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RISK IDENTIFICATION AND MITIGATION STRATEGIES FOR WORKERS IN VEHICLE WASHING OPERATIONS

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ABSTRACT

This study identifies and evaluates occupational health and safety risks faced by workers in vehicle washing operations in Mataram, Nusa Tenggara Barat, focusing on motorcycle and car wash services. Through observational studies conducted on April 6, 2025, key hazards were identified, including musculoskeletal disorders (MSDs) from non-ergonomic postures, chemical exposure from soap, slipping on wet floors, and noise from compressors. The Rapid Entire Body Assessment (REBA) method revealed high ergonomic risks, with REBA scores of 10 for both motorcycle and car wash workers, indicating a significant risk of MSDs due to prolonged bending and repetitive motions. Bowtie Analysis further mapped causes, consequences, and control measures, emphasizing non-ergonomic postures and chemical hazards as primary concerns. Preventive strategies, such as ergonomic training, long-handled tools, and personal protective equipment (PPE), were proposed to mitigate risks. The findings align with global studies reporting high MSD prevalence among sanitation workers, underscoring the need for ergonomic interventions and safety protocols. This study contributes to the literature by offering tailored risk mitigation strategies for the vehicle washing industry, advocating for enhanced worker safety, improved productivity, and reduced occupational health risks through comprehensive risk management and ergonomic solutions.

Keywords: *Musculoskeletal disorders (MSDs), Ergonomic risks, Vehicle washing operations, Rapid Entire Body Assessment (REBA), Bowtie analysis*

1. Introduction

The vehicle washing industry, encompassing both motorcycle and car cleaning services, plays a vital role in maintaining the aesthetics and functionality of vehicles. This sector includes various operations, such as automatic car washes, manual hand washing, and detailing services, which are prevalent in urban areas. Despite its importance, the industry is often overlooked in terms of occupational health and safety, leading to potential risks for workers [1]. the Occupational Safety and Health Administration (OSHA) recommends hazard prevention and control strategies to protect workers from workplace hazards and minimize safety and health risks [2]. By adopting these measures, vehicle washing operations can enhance worker safety and health, leading to improved productivity and reduced absenteeism.

Musculoskeletal disorders (MSDs) among workers in vehicle washing and related sectors, highlighting the prevalence and ergonomic risks associated with these occupations. A systematic review and meta-analysis by Tolera et al., (2024) found that 40.52% of sanitation workers globally reported MSDs, with solid waste collectors exhibiting the highest prevalence at 45.12% . Similarly, a study by

Jin et al., (2025) on vehicle assembly workers reported significant reductions in MSD symptoms following a one-year ergonomic intervention, including training and workstation adjustments. About 66.5% of automotive industry workers experienced low back disorders, while 58% reported neck and shoulder issues [5].

A total of 228 studies from 23 countries were reviewed, with 51 studies eligible for assessing occupational health and safety outcomes among sanitary workers. Respiratory problems were the most common health issue, representing 52% of the findings, followed by gastroenteritis at 27%. Of the 8,962 workers, 4,742 (54%) were sewage workers, 1,714 (19%) were street sweepers, and 1,441 (16%) were solid waste collectors, with sewage workers making up the majority of the health and safety outcomes [6].

The study identified several predictors for injuries among sanitation workers, such as age (OR: 22.57), education level (OR: 2.22), job experience (OR: 1.92), and behavioral factors like smoking (OR: 2.6), sleep disturbances (OR: 2.57), and lack of personal protective equipment (OR: 2.62). Additionally, socio-demographic factors like education (OR: 6.73), age (OR: 7.56), and job experience (OR: 10.79), along with work conditions such as working over 8 hours (OR: 3.5) and time pressure (OR: 3.25), significantly contributed to MSDs [7].

A study on cleaners, which can be extrapolated to vehicle washers due to similar physical demands, found a high prevalence of MSDs, with 81.98% of workers experiencing symptoms in the past week and 84.86% in the past year. Factors contributing to MSDs include prolonged exertion, repetitive movements, and poor posture during work tasks [8], [9]. Workers in vehicle washing and lubricating activities face significant mechanical risks, including exposure to chemicals and environmental hazards. These risks can lead to accidents and occupational diseases, highlighting the need for preventive measures [10, 11].

REBA analysis shows that increasing ergonomic awareness and providing training on proper postures can significantly reduce the risk of musculoskeletal disorders (MSDs), especially in industries like vehicle maintenance, where workers may not be aware of the risks. Bowtie analysis, an advanced risk assessment tool, helps visualize the risk map and trace the causes to their potential effects, while also allowing the assignment of controls and tracking of risk control performance [12, 13, 14].

