RESEARCH PAPER

ASSESSMENT OF ENVIRONMENTAL RISKS ASSOCIATED WITH METRO RAIL CONSTRUCTION ACTIVITIES

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ABSTRACT

The rapid urbanization of India and the rising demand for public transportation are directly responsible for the expansion of metro rail networks in key cities across the country. Metro rail projects are a crucial component of sustainable urban transportation because they have the potential to reduce operating-related traffic congestion, fuel consumption, and greenhouse gas emissions. However, their building operations may pose significant environmental risks. The current study examines the potential environmental risks posed by the construction of metro rail lines in India. The primary areas of investigation are traffic, worker health and safety, air, noise, vibration, water, and construction and demolition waste. To conduct a qualitative environmental risk assessment, the study used secondary data gathered from research papers, EIA reports, government publications, and metro rail project documents. Potential environmental dangers were listed, evaluated, and categorized using a risk assessment matrix based on the severity of the effect and likelihood of occurrence. During the construction period, the most significant environmental issues found to be dust from excavation and material handling, construction noise, traffic congestion, and improper waste management. The research's findings also point to the possibility of having an impact on nearby neighborhoods, public services, natural resources, and construction workers. Methods for reducing dust, noise barriers, environmentally friendly waste management, traffic management strategies, ongoing environmental monitoring, and strict adherence to environmental regulations are all included as additional mitigation strategies. The findings of this study may be helpful to policymakers, metro rail authorities, urban planners, and construction agencies in their efforts to encourage sustainable infrastructure development and reduce environmental impacts. In terms of ecologically responsible design and implementation, the proposed framework could be helpful for future metro rail construction projects in India.

Keywords: *Metro Rail Construction, Environmental Risk Assessment, Sustainable Infrastructure, Air Pollution, Noise Pollution, Environmental Impact Assessment (EIA)*

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I. INTRODUCTION

In 2014, India produced 3202 Mt of CO2 equivalents, or 6.55 percent of the world's total greenhouse gas emissions. As stated in its quantitative Intended Nationally Determined Contributions (INDC) targets, India intends to reduce its greenhouse gas emission intensity relative to GDP by 33–35% by 2030 from 2005 levels in order to fulfill the global greenhouse gas mitigation objectives outlined in the Paris Agreement. Road transportation accounts for nearly 88% of India's greenhouse gas emissions, accounting for 13% of the sector's overall contribution. In light of the ongoing rise in travel demand, achieving emissions reductions necessary to meet INDC goals will be extremely challenging unless robust, long-term mitigation measures are implemented. Within this framework, metro rail projects are leading green transportation policy efforts in India to reduce emissions from urban transportation. However, building and operating a metro line comes with financial costs, GHG emissions, and energy consumption issues. The number of passengers, the carbon intensity of the power used, and the power requirement of the trains and stops all play a role in how well rail systems can reduce emissions. Therefore, having a comprehensive and differentiated understanding of the patterns and factors influencing the environmental consequences of metro rails throughout their lifespan is essential to achieving the government's emissions reduction goals. LCA is still in its infancy on metro rails, despite its increasing use on HSRs and commuter trains. Only a small number of LCA studies have conducted comprehensive life cycle assessments of the environmental impacts of metro rail transit. Although some of them have conducted life cycle assessments of the slab tracks and trains, they have not taken into account the environmental costs of constructing and maintaining energy- and material-intensive metro stations, power distribution systems, and infrastructure renewal and upkeep. Additionally, the majority of previous research on the environmental performance of metro rails centered on just one or two environmental effect categories, such as embodied energy or greenhouse gas emissions. In a few recent studies, the greenhouse gas emissions from India's metro rail projects were calculated. Despite this, a recent assessment of embodied emissions of rail infrastructure demonstrates that a comprehensive life cycle assessment (LCA) of metro rails in India has not been carried out. These effect categories have not yet been utilized in any other study to evaluate the life cycle environmental performance of the UGM rail transport system in India. The intended outcomes of this study are more environmentally conscious city planning and improved decision-making in the MMR. The foundation for subsequent research on India's metro rail system is established by this study. The standardized environmental effects per PKT and per TKM, which are also provided, can be used to estimate current and potential metro rail projects in India. While building metro rail will have social and environmental benefits in the long run, there are numerous short-term but significant environmental concerns that must be taken into consideration. Particulate matter (PM 2.5 and PM 10) is released in large quantities by massive construction activities like digging, tunneling, piling, mixing concrete, and transporting materials. Dust pollution as a result worsens air quality and puts residents' and construction workers' respiratory health at risk. Heavy machinery like excavators, piling rigs, cranes, compressors, and trucks are frequently used in residential areas, schools, and hospitals, all of which are particularly susceptible to the negative health effects of excessive noise and vibration. Traffic jams, longer travel times, higher fuel costs, and emissions from automobiles caused by heavy construction equipment, temporary road closures, and traffic diversion routes also have an impact on public convenience and urban mobility. Construction and demolition (C&D) waste, which includes excavated soil, concrete rubble, steel scrap, lumber, and packaging materials, can degrade land, obstruct drainage systems, and pollute the environment if it is not properly managed. C&D waste is generated by metro rail projects. Additionally, lubricants, cement slurry, construction chemicals, and fuels that may have leaked accidentally may have contaminated surface and groundwater resources, posing long-term risks to human health and the environment. A few of the numerous occupational hazards that construction workers face on the job include dust inhalation, operating heavy machinery, electrical risks, falling from great heights, and accidents involving confined spaces [1, 2] Therefore, worker safety must be a top priority for sustainable construction management to be effective. As a result of an increase in the incidence of respiratory diseases, cardiovascular diseases, stress-related illnesses, eye irritability, and skin allergies brought on by these environmental and occupational hazards, populations residing close to construction corridors may experience a decline in quality of life. Systematic environmental risk assessments, ongoing project monitoring, and appropriate mitigation measures are essential for ensuring the sustainable expansion of India's metro rail infrastructure while minimizing adverse environmental effects.

