dispersion reduces particulate concentrations at peripheral areas.

These results confirm that dust control measures, such as bag filters, water sprinklers, and covered storage, need enhancement in high-risk zones to ensure compliance and protect worker and community health.

Table 7 Noise Level Measurements (DB (A)) Recorded At 1-Hour Intervals Over 2 Weeks

Location	Minimum dB(A)	Maximum dB(A)	Average dB(A)	Regulatory Limit	Status
Batching Area	86	103	94	90	✕ Exceeded
Generator Room	91	110	98	90	✕ Exceeded
Transit Mixer Parking	79	97	88	90	✔ Acceptable
Aggregate Section	72	94	84	90	✔ Within Limit
Plant Boundary	60	75	67	75	✔ Within Limit
Nearby Residential Zone	52	68	59	55	✕ Slightly Exceeded

Noise measurements across the RMC plant and surrounding areas highlighted several zones exceeding regulatory limits (90 dB(A) for operational areas; 55 dB(A) for residential zones).

- Batching Area: Noise levels ranged from 86–103 dB(A) with an average of 94 dB(A), exceeding limits due to mechanical and pneumatic operations.
- Generator Room: Maximum of 110 dB(A) and average of 98 dB(A) indicate high-intensity sound from diesel generators.
- Transit Mixer Parking & Aggregate Section: Averaged 88 dB(A) and 84 dB(A), within acceptable limits.
- Plant Boundary: Average 67 dB(A), compliant with industrial limits.
- Nearby Residential Zone: Slightly exceeded at 59 dB(A), highlighting potential community disturbance.

Mitigation measures, such as noise barriers, equipment maintenance, and restricted operational hours, are recommended to reduce exposure.

Table 8 Wastewater & Slurry Analysis

Parameter	Min	Max	Average	Standard Limit	Status
pH	11.1	12.6	11.9	6–9	✕Exceeded
Suspended Solids (mg/L)	1,950	3,480	2,780	500	✕Exceeded
Total Dissolved Solids (mg/L)	1,180	1,650	1,410	2100	✔ Within Limit
Turbidity (NTU)	680	980	810	200	✕Exceeded
Oil & Grease (mg/L)	5.4	13.2	9.1	10	✕Slightly Exceeded
Chloride (mg/L)	410	560	490	1000	✔ Safe

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Sulphates (mg/L)	510	700	610	1000	✔ Safe
Heavy Metals (mg/L)	0.09	0.17	0.13	0.10	✕Exceeded

Water samples collected from washout pits, settling tanks, and runoff areas showed several parameters exceeding regulatory limits:

- pH: Averaged 11.9, significantly above the standard 6–9 range, indicating highly alkaline conditions.
- Suspended Solids: Mean concentration of 2,780 mg/L exceeded the 500 mg/L limit, reflecting high sediment loads.
- Turbidity: Averaged 810 NTU, surpassing the 200 NTU limit.
- Oil & Grease: Slightly exceeded at 9.1 mg/L versus 10 mg/L limit.
- Heavy Metals: Mean of 0.13 mg/L exceeded the 0.10 mg/L regulatory limit.
- TDS, Chloride, and Sulphates: Values remained within acceptable limits.

These results highlight the need for enhanced wastewater treatment, containment, and sediment management to mitigate water pollution risks.

Table 9 Water Consumption

Process	Water Consumption (L/m³ concrete)	Percentage of Total Usage
Mixing Water	160	38%
Aggregate Washing	120	28%
Truck Mixer Cleaning	80	19%
Equipment/Cycle Washout	50	12%
Domestic/Other Use	10	3%

- Average Total Water Use = 420 L per m³ of concrete
- Water usage in the RMC plant was monitored across different processes to identify major consumption points:
- Mixing Water: 160 L/m³, accounting for 38% of total usage, is the largest single contributor.
- Aggregate Washing: 120 L/m³ (28%), used to remove dust and fines from coarse and fine aggregates.
- Truck Mixer Cleaning: 80 L/m³ (19%), essential for maintaining concrete quality and preventing material buildup.
- Equipment/Cycle Washout: 50 L/m³ (12%), includes cleaning of batching units and conveyor belts.
- Domestic/Other Use: 10 L/m³ (3%), covering staff facilities and miscellaneous uses.