The objective of this study is to identify and assess the risks faced by workers in vehicle washing operations and propose effective mitigation strategies to improve their safety and health. This study seeks to contribute to the existing literature by providing a comprehensive analysis of the specific hazards faced by vehicle wash workers, using methods like REBA and Bowtie Analysis. The novelty of this study lies in its integrated approach to risk identification and mitigation in the vehicle washing sector, combining traditional risk assessment techniques with ergonomic solutions and safety protocols tailored to the specific needs of vehicle wash workers.

The study intends to fill the gap in the literature regarding effective risk management strategies for this under-explored industry. The scope of the study includes an in-depth examination of both motorcycle and car wash operations, focusing on tasks with the highest potential for injury, and evaluating the practical implications of various risk mitigation strategies in real-world settings.

2. Research Method

2.1. Research Location and Observation of Workers

The first step in the research process involves selecting the research location, which is critical in understanding the context of workplace risks. This includes choosing a specific industry or work environment where the workers' activities and potential hazards are observed in real-time. The research focuses on observational data to gather insights into the workers' tasks, their working conditions, and any hazardous scenarios they may be exposed to.

- Location Selection: The research will focus on a vehicle washing process conducted by worker in Mataram, Nusa Tenggara Barat.

- Observational Study: Researchers will directly observe workers performing their tasks, noting any potentially hazardous activities, interactions with machinery, manual handling, and environmental risks. This real-time data collection helps in understanding the nuances of risk exposure, the safety protocols in place, and worker behavior in different work situations.

2.2. Risk Identification

Risk identification is a critical part of understanding the potential threats to worker safety and health. The following steps are followed to identify and assess the risks in the workplace:

- Identify Hazards: Researchers will observe and identify all hazards that could potentially cause harm to workers. These may include physical, chemical, ergonomic, biological, or environmental hazards.
- Risk Matrix: After identifying the risks, a Risk Matrix will be used to categorize the identified hazards based on their severity and likelihood of occurrence. The Risk Matrix helps to prioritize the risks by categorizing them into four levels:
  - Low Risk: Risks that are unlikely to cause harm or have minimal consequences. These are typically managed with routine procedures.
  - Medium Risk: Risks that could cause moderate harm or disruption but are unlikely to cause significant long-term effects. These require more focused safety measures.
  - High Risk: Risks that have the potential to cause serious injury or harm, requiring immediate action and additional safety protocols.
  - Very High Risk: Risks that are highly likely to result in catastrophic events or significant harm, demanding urgent attention and drastic preventive measures.

2.3. REBA Analysis

The REBA (Rapid Entire Body Assessment) analysis is a tool used to assess ergonomic risks associated with work-related tasks. It focuses on body posture, repetitive movements, and manual handling tasks. The steps in conducting a REBA analysis include [14, 15, 16]:

- Step 1: Identify the Task
  The first step involves observing and identifying the specific tasks performed by workers, particularly those involving awkward postures, repetitive motions, or manual handling of loads.
- Step 2: Evaluate Posture
  In this step, the body postures of the worker during the task are evaluated. This includes assessing the angles of the joints (neck, back, arms, etc.) and the overall body position while performing the task.
- Step 3: Assess Force
  Researchers observe the amount of force exerted by the worker in carrying out the task, such as lifting, pushing, or pulling objects.
- Step 4: Evaluate Repetition
  The frequency of the task is assessed, considering how often the worker performs the same motion or action over a period.
- Step 5: Risk Scoring
  A numerical score is assigned based on the posture, force, and repetition observed. The higher the score, the greater the risk for musculoskeletal disorders (MSDs).
- Step 6: Risk Action Level
  The final score helps classify the risk level for the worker. If the score is high, immediate corrective actions (such as changing postures or redesigning the workstation) are required.