A. Objectives of the Study

- The primary objective is to discover the environmental risks associated with building the metro train. This includes determining how building operations would impact the noise, water, soil, and air quality of the surrounding area. utilizing a qualitative approach to identify environmental threats. It is necessary to provide appropriate mitigation strategies in order to lessen the negative effects that the construction of the metro line has on the environment.

II. LITERATURE REVIEW

Existing life cycle assessment (LCA) studies have assessed the environmental performance of project-specific high-speed rails (HSR) in the UK (Miyoshi and Givoni, 2014; National Rail, 2009), California (Chang and Kendall, 2011; Chester and Horvath, 2010), China (Jia and Liu, 2022; Liu et al., 2018, 2019, 2021; Wang et al., 2021; Zhou et al., 2023), Japan (International Union of Railways, 2016), Portugal (Jones et al., 2017), Spain (Bueno et al., 2017; Kortazar et al., 2023; Pons et al., 2020), France (de Bortoli et al., 2020) and Texas (Chipindula et al., 2021). Several LCA case studies on commuter rails in different countries have focused on environmental effects (Hanson et al., 2016; Morita and Shibahara, 2013; Shinde et al., 2018; Stripple and Uppenberg, 2010). Del Pero et al. (2015) quantified the environmental impacts of the metro trains (rather than the whole infrastructure) that will operate in Rome, Italy. Saxe et al., 2017 explored how variations in transit-oriented residential density influence the GHG emissions payback period for the Sheppard Subway Line in Toronto, Canada. De Andrade and D'Agosto (2016) studied the energy use and carbon dioxide (CO_2) emission of Rio de Janeiro Metro, Brazil. They also analysed the impact of future electricity mix and vehicle ridership on the payback period of CO_2 emissions. Shanghai metro life cycle GHG emissions were calculated by Li et al. , 2018 and compared with the GHG emissions from other case studies conducted around the world. However, most of the studies focus on assessing the environmental impacts of metro rails, without accounting for access/egress travel in door-to-door trips. There is a major knowledge gap on the contribution of access and egress to metro stations to the environmental impacts of door-to-door trips. Therefore, improved LCA approaches are required to assess the environmental performance of all life cycle stages of the whole metro infrastructure with regard to relevant impact categories. The remainder of the paper is organised as follows. Section 3 details the aim and scope of the study, system boundary, functional units and inventory data used. Section 4 presents the results. Sections on the discussion of results and conclusions.

Table 1. Summary of Previous Studies

Author	**Year**	**Study Area**	**Main Findings**
Del Pero et al.	2015	Italy	Environmental impact of metro trains
Li et al.	2018	Shanghai	Metro construction produces high GHG emissions
Ghate & Qamar	2020	India	Metro reduces operational emissions
Aryan	2023	India	Infrastructure LCA review

et al.			
Liu et al.	2021	China	Environmental impacts of subway construction

A. Research Gap

Environmental management and metro rail life cycle evaluation make up the bulk of the material. Nevertheless, there is a dearth of research that has examined the potential environmental hazards posed by metro rail development in India. Impacts during the construction phase, including dust, noise, vibration, traffic disruption, construction waste, water contamination, occupational health, and community safety, have received comparatively less attention in prior research compared to operational sustainability, energy consumption, and greenhouse gas emissions. The use of systematic risk evaluation approaches to prioritise construction-related risks is also lacking in integrated environmental risk assessment frameworks. Therefore, the purpose of this research is to assess the potential environmental impacts of building metro rail in India and to provide solutions that would allow for the development of such infrastructure in a sustainable manner.