Table 10 Solid Waste Generation

Waste Type	Quantity (kg/day)	Source	Environmental Risk
Concrete Slurry	2,200	Truck wash	Soil & water contamination
Returned Concrete	1,450	Transit mixers	Hard waste accumulation
Cement Dust	380	Silos & batching tower	Air pollution
Aggregate Fines	920	Sieving, handling	Particulate dispersion
Packaging Waste	75	Admixtures	Landfill burden

Table 11 **Energy Consumption & Carbon Emissions- Electricity Use**

Waste Type	**Quantity (kg/day)**	**Source**	**Environmental Risk**
Concrete Slurry	2,200	Truck wash	Soil & water contamination
Returned Concrete	1,450	Transit mixers	Hard waste accumulation
Cement Dust	380	Silos & batching tower	Air pollution
Aggregate Fines	920	Sieving, handling	Particulate dispersion
Packaging Waste	75	Admixtures	Landfill burden

Total Electricity CO_2 = 800 kg/day

4.4.Risk Assessment in Ready-Mix Concrete (RMC) Plants

Risk assessment is a core component of the Environmental Risk Assessment (ERA) process, providing a structured and systematic approach to evaluate identified environmental hazards based on their likelihood of occurrence and the severity of their consequences. In ready-mix concrete (RMC) plants, this step is particularly important due to the continuous, high-volume nature of operations involving material handling, mechanical processes, fuel consumption, and wastewater generation. Even routine activities, if inadequately controlled, can result in cumulative environmental degradation affecting air, water, soil, and surrounding communities. Risk assessment was undertaken to prioritize environmental hazards and support the development of targeted mitigation protocols. The approach integrates qualitative judgment with semi-quantitative scoring to ensure both practical relevance and analytical rigor. The framework adopted aligns with internationally accepted environmental management principles, including ISO 14001, and incorporates hazard identification outputs, environmental monitoring data, regulatory standards, and expert evaluation. Each identified hazard was assessed using a five-point likelihood scale, reflecting the frequency of occurrence under normal operating conditions, and a five-point severity scale, reflecting the magnitude of environmental and health impacts. The multiplication of likelihood and severity scores produced a risk score, enabling clear categorization into low, medium, high, and very high risk levels. This method allows direct comparison across different environmental aspects such as air emissions, wastewater discharge, noise exposure, soil contamination, and energy-related emissions. The risk assessment results highlight that air pollution and water contamination represent the most critical risks in RMC plants, followed by noise, soil, and energy-related impacts. By ranking risks systematically, this assessment provides a strong decision-making foundation for prioritizing corrective actions, allocating resources effectively, and advancing proactive, compliant, and sustainable environmental management in RMC plant operations.

Table 12 **Quantitative Environmental Risk Assessment – RMC Plant**

Environmental Aspect	**Hazard Source**	**Measured Value**	**Likelihood (L)**	**Severity (S)**	**Risk Score (L×S)**	**Risk Category**
Air	Aggregate unloading	PM_{10} = 210 µg/m³	5	4	20	Very High
Air	Conveyor transfer	PM_{10} = 185 µg/m³	5	4	20	Very High
Air	Cement silo vent	$PM_{2.5}$ = 95 µg/m³	4	3	12	High
Air	DG set exhaust	NO_2 = 92 µg/m³	3	3	9	Medium
Water	Mixer washing	pH = 11.2	4	5	20	Very High

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Water	Slurry overflow	TSS = 1,200 mg/L	4	5	20	Very High
Soil	Slurry seepage	Alkalinity = 1,480 mg/kg	4	4	16	High
Soil	Diesel spill	Oil & grease = 26 mg/kg	3	3	9	Medium
Noise	Concrete mixer	88 dB(A)	5	3	15	High
Noise	DG set	90 dB(A)	4	4	16	High
Noise	Vehicle movement	82 dB(A)	4	3	12	High
Energy	Power consumption	1,150 kWh/day	3	3	9	Medium
Energy	Cement usage	1,980 kg CO_2/day	4	4	16	High
Water	Mixer washing	pH = 11.2	4	5	20	Very High
Water	Slurry overflow	TSS = 1,200 mg/L	4	5	20	Very High
Soil	Slurry seepage	Alkalinity = 1,480 mg/kg	4	4	16	High
Soil	Diesel spill	Oil & grease = 26 mg/kg	3	3	9	Medium