2.4. Bowtie Analysis

Bowtie analysis is a risk management technique that visualizes the relationships between causes, top events, consequences, and control measures. It is often used to assess complex safety risks. The steps for conducting Bowtie analysis are as follows [17, 18]:

- Step 1: Identify the Top Event
  The "Top Event" is the central event or hazard that leads to the risk. It represents a critical failure point, such as an accident, equipment malfunction, or exposure to harmful substances. Identifying the top event is crucial because it serves as the starting point for analyzing risk.
- Step 2: Identify Causes
  The next step is to identify the causes that lead to the occurrence of the top event. These could be unsafe conditions, human error, or equipment failure. Each cause is mapped to show how it leads to the top event.
- Step 3: Identify Consequences
  Once the top event is identified, the potential consequences are outlined. This includes the direct and indirect outcomes of the event. Consequences may range from minor injuries to catastrophic damage to the environment or loss of life.
- Step 4: Output (Prevention, Mitigation, and Recovery)
  After identifying the causes and consequences, the next step involves defining preventive, mitigating, and recovery measures:
  - Prevention: These are measures designed to stop the top event from occurring, such as safety training, hazard identification, and maintenance routines.
  - Mitigation: These actions aim to reduce the impact of the top event if it occurs, like emergency response protocols, personal protective equipment (PPE), and safety barriers.
  - Recovery: These are actions taken after an event occurs to restore normal operations, such as medical treatment, disaster recovery plans, and system recovery strategies.
- Step 5: Control Measures and Escalation Factors
  Control measures refer to the actions implemented to reduce or eliminate risk factors. Escalation factors are conditions that could make a situation worse. These factors, such as environmental conditions or lack of training, need to be controlled to prevent a situation from escalating. Controls include:
  - Administrative controls (e.g., procedures, training)
  - Engineering controls (e.g., safety equipment, machine redesigns)
  - Personal protective equipment (e.g., helmets, gloves)

3. Results and Discussions

3.1. Risk Identification

Observations conducted on April 6, 2025, at vehicle washing business in Mataram, Nusa Tenggara Barat, to identified key safety and health risks for motorcycle and car wash workers. The observations, carried out during operational hours (08:00–17:00), focused on work processes, workplace conditions, and worker behavior. For motorcycle wash workers, key risks include slipping on wet floors, skin irritation from soap exposure, musculoskeletal injuries due to non-ergonomic postures, tripping over cables, and exposure to exhaust fumes. High-risk issues, such as skin irritation and musculoskeletal injuries, stem from the lack of personal protective equipment (PPE) like gloves and prolonged awkward postures, such as bending while cleaning undercarriages or wheels. Slipping on wet floors is a medium risk due to its frequent occurrence but relatively minor impact (e.g., minor injuries to hands or feet). Tripping over cables and exhaust fume exposure are low risks due to their low frequency and severity.

For car wash workers, major risks include slipping due to soap spills, musculoskeletal injuries from non-ergonomic postures (especially when cleaning car roofs), noise from compressors, and burns from hot exhaust pipes. Soap spills and musculoskeletal injuries are high-risk due to their frequency and potential for serious injury or long-term muscle strain. Compressor noise poses a medium risk, potentially causing hearing issues if workers are exposed without ear protection. Burns from exhaust pipes are low risk due to infrequent occurrence and minor impact.

Table 1 Vehicle wash workers risk analysis

Job type	Stage	Hazard type/source	Hazard description	Cause	Consequence
Motorcycle Wash	Spraying/rinsing with water	Hose	Slipping on wet floor	Water spreading in work area	Minor injury to hands/feet
	Scrubbing motorcycle body	Chemical (soap)	Skin irritation	No gloves used	Redness/itching skin
	Cleaning undercarriage and wheels	Non-ergonomic posture	Back, knee, or hand pain	Working in a bent position	Long-term muscle injury
	Drying/wiping motorcycle	Drying hose	Tripping over cable	Cable scattered on floor	Minor to moderate injury
	Starting motorcycle	Exhaust fumes	Breathing difficulty from fumes	Poor ventilation	Respiratory irritation
Car Wash	Preparing tools and materials	Chemical (soap)	Soap spills	Unstable storage	Slippery floor, risk of slipping
	Spraying with high-pressure water	Hose	Slipping on wet floor	Water spreading in work area	Minor injury to hands/feet
	Scrubbing car body (including roof)	Non-ergonomic posture, slipping	Muscle pain, injury, or falling	Non-ergonomic work position	Minor to serious muscle injury
	Cleaning wheels	Non-ergonomic posture	Slipping when standing	Non-ergonomic work position	Muscle injury/physical fatigue
	Drying/wiping car with compressor and cloth	Noise	Loud compressor noise	No ear protection used	Hearing disturbance (ringing ears)
	Final inspection	Running engine	Burn from exhaust pipe	Engine not turned off	Minor burn