III. METHODOLOGY

A. Research Design

This descriptive and qualitative research examines the effects of the building of metro rail in India on the environment via the lens of an environmental risk assessment. The primary goals of the research are to catalogue all potential environmental risks associated with metro rail construction, rank them in order of severity, and then provide solutions. We identified possible consequences on the physical, biological, and socio-economic environment using a systematic evaluation approach. Analysed were potential threats to the environment using a qualitative risk assessment matrix that took into account both the frequency and severity of potential consequences. The overarching goal of this research is to provide the groundwork for a more sustainable metro rail construction by identifying key environmental hazards and suggesting appropriate mitigation strategies.

B. Study Area

Delhi Metro Rail Project (DMRC)

One of the biggest and most successful urban mass rapid transport systems in India, the Delhi Metro Rail Project (DMRC) served as a reference point for the research. Latitude 28°24′-28°53′ N and longitude 76°50′-77°20′ E are the coordinates of Delhi, the capital of India. It is one of the world's biggest metropolitan regions, with a population of about 20 million and an area of around 1,484 km².

Delhi has a monsoon season, chilly winters, and very scorching summers. Significant environmental concerns, including low air quality, excessive noise levels, and strain on natural resources, have resulted from fast urbanisation, intense traffic congestion, industrial activity, and growing human density.

Both Delhi and the surrounding NCR are served by the Delhi Metro system. It links several types of buildings and areas via at-grade, subterranean, and elevated corridors, including residential, commercial, industrial, institutional, and transit centers. The construction activities, which include digging, tunnelling, piling, and concreting as well as developing stations and relocating utilities, might potentially affect adjacent communities and sensitive environmental receptors including schools, hospitals, parks, bodies of water, and historic buildings.

As a case study of the environmental concerns associated with metro rail construction in India, the Delhi Metro Rail Project is well-suited to examine the effects of such massive infrastructure development in highly populated metropolitan regions.

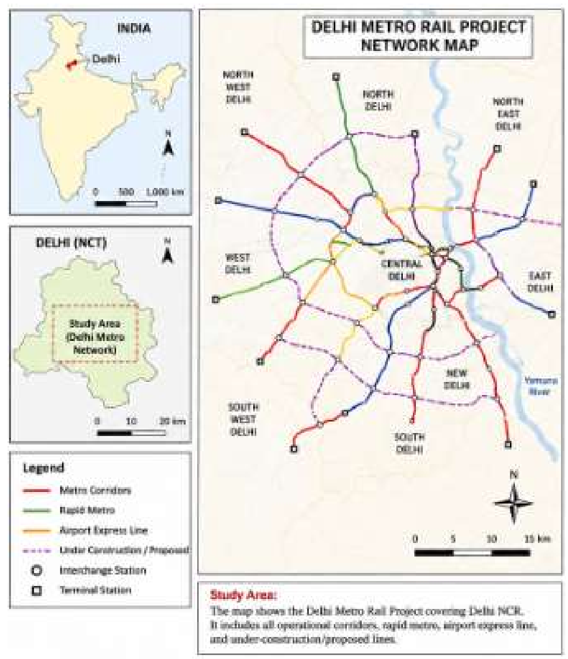

Figure 1 here: Location Map of Delhi Metro Rail Project (DMRC).

C. Data Collection

Data for the research came from a variety of sources, some original and others secondary.