Table 13 Compliance-Based Risk Evaluation

Aspect	Measured Value	Permissible Limit	Compliance Status	Risk Impact
PM_{10}	210 µg/m³	100 µg/m³	Non-compliant	Very High
$PM_{2.5}$	95 µg/m³	60 µg/m³	Non-compliant	High
Noise	88 dB(A)	75 dB(A)	Non-compliant	High
Effluent pH	11.2	6.5–8.5	Non-compliant	Very High
TSS	1,200 mg/L	100 mg/L	Non-compliant	Very High
CO_2	1,980 kg/day	Best practice ≤1,600	Exceeded	High

4.5.Development of Mitigation Protocols

The development of mitigation protocols represents a crucial stage in the Environmental Risk Assessment (ERA) process, as it converts identified and prioritized environmental risks into practical, feasible, and cost-effective control measures. In ready-mix concrete (RMC) plants, mitigation protocols are designed to either eliminate environmental hazards at their source or reduce their likelihood and severity to acceptable levels. Based on the outcomes of the risk assessment, a structured hierarchy of controls engineering, administrative, and operational—is adopted to address key risks related to air pollution, wastewater generation, noise exposure, soil contamination, and high energy consumption. Engineering controls form the backbone of mitigation and include dust suppression systems such as water sprinklers, enclosed conveyors, and high-efficiency bag filters for cement silos. Water-related risks are addressed through closed-loop wastewater recycling systems, lined washout pits, and pH neutralization measures to prevent soil and groundwater contamination. Noise impacts are mitigated using acoustic enclosures, vibration isolators, and scheduled maintenance of high-noise equipment. Energy-efficient motors, optimized batching systems, and alternative cementitious materials contribute to reduced energy use and carbon emissions. Administrative and operational measures support these controls through the implementation of an Environmental Management System aligned with ISO 14001**,** standardized operating procedures, regular training, and improved housekeeping practices. The integration of these mitigation protocols ensures regulatory compliance, enhanced environmental performance, and sustainable operation of RMC plants while minimizing impacts on workers, communities, and the surrounding environment.

4.6.Validation and Expert Review

Validation and expert review represent a critical quality assurance stage in the Environmental Risk Assessment (ERA) framework, ensuring that proposed mitigation measures for ready-mix concrete (RMC) plants are technically sound, practical, and effective. This stage verifies that engineering, administrative, and operational controls are capable of reducing identified environmental risks under real operating conditions and in compliance with regulatory requirements. Through systematic validation, the gap between theoretical risk mitigation strategies and their field-level applicability is effectively bridged.

The expert review process involves consultation with professionals experienced in environmental engineering, RMC plant operations, pollution control, safety management, and regulatory compliance. Experts critically assess the adequacy of proposed controls for managing key risks such as dust emissions, wastewater and slurry handling, noise exposure, soil contamination, and energy consumption. Technical validation focuses on the performance, capacity, and reliability of engineering controls, while administrative and operational validation ensures that management systems, procedures, training, and monitoring mechanisms are clear, enforceable, and sustainable.

Benchmarking against best industry practices further strengthens the validation process by aligning mitigation protocols with proven performance standards. Based on expert feedback, mitigation measures are refined, optimized, and prioritized for effective implementation. Overall, validation and expert review enhance the credibility, robustness, and long-term effectiveness of the mitigation framework, supporting continuous improvement and sustainable environmental management in RMC plant operations.

4.7.Implementation Plan and Monitoring Framework

The implementation plan and monitoring framework constitute the final and most critical stage of the Environmental Risk Assessment (ERA) process, ensuring that proposed mitigation measures are effectively translated into routine practice within ready-mix concrete (RMC) plant operations. While risk identification and mitigation design establish a strong foundation, their success depends on systematic execution, accountability, and continuous performance tracking. Given the continuous nature of RMC operations and the cumulative environmental impacts involved, a structured implementation and

