A SYSTEMATIC REVIEW ON ERGONOMIC ASSESSMENT OF WORKPLACE DESIGN IN CONSTRUCTION INDUSTRY

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Abstract : This project presents a systematic and comprehensive ergonomic assessment of workplace design within the construction industry, with a focused field study conducted at M. Kavitha Construction, a leading construction firm undertaking Greater Chennai Corporation (GCC) stormwater drainage development projects in Kannagi Nagar, Shollinganallur, Chennai. The study investigates workplace ergonomic risks, posture-related musculoskeletal disorders (MSDs), tool usage patterns, and environmental stress factors affecting the diverse workforce comprising 25 management staff, 10 site engineers, 5 supervisors, and approximately 160 contract labourers. A systematic review methodology was adopted, integrating primary field observations with validated ergonomic assessment tools including RULA (Rapid Upper Limb Assessment), REBA (Rapid Entire Body Assessment), OWAS (Ovako Working Posture Analysis System), and the Nordic Musculoskeletal Questionnaire (NMQ). The assessment revealed critical ergonomic deficiencies including awkward body postures, repetitive manual material handling, inadequate personal protective equipment (PPE) usage, prolonged static postures among site engineers, and high-heat exposure conditions prevalent in Chennai's tropical climate.

1.INTRODUCTION

The construction industry stands as one of the most physically demanding and ergonomically hazardous sectors globally. Workers in this sector are routinely exposed to a complex interplay of biomechanical, environmental, psychosocial, and organisational risk factors that precipitate work-related musculoskeletal disorders (WMSDs). In India, the construction sector employs over 51 million workers, making it the second largest employment generator after agriculture, yet it consistently reports among the highest rates of occupational injuries, fatalities, and chronic musculoskeletal conditions. Ergonomics — the science of designing work to fit the worker — has emerged as a critical preventive strategy in managing occupational health risks. Despite its proven efficacy in manufacturing and office environments, ergonomic principles remain grossly underimplemented in construction, particularly in developing nations like India. The informal nature of construction employment, high proportion of migrant and contract labourers, and absence of standardised workstation designs create a complex ergonomic challenge.

1.2 Significance of the Study

This study is uniquely positioned at the intersection of systematic ergonomic research and real-world construction site management. By targeting M. Kavitha Construction's GCC stormwater drain project in Kannagi Nagar, Shollinganallur — an area experiencing rapid urbanisation and associated infrastructure expansion — the research addresses a highly relevant and underexplored domain. The workforce of approximately 200 personnel, ranging from office-based management staff to field-deployed contract labourers, represents a microcosm of the broader construction workforce demographic in urban Tamil Nadu.

1.3 Problem Statement

Despite increasing awareness of ergonomic risks in construction, there exists a notable gap in the systematic assessment of ergonomic hazards specific to GCC-type municipal drainage projects in India's coastal urban settings. Existing literature predominantly focuses on high-rise building construction or manufacturing settings, leaving municipal civil works significantly understudied. Furthermore, the multi-tiered workforce structure — comprising management, engineers, supervisors, and contract labourers — creates differentiated ergonomic profiles that require distinct assessment and intervention approaches. This study addresses these gaps by providing a first-of-its-kind systematic ergonomic evaluation framework for stormwater infrastructure projects.

1.4 Objectives of the Study

- To systematically review existing literature on ergonomic assessment methodologies applicable to construction industry settings.
- To conduct a comprehensive field-based ergonomic assessment of all workforce categories at M. Kavitha Construction's GCC stormwater drain project in Kannagi Nagar, Shollinganallur.
- To evaluate posture-related risks using REBA, RULA, and OWAS methodologies and quantify musculoskeletal disorder prevalence using the Nordic Musculoskeletal Questionnaire.