Primary Data

- Taking notes at the metro construction sites, looking at things like dust production, noise levels, traffic jams, and garbage disposal methods. Talking to project managers, environmental experts, and engineers (if relevant)

Secondary Data

- Guidelines have been issued by the Ministry of the Environment, Forests, and Climate Change

(MoEFCC), as have papers presented at conferences, published in journals, and books official documents pertaining to the construction of metro rail and the administration of environmental protection. The Delhi Metro Rail Corporation (DMRC) reports Assessments of Environmental Impact (EIA) documents Publications of the Central Pollution Control Board (CPCB)

D. Environmental Parameters

In its evaluation of the environment, the following factors were taken into account:

- Air Pollutant Levels (PM2.5, PM10, Respiratory Dust) Noise Disturbance Water Purity The contamination of soil.
- Problems with Congestion and Rerouting Traffic Waste from building and tearing down structures Workers' Well-being and Protection on the Job Disruption to the Community and Public Discomfort

Table 2. Environmental Parameters Used

Parameter	**Indicator**	**Source**
Air Quality	$PM_{2.5}$, PM_{10}	CPCB
Noise	dB(A)	CPCB
Water	pH, TSS	EIA
Soil	Contamination	EIA
Waste	Quantity	Site Reports
Traffic	Congestion	Field Observation

E. Environmental Risk Assessment Method

A Likelihood × Severity Risk Matrix, a qualitative tool, was used to assess environmental threats. Both the probability of each environmental danger occurring and the severity of its possible effects were considered. We ranked the risks from least to most severe, using the scale from low to very high.

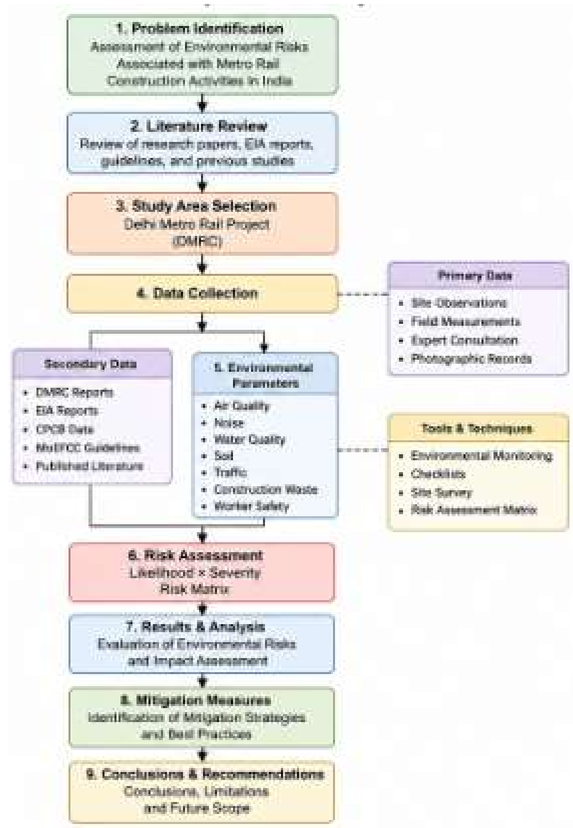

Figure 2: Research Methodology Flow Chart.

IV. RESULTS

A. Air Pollution Assessment

Construction operations, such as digging, drilling, mixing concrete, and transporting building supplies, produced substantial amounts of dust. When the weather was dry, the levels of fine particulate matter (PM2.5 and PM10) rose. Heavy equipment fuelled by diesel and construction trucks further increased the gaseous emissions. Particularly in densely populated areas, the dust that was being produced posed a threat to workers, residents, and commuters.

B. Noise Pollution Assessment

Piling, drilling, operating heavy equipment, and transportation all contributed to elevated noise levels. There may be public health and everyday activity consequences to the increased short-term noise exposure caused by construction sites' closeness to residential, educational, and medical contexts.

C. Traffic Impact Assessment

Due to construction, lane closures, material transportation, and road diversions, the metropolitan area's traffic flow was significantly affected. Vehicle emissions, fuel usage, and travel times were all negatively impacted by congestion.

D. Construction Waste Assessment

A great deal of dirt, broken concrete, discarded steel, wood, packaging and other demolition trash was produced by the building operations. Land damage, drainage system obstruction, and secondary contamination are all possible outcomes of improper disposal.

Figure 3: Construction Waste Management Flow

E. Water Pollution Assessment

Lack of adequate management of runoff posed a threat to local surface and groundwater resources due to the presence of suspended particles, cement slurry, oils, lubricants, and construction chemicals.

F. Occupational Health and Safety Risks

Operating heavy machinery, breathing in dust, being subjected to high levels of noise and vibration, potential electrical dangers, and accidents were all concerns that construction workers had to contend with. Risks to occupational health were reduced by the use of PPE (personal protective equipment), safety training, and workplace monitoring.