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monitoring approach is essential for sustained environmental protection. The implementation plan defines clear roles, responsibilities, timelines, and resource requirements for deploying engineering, administrative, and operational controls. A phased implementation strategy is adopted, prioritizing high- and very high-risk issues such as dust emissions, wastewater management, slurry handling, and noise control, followed by medium-risk measures related to energy efficiency and housekeeping. Integration with an Environmental Management System (EMS) aligned with ISO 14001 ensures consistency through the Plan–Do–Check–Act cycle. The monitoring framework establishes measurable indicators for air, water, noise, soil, energy, and waste performance, supported by routine inspections, audits, and data analysis. Performance metrics are compared against baseline values to evaluate improvement. Deviations trigger corrective and preventive actions, while documentation and management review support continual improvement. Together, the implementation plan and monitoring framework ensure accountability, regulatory compliance, and long-term environmental sustainability in RMC plant operations.

Table 14 **Environmental Monitoring Indicators and Performance Parameters**

Environmental Aspect	Monitoring Indicator	Unit	Baseline Value	Target Value	Monitoring Method
Air Quality	PM_{10}	µg/m³	210	≤100	Ambient air monitoring
Air Quality	$PM_{2.5}$	µg/m³	95	≤60	Ambient air monitoring
Water Quality	Ph	—	11.2	6.5–8.5	Grab sampling
Water Quality	TSS	mg/L	1,200	≤100	Laboratory analysis
Noise	Sound pressure level	dB(A)	88	≤75	Sound level meter
Soil	Alkalinity	mg/kg	1,480	≤500	Soil testing
Energy	Power consumption	kWh/m³	6.4	≤5.0	Energy meter
Emissions	CO_2 emission	kg/day	1,980	≤1,600	Emission estimation
Waste	Slurry recycling rate	%	65	≥85	Plant records

4.8.Documentation and Reporting

Documentation and reporting form a vital component of the Environmental Risk Assessment (ERA) and environmental management process in ready-mix concrete (RMC) plants. Effective documentation ensures that all environmental findings, risk assessment results, mitigation measures, and performance outcomes are systematically recorded and retained. These records provide verifiable evidence of compliance with environmental regulations, permit conditions, and internal management commitments, while also supporting audits and inspections. Environmental documentation includes baseline data, monitoring results, identified hazards, risk scores, and prioritization outcomes related to air, water, soil, noise, and energy aspects. Mitigation strategies are documented through action plans, standard operating procedures (SOPs), technical manuals, and maintenance records to ensure consistent implementation. Regular environmental reports summarize monitoring results, compliance status, deviations, and corrective actions, and are submitted to management and regulatory authorities as required.

Incident and non-conformance reporting enables root cause analysis and tracking of corrective and preventive actions to closure. Documentation also supports management review by providing structured inputs for evaluating performance trends and improvement opportunities. Overall, systematic documentation and transparent reporting enhance accountability, ensure regulatory compliance, and promote continual environmental improvement in RMC plant operations.

5. Results and Discussion

The Environmental Risk Assessment (ERA) conducted at the selected ready-mix concrete (RMC) plant. The results show that RMC operations generate significant environmental risks related to air pollution, water contamination, noise exposure, soil degradation, and energy consumption. Risk prioritization identified air emissions from material handling and wastewater from concrete wash operations as the most critical concerns. Noise and energy-related impacts were assessed as moderate to high, while soil contamination posed medium but long-term risks. The discussion indicates that these impacts are closely linked to batching, material transfer, and waste handling activities. Evaluation of the proposed mitigation protocols demonstrates a clear reduction in risk levels, confirming that systematic controls, EMS integration, and continuous monitoring significantly improve environmental performance and regulatory compliance.

Conclusion

This study systematically evaluated the environmental risks associated with ready-mix concrete (RMC) plant operations and developed effective mitigation protocols using a structured Environmental Risk Assessment (ERA) framework. Key risks related to air emissions, wastewater and slurry disposal, noise pollution, soil contamination, and energy consumption were identified and prioritized. The findings reveal that particulate matter emissions and wastewater management represent the most critical environmental challenges, while noise and energy-related emissions pose significant long-term sustainability concerns. The proposed mitigation measures demonstrate that integrating engineering, administrative, and operational controls can substantially reduce environmental risks. Incorporation of these controls within an ISO 14001–aligned Environmental Management System ensures consistency, compliance, and continual improvement. Overall, the study confirms that proactive environmental risk management is both feasible and essential for sustainable and responsible RMC plant operations.

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