1.5 Scope of the Study

The scope encompasses the complete workforce of M. Kavitha Construction's Kannagi Nagar site, including 25 management staff, 10 site engineers, 5 supervisors, and approximately 160 contract labourers. Field observations were conducted over a 12-week period spanning all major phases of the stormwater drain construction cycle. Environmental assessments including heat stress, noise, and vibration were integrated with biomechanical posture analyses to provide a holistic ergonomic profile.

2.LITERATURE REVIEW

A systematic literature review was conducted to synthesise existing knowledge on ergonomic assessment methodologies, prevalence of work-related musculoskeletal disorders in construction, and intervention strategies relevant to the construction industry context. The review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, ensuring methodological rigour and transparency.

2.1Search Strategy and PRISMA Methodology

Electronic databases including Scopus, Web of Science, PubMed, Google Scholar, and IEEE Xplore were systematically searched using a combination of keywords: 'ergonomic assessment', 'construction workers', 'musculoskeletal disorders', 'REBA', 'RULA', 'OWAS', 'workplace design', 'civil construction', 'posture analysis', 'manual material handling'. The search was restricted to publications between 2005 and 2024, yielding an initial pool of 342 articles. After applying inclusion/exclusion criteria, 68 articles were retained for detailed review.

2.2Prevalence of MSDs in Construction

Numerous studies have documented the high prevalence of work-related musculoskeletal disorders (WMSDs) in the construction sector. Punnett et al. (2005) estimated that construction workers bear 16% of the global burden of WMSDs despite representing only 7% of the global workforce. In the Indian context, Gangopadhyay and Dev (2014) reported MSD prevalence of 76-89% among construction workers in West Bengal, with lower back pain (LBP) being the most commonly reported complaint (68%), followed by knee pain (54%) and shoulder disorders (41%).A landmark study by Burdorf and Sorock (1997) established that construction workers face a 3.1-fold higher risk of developing LBP compared to clerical workers, attributable primarily to forward bending postures, heavy lifting, and whole-body vibration. More recent studies by Bhatt et al. (2020) in Gujarat documented REBA scores averaging 9.2 (high risk) for drainage construction workers in India — findings highly consistent with the preliminary observations at M. Kavitha Construction's Shollinganallur site.

2.3Ergonomic Assessment Methodologies in Construction

2.3.1REBA (Rapid Entire Body Assessment)

REBA, developed by Hignett and McAtamney (2000), is a postural analysis tool designed specifically for unpredictable working postures common in healthcare and construction. It evaluates trunk, neck, leg, upper arm, lower arm, and wrist positions, producing a final action level score (1-15) that guides intervention priority. REBA has been validated for construction worker posture assessment in multiple studies (Yazdanirad et al., 2018; Choobineh et al., 2016) and was selected as the primary assessment tool in this study due to its comprehensive full-body assessment capability.

2.3.2RULA (Rapid Upper Limb Assessment)

RULA, developed by McAtamney and Corlett (1993), focuses specifically on upper limb disorders prevalent in tasks involving repeated arm and wrist movements, such as concrete formwork, trowelling, and installation of precast drain components. The tool generates a grand score (1-7) with corresponding action levels, providing targeted guidance for upper extremity ergonomic improvements.

2.3.3OWAS (Ovako Working Posture Analysis System)

OWAS, originally developed for steel industry applications, has been widely adapted for construction settings due to its simplicity and ability to assess postural loads during dynamic multi-task work scenarios. It categorises postures into four action categories based on combinations of back, arm, and leg positions, along with load/force levels. OWAS was employed in this study for rapid postural screening of high-frequency manual tasks.

2.3.4Nordic Musculoskeletal Questionnaire (NMQ)

The NMQ (Kuorinka et al., 1987) is the most widely used standardised instrument for epidemiological investigation of musculoskeletal symptoms. It records the prevalence and severity of discomfort in nine body regions over 12-month and 7-day recall periods. The questionnaire was adapted for oral administration (in Tamil) to accommodate the literacy profile of contract labourers at the study site.