G. Environmental Risk Matrix

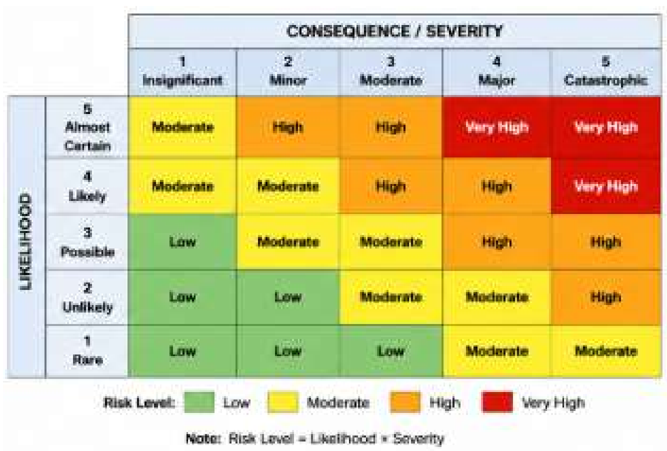

Figure 4: Environmental Risk Matrix

Environmental Hazard	Likelihood	Severity	Risk Level
Dust Emission	High	High	Very High
Noise Pollution	High	Medium	High
Construction Waste	Medium	High	High
Traffic Congestion	High	Medium	High
Water Pollution	Medium	Medium	Moderate
Worker Safety	High	High	Very High
Vibration	Medium	Medium	Moderate

Table 3. Environmental Impacts During Metro Construction

Environmental Component	**Major Impact**	**Risk Level**
Air	Dust	Very High
Noise	Heavy machinery	High
Water	Runoff contamination	Moderate
Soil	Excavation	Moderate
Traffic	Congestion	High
Waste	Debris	High

V. DISCUSSION

Dust emissions and occupational health hazards are the most important environmental dangers associated with metro rail construction operations, according to the study. Construction activities such as excavating, drilling, mixing concrete, and transporting materials significantly raise particulate matter levels, which in turn impact public health and air quality. Prior research on metro rail construction also found that dust and noise pollution were the primary environmental concerns. Congestion and construction debris have a significant influence on urban environmental quality because they cause lane closures, increase car emissions, and lead to incorrect garbage disposal. Due to insufficient control of construction runoff or heavy rainfall, the likelihood of water contamination was minimal. Dust suppression, recycling, noise barriers, traffic management plans, and constant environmental monitoring are some of the efficient environmental management strategies that have been shown to considerably reduce environmental hazards during the building of metro rail.

Figure 5: Dust Suppression and Mitigation Measures

VI. LIMITATIONS AND FUTURE WORK

Secondary sources and qualitative environmental risk assessments form the backbone of this investigation. This analysis may overlook site-specific differences across metro construction projects. Since the Delhi Metro Rail Project is only used as an example in the research, the results may not be generalisable to other Indian metro systems. The capacity to assess cumulative environmental consequences during the whole of the construction phase is further limited by the absence of data from long-term environmental monitoring. Future studies should incorporate field-based environmental monitoring, GIS analysis, remote sensing methods, environmental sensors based on the Internet of Things (IoT), quantitative risk modelling, and life cycle assessment approaches to better understand the environmental risks linked to metro rail construction activities.

VII. CONCLUSION

By alleviating gridlock on city streets, cutting down on the use of fossil fuels, and lowering emissions of greenhouse gases, metro rail systems may play a significant role in fostering sustainable urban mobility. Nevertheless, several environmental consequences, both temporary and severe, requiring meticulous planning and efficient management, are associated with metro rail systems throughout their development phases. With a focus on the Delhi Metro Rail Project, this research aims to identify and evaluate the most pressing environmental concerns raised by the building of metro rail systems in India. The most significant environmental issues that arise during construction, according to the data, are dust emissions, noise pollution, traffic interruption, trash from demolition and construction, and risks to occupational health. Dust production and worker safety were determined to be the most significant risk variables because of the high likelihood of their occurrence and the serious effects they may have on human health and the environment. There has to be continuous monitoring and mitigation of the Moderate Risk implications of water pollution and vibration. Implementing suitable environmental management measures such as noise barriers, dust suppression, waste segregation and recycling, traffic management plans, environmental monitoring, worker safety programs, and strict compliance with environmental regulations can significantly reduce adverse environmental impacts, according to the qualitative environmental risk assessment. In order to construct sustainable infrastructure, the research stresses that environmental risk assessment must be a part of metro rail project planning, design, and implementation. Government agencies, metro rail authorities, engineers, urban planners, and policy makers may all benefit from the suggested assessment methodology, which can aid in the identification of priority environmental concerns and the implementation of effective mitigation methods. To increase the sustainability of future metro rail projects in India and to strike a balance between infrastructure growth and environmental conservation, environmentally responsible building approaches are important.

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