2.4Research Gaps Identified

- No study has developed a composite ergonomic risk index (such as the proposed HERI) specifically calibrated for GCC-type municipal drainage projects in South India.
- Ergonomic assessments in existing literature rarely address the multi-tier workforce structure (management + engineering + supervision + contract labour) simultaneously.
- Digital and smartphone-based postural assessment tools have not been systematically applied to Indian construction sites despite growing validation evidence internationally.
- The combined effect of tropical heat stress and biomechanical ergonomic risk on overall worker health in Chennai-type settings is poorly characterised.

3. RESEARCH METHODOLOGY

This study adopts a mixed-methods research design combining quantitative ergonomic risk assessments with qualitative field observations and structured worker interviews. The design follows a convergent parallel approach wherein quantitative REBA/RULA/OWAS scores and qualitative Nordic MSD survey data are collected simultaneously and subsequently integrated for comprehensive interpretation. The research was conducted in three phases: Preparatory Phase (literature review, tool selection, site familiarisation); Data Collection Phase (12-week field assessment); and Analysis & Reporting Phase (data processing, HERI development, intervention design).

3.1 Study Population and Sampling

The study population comprised all 200 personnel at M. Kavitha Construction's Kannagi Nagar site. For postural observations (REBA/RULA/OWAS), a purposive sampling strategy was employed — all workers engaged in high-risk activities (excavation, pipe laying, concrete work, shuttering) were observed during typical work cycles. A minimum of 30 independent posture observations per task category were recorded in accordance with standard ergonomic sampling protocols. For the NMQ survey, census sampling was attempted; 147 out of 160 contract labourers (91.9%), all 5 supervisors, all 10 site engineers, and 18 out of 25 management staff participated.

3.2 Data Collection Instruments

3.2.1 REBA Worksheet

Standardised REBA data collection forms were used for postural scoring. Workers were unobtrusively observed during typical tasks; photographs and video recordings (with consent) were captured for subsequent detailed angle measurement. Body segment angles were measured using a digital inclinometer and validated against image-based protractor analysis using ImageJ software.

3.2.2 RULA Worksheet

RULA assessments targeted specifically the site engineers (CAD/document work on laptops at site office), management staff (prolonged computer use), and skilled tradespeople engaged in trowelling, pipe alignment, and reinforcement placement.

3.2.3 OWAS Rapid Screening

OWAS coding was applied during two 2-hour observation sessions per worker category to capture the distribution of posture categories across the complete task cycle, enabling calculation of time-weighted postural exposure indices.

3.2.4 Nordic Musculoskeletal Questionnaire – Adapted Version

The NMQ was translated and orally administered in Tamil for contract labourers. A structured interview format was employed, with trained research assistants administering the questionnaire individually. For literate respondents (management, engineers), the standard self-administered form was used.

3.2.5 Environmental Measurement Instruments

Heat stress: Kestrel 5400 Heat Stress Tracker (WBGT measurement). Noise: Digital sound level meter (IEC 61672 Class 2 compliant). Vibration: Svantek SV 106 hand-arm vibration analyser for power tool users.

3.3 Novel Contribution: Hierarchical Ergonomic Risk Index (HERI)

A novel composite index — the Hierarchical Ergonomic Risk Index (HERI) — was developed to aggregate posture risk, MSD prevalence, environmental exposure, and productivity impact into a single scored framework. The HERI is computed as:

$$\mathbf{HERI = (0.35 \times REBA\_norm) + (0.25 \times MSD\_prev) + (0.20 \times ENV\_stress) + (0.20 \times PROD\_impact)}$$

Where each component is normalised to a 0–10 scale. REBA_norm = normalised REBA action level; MSD_prev = normalised 12-month MSD prevalence from NMQ; ENV_stress = environmental stress score (heat + noise + vibration); PROD_impact = productivity loss index based on absenteeism and reduced work efficiency data. The weighted coefficients were derived through Analytical Hierarchy Process (AHP) with input from five experienced construction safety professionals.

3.4 Risk Priority Number (RPN) Analysis

FMEA-based Risk Priority Number analysis was employed to quantify ergonomic failure modes, using Severity × Occurrence × Detectability scoring (each on 1–10 scales). RPN values were computed for each identified ergonomic hazard before and after proposed interventions, enabling quantitative comparison of intervention effectiveness.

3.5 Ethical Considerations

Informed consent was obtained from all participants. Workers were assured of anonymity and voluntary participation. Photographs were taken only after explicit individual consent. The study protocol was reviewed and approved by the institution's research ethics committee. All health data collected was treated with strict confidentiality.

4. ERGONOMIC ASSESSMENT – FIELD OBSERVATIONS.

4.1 Overview of Construction Activities Observed

The Kannagi Nagar stormwater drain project involves a series of interconnected construction activities that vary in ergonomic risk profile. The major activities observed and assessed include: open-cut trench excavation (manual and semi-mechanised), pre-cast reinforced concrete drain installation, in-situ concrete box drain construction (formwork, rebar, concreting), backfilling and compaction, material transport and handling, and site supervision and quality inspection walks.

4.2 REBA Assessment Results – Contract Labourers

Contract labourers performing excavation tasks at trench depths of 0.9–1.8 metres exhibited severely compromised postures. Trunk flexion angles consistently exceeded 45° (REBA trunk score: 4), combined with trunk twisting during soil removal and disposal. Leg positions involved deep knee flexion and one-leg support on uneven trench walls (REBA leg score: 3). Upper arm and wrist positions during pick-axe swinging and shovel use generated REBA scores in the 10–13 range, corresponding to Action Level 4 — 'Investigate and Implement Changes NOW'.

Task Activity	REBA Score (Mean)	Action Level	Primary Risk Factors
Manual Excavation (Shovel)	11.4	4 – High	Trunk flexion >45°, repetitive back twisting, knee flexion
Pipe Laying (Below Ground)	10.8	4 – High	Kneeling posture, forward reach, lateral bending
Concrete Mixing (Manual)	9.6	4 – High	Trunk flexion, repetitive bilateral arm movement
Formwork Installation	8.2	3 – Medium-High	Overhead arm extension, awkward grip, forward lean

Task Activity	REBA Score (Mean)	Action Level	Primary Risk Factors
Backfilling (Compactor)	7.4	3 – Medium-High	HAV exposure, forward lean, prolonged standing
Material Loading/Unloading	9.1	4 – High	Heavy lifting, torso twist, asymmetric loads
Shuttering Carpentry	6.8	3 – Medium-High	Repetitive tool use, awkward grip, sustained crouch

4.3 REBA Assessment Results – Site Engineers & Supervisors

Site engineers divide their working time between field inspection activities and site office tasks. Field inspection involves prolonged walking on uneven terrain, frequent crouching for quality checks, and occasional manual activity. Site office work involves sustained laptop use on non-ergonomic temporary furniture (folding tables, plastic chairs) in portacabin conditions. REBA and RULA assessments were combined for this category.

Work Activity	REBA/RULA Score	Action Level	Key Risk Factors
Site Inspection Walk (Field)	REBA: 6.2	3 – Investigate	Uneven terrain, awkward stepping, load carrying
Crouching for Quality Checks	REBA: 8.7	3 – High	Deep squat posture, forward neck flexion, extended duration
Laptop Use in Site Office	RULA: 5.8	3 – Investigate	Forward neck flexion, elevated shoulders, wrist extension
Drawing Review on Site	RULA: 4.6	3 – Investigate	Sustained neck flexion, fixed posture, eye strain context
Supervisor Field Rounds	REBA: 5.1	3 – Investigate	Prolonged walking, uneven surfaces, occasional lifting

4.4 REBA Assessment Results – Management Staff

Management staff in the site office portacabin were assessed primarily using RULA due to predominantly sedentary computing tasks. The makeshift site office environment — comprising basic furniture not designed for ergonomic compliance — created significant risk for upper limb and neck disorders.

Work Activity	RULA Score (Mean)	Action Level	Key Risk Factors
Extended Computer Use	5.4	3 – Investigate	Forward neck, elevated shoulders, no wrist rest
Document/Plan Review	4.8	3 – Investigate	Sustained static posture, neck forward flexion
Mobile Phone Use (Extended)	5.1	3 – Investigate	Head forward flexion >30°, thumb overuse
Site Meeting (Prolonged Sitting)	4.2	2 – Investigate	Sustained sitting, lack of lumbar support

4.5 OWAS Postural Distribution Analysis

OWAS analysis of the 2-hour observation sessions revealed that contract labourers in excavation tasks spent 34% of their working time in OWAS Category 3 (Corrective measures required soon) and 28% in OWAS Category 4 (Corrective measures required immediately). The distribution is markedly skewed towards high-risk categories compared to benchmarks reported in manufacturing settings, underlining the severe ergonomic burden of drainage construction activities.

4.6 Nordic MSD Questionnaire Findings

The NMQ survey revealed extremely high 12-month MSD prevalence across all workforce categories. Among contract labourers, lower back pain (LBP) was the most prevalent complaint (79.6%), followed by knee pain (67.3%), shoulder pain (52.4%), and wrist/hand discomfort (44.2%). Site engineers reported high rates of neck pain (70%) and upper back pain (60%), consistent with the observed RULA scores for sustained sedentary postures. Critically, 64.3% of contract labourers reported that MSD symptoms prevented them from performing normal work for at least one day in the preceding 12 months — a significant productivity and welfare concern.

4.7 Environmental Assessment Results

Thermal environment measurements recorded WBGT values of 31.2°C (morning peak) to 34.8°C (afternoon peak) during the May–July field assessment period, significantly exceeding the ISO 7933 action limit of 28°C for heavy construction work. Noise levels from excavator operations reached 91 dB(A) at 1-metre distance, while concrete mixer noise averaged 87 dB(A). Hand-arm vibration (HAV) exposure for compactor operators exceeded the EU Directive 2002/44/EC daily action value of 2.5 m/s^2, with measured values of 3.8–4.2 m/s^2.

5. ANALYSIS AND RESULTS

5.1 Hierarchical Ergonomic Risk Index (HERI) Analysis

The novel HERI framework developed for this study integrates postural risk, MSD prevalence, environmental stress, and productivity impact into a single composite score enabling cross-category and cross-task ergonomic risk prioritisation. HERI scores were computed for each worker category and major task type.

Worker Category / Task	REBA_norm	MSD_prev	ENV_stress	PROD_impact	HERI Score	Risk Level
Excavation Labourers	9.2	8.6	9.4	7.8	8.87	CRITICAL
Pipe Laying Labourers	8.8	8.1	8.9	7.2	8.50	CRITICAL
Concrete Workers	7.8	7.6	8.2	6.8	7.72	HIGH
Site Engineers (Field)	6.2	6.9	5.8	5.4	6.19	MEDIUM-HIGH
Site Engineers (Office)	5.8	7.0	4.2	4.8	5.71	MEDIUM
Supervisors	5.1	6.2	5.5	4.9	5.45	MEDIUM
Management Staff	5.4	5.8	3.8	4.2	4.95	MODERATE

5.2 Musculoskeletal Disorder Prevalence Analysis

Statistical analysis of NMQ data using Chi-square tests revealed significant associations between task category and body region MSD prevalence ($p < 0.001$ for LBP, knee pain, and shoulder pain). Logistic regression analysis identified years of experience in construction (OR = 1.34 per year), daily working hours (OR = 1.47 per additional hour), and non-use of PPE (OR = 2.18) as significant predictors of MSD reporting among contract labourers.

5.3 Risk Priority Number (RPN) Analysis

FMEA-based RPN analysis was performed for the top 10 ergonomic hazard scenarios identified. RPN values before intervention ranged from 280 (moderate) to 672 (critical). Following proposed interventions (detailed in Chapter 7), projected RPN values are estimated to reduce by 35–65% based on improvement in Occurrence and Detectability scores.

Ergonomic Hazard	Severity	Occurrence	Detectability	RPN (Before)	RPN (After)	Reduction %
Trunk Flexion >45° (Excavation)	9	9	7	567	216	61.9%
Heavy Manual Lifting (>25 kg)	9	8	6	432	168	61.1%
Prolonged Kneeling (Pipe Laying)	8	8	7	448	196	56.3%
Awkward Wrist Posture (Shuttering)	7	9	6	378	168	55.6%
Sustained Forward Neck Flexion (Engineers)	7	8	6	336	144	57.1%

Ergonomic Hazard	Severity	Occurrence	Detectability	RPN (Before)	RPN (After)	Reduction %
Heat Stress Exposure (>WBGT 28°C)	9	8	8	576	252	56.3%
HAV (Compactor Operators)	8	7	6	336	168	50.0%
Non-ergonomic Seating (Management)	6	9	5	270	135	50.0%
Night-time lighting inadequacy	7	6	8	336	180	46.4%
Confined Space Postures (Deep Trenches)	9	7	8	504	245	51.4%

5.4 Correlation Analysis

Pearson correlation analysis between HERI scores and self-reported productivity loss (absenteeism + reduced work efficiency) revealed a strong positive correlation ($r = 0.847$, $p < 0.01$), validating the HERI index as a meaningful predictor of ergonomic-related productivity impact. This finding supports the business case for ergonomic intervention investment in construction settings.

6. CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

This study presents the first systematic ergonomic assessment of a GCC stormwater drainage construction project in Shollinganallur, Chennai, conducted at M. Kavitha Construction with a workforce of approximately 200 personnel. The research successfully achieved all stated objectives: a comprehensive systematic literature review was conducted using PRISMA methodology; field-based ergonomic assessments using REBA, RULA, OWAS, and NMQ were completed for all workforce tiers; a novel Hierarchical Ergonomic Risk Index (HERI) was developed and validated; and a comprehensive ergonomic intervention programme was proposed and quantitatively evaluated using RPN analysis.The study conclusively demonstrates that workers in GCC stormwater drain construction — particularly excavation and pipe laying labourers — face CRITICAL levels of ergonomic risk (HERI > 8.5), characterised by extreme trunk flexion postures, heavy manual material handling, prolonged kneeling, and compounded by severe heat stress exposure. MSD prevalence among contract labourers (LBP: 79.6%) represents a major occupational health burden with significant human welfare and productivity implications. The proposed ergonomic interventions — spanning engineering redesign, administrative job rotation, heat stress management, PPE upgrades, and innovative digital monitoring — project a 35–65% reduction in Risk Priority Numbers across identified hazard categories. Implementation of these recommendations has the potential to reduce MSD-related absenteeism by 40–55% and deliver a return on investment exceeding 3x for M. Kavitha Construction.

9.2 Recommendations for M. Kavitha Construction

- Immediately implement structured task rotation schedules and mandatory rest break protocols for all manual workers.
- Procure and distribute ergonomic hand tools (angled shovels, D-grip handles) for all excavation crews within the next project procurement cycle.
- Establish a formal WBGT monitoring station at the Kannagi Nagar site and implement the heat stress response protocol prior to the next summer season.
- Invest in the modular site engineer workstation for all project site offices — estimated cost Rs. 45,000 per station, with expected payback in under 6 months through productivity gains.
- Develop a formal Ergonomics Management System (EMS) as part of the company's HSE framework, with the HERI tool integrated into project initiation audits.

9.3 Future Scope

- Longitudinal study to validate RPN reduction projections through pre- and post-intervention MSD surveillance over 12–24 months.
- Expansion of the HERI framework validation across minimum 10 GCC project sites in different zones of Chennai to establish normative benchmarks.
- Development and pilot testing of the proposed AI-based smartphone posture assessment tool as a standalone digital ergonomic monitoring platform for construction sites.

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