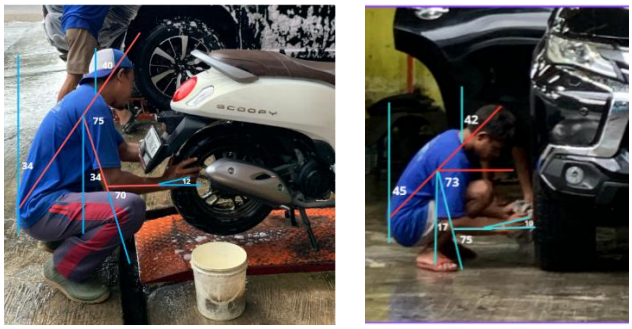
Table 2 Vehicle wash workers risk assessment scores

Job Type	Stage	Risk assessment		
		Frequency	Severity	Risk Level
Motorcycle Wash	Spraying/rinsing with water	3	2	M (6)
	Scrubbing motorcycle body	3	3	H (9)
	Cleaning undercarriage and wheels	3	3	H (9)
	Drying/wiping motorcycle	2	2	L (4)
	Starting motorcycle	1	1	L (1)
Car Wash	Preparing tools and materials	3	3	H (9)
	Spraying with high-pressure water	3	2	M (6)
	Scrubbing car body (including roof)	3	3	H (9)
	Cleaning wheels	3	2	M (6)
	Drying/wiping car with compressor and cloth	2	3	M (6)
	Final inspection	1	1	L (1)

3.2. REBA Analysis

Based on the risk identification results (Table 2), activities with high risk include cleaning the undercarriage and wheels for motorcycle wash workers and scrubbing the car body (including the roof)

for car wash workers. To further validate these findings, the Rapid Entire Body Assessment (REBA) method was applied to evaluate ergonomic risks at two vehicle washing. REBA assesses posture angles of the neck, trunk, legs, upper arms, lower arms, and wrists to determine the risk of musculoskeletal disorders (MSDs). Scores range from 1 to 15, with higher scores indicating greater risk and the need for immediate action.



(a) Motorcycle wash (b) Car wash

Figure 1 Vehicle washing process

For motorcycle wash workers, the REBA score is 10, indicating a high risk of MSDs. Workers adopt a bent posture, with the neck at 40° and trunk at 34°, while upper arms move between 34°–75°. This posture, common when cleaning undercarriages or wheels, strains the lower back, shoulders, and knees. Prolonged bending and repetitive hand movements during scrubbing or wiping increase the risk of long-term muscle pain or injuries, such as lower back pain.

Table 3 REBA score calculation for vehicle wash workers

Body Part	Motorcycle wash		Car wash	
	Angle (°)	Score	Angle (°)	Score
Neck	40°	3	42°	3
Trunk	34°	4	45°	4
Legs	60°	2	60°	2
Upper Arm	34°–75°	4	17°–73°	4
Lower Arm	70°	2	75°	2
Wrist	12°	2	10°	2
Table A		7		7
Table B		6		6
Table C		9 + 1 = 10		9 + 1 = 10

For car wash workers, a REBA score of 10 also indicates high risk. Workers bend their neck at 42° and trunk at 45° while scrubbing car bodies, especially when reaching the roof, which adds strain to the shoulders (upper arms at 17°–73°). Cleaning car roofs heightens the risk of muscle injury and falling. The legs, at a 60° angle, show moderate instability, contributing to fatigue. The lack of ergonomic tools and repetitive motions further elevate MSD risks.

3.3. Bowtie Analysis

Based on the risk identification results, the primary issues lie in: (1) non-ergonomic postures during vehicle washing (motorcycle undercarriage and wheels, and scrubbing car body including the

roof) and (2) chemical hazards from scrubbing the motorcycle body. To further analyze these risks, a Bowtie Analysis was conducted to map the hazards, top events, causes, consequences, output (prevention, mitigation, and recovery) and control measures, including escalation factors and their controls. The table below outlines the Bowtie Analysis for the identified high-risk activities:

Table 4. Bowtie analysis for vehicle washing activities

Activity	Hazard	Top event	Cause	Consequence	Output	Escalation factors	Escalation controls
Cleaning undercarriage and wheels (Motorcycle)	Non-ergonomic posture	Musculoskeletal injury	- Lack of ergonomic tools - Prolonged bending posture - Insufficient training on safe postures	- Chronic back/knee pain - Reduced productivity - Long-term muscle injury	Prevention: Provide ergonomic tools (e.g., long-handled brushes, small stools); conduct training on safe postures; set work time limits. Mitigation: Regular breaks to reduce strain; job rotation to vary tasks. Recovery: Provide first-aid facilities; offer medical rehabilitation; monitor worker health.	- Worker non-compliance with posture training - Limited tool availability	- Enforce SOPs with regular checks - Budget allocation for ergonomic tools
Scrubbing car body including roof (Car)	Non-ergonomic posture	Musculoskeletal injury or fall	- Reaching high areas without stable platforms - Awkward bending/standing posture - Lack of training on safe postures	- Muscle strain - Fall-related injuries (e.g., sprains, fractures) - Reduced productivity	Prevention: Use stable platforms or ladders; train workers on safe postures; ensure two workers for roof cleaning. Mitigation: Limit time spent in awkward postures; provide rest breaks. Recovery: Immediate first-aid for injuries; access to medical care; incident reporting system.	- Inadequate platform maintenance - Worker fatigue	- Regular platform inspections - Mandatory rest schedules
Scrubbing motorcycle body	Chemical exposure (soap)	Skin irritation or chemical injury	- No use of PPE (e.g., gloves) - Improper handling of chemicals - Lack of awareness or training	- Skin redness/itching - Chemical burns - Long-term skin conditions	Prevention: Mandate PPE (gloves, goggles); provide chemical handling training; use safer cleaning agents. Mitigation: Ensure proper chemical storage; limit exposure time. Recovery: Provide first-aid kits for skin treatment; access to medical care; document chemical-related incidents.	- Non-compliance with PPE use - Lack of regular training	- Enforce PPE usage with supervision - Schedule regular K3 training sessions

This study investigates the risks faced by workers in vehicle washing operations, specifically in motorcycle and car wash services in Mataram, Nusa Tenggara Barat. The findings show a significant prevalence of ergonomic risks and chemical hazards that could lead to musculoskeletal disorders (MSDs) and other health issues. These results contribute to the understanding of workplace safety in an often-overlooked sector and offer valuable insights into risk identification and mitigation strategies. The data gathered from this study is compared with similar research to highlight the generalizability of the findings and areas for improvement in safety protocols.

Our observations identified several key risks in vehicle washing operations, which include both physical hazards (such as musculoskeletal injuries due to non-ergonomic postures) and chemical risks (like skin irritation from soap exposure). The risk levels, calculated using a risk matrix and risk assessment scores, showed that tasks such as scrubbing the motorcycle body and cleaning the car roof present high risks due to frequent awkward postures and prolonged exertion. For motorcycle wash workers, high risks include musculoskeletal injuries from bending during undercarriage cleaning (scoring 9 on the risk matrix), while for car wash workers, high risks are associated with non-ergonomic postures during body scrubbing and the noise from compressors. These findings are aligned with similar research studies on ergonomic risks in other sectors.

Tolera et al. (2024) [3] found that 40.52% of sanitation workers globally reported musculoskeletal disorders, with solid waste collectors experiencing the highest prevalence at 45.12%. This is comparable to the findings in our study, where musculoskeletal risks in vehicle washing also show a significant potential for long-term injuries, particularly from bending and repetitive motions. This similarity suggests that workers in physically demanding jobs, regardless of industry, share common risks related to ergonomic stress.

The study by Jin et al. (2025) [4] on vehicle assembly workers shows a marked reduction in MSD symptoms following ergonomic interventions. In their study, 66.5% of workers reported low back disorders before interventions, and after one year, significant improvements were noted with ergonomic adjustments. This result parallels our findings, where tasks such as cleaning undercarriages and scrubbing car roofs are associated with high REBA scores (10), indicating a high likelihood of developing MSDs. The use of ergonomic tools, such as long-handled brushes or stools for motorcycle washers and stable platforms for car washers, could similarly mitigate these risks.

Moreover, the research by Chuppawa and Aungudornpukdee (2017) [8] on cleaners, which can be extrapolated to vehicle washers, found a high prevalence of MSDs, with 81.98% of workers reporting symptoms in the past week. This is consistent with the findings in our study, where workers are exposed to prolonged physical strain without adequate training on safe postures. These findings suggest that interventions, such as ergonomic training and workstation redesigns, could have a significant impact on reducing MSD prevalence.

The application of the Rapid Entire Body Assessment (REBA) method in this study provided a clear indication of the ergonomic risks posed by specific tasks. With a REBA score of 10 for both motorcycle and car wash workers, our results align with previous studies that have highlighted the importance of addressing posture-related risks. The REBA method to identify risks in automotive companies, finding similar patterns of posture-related MSDs among workers, reinforcing the applicability of this method across different industries [19].

The Bowtie analysis conducted in this study further validated the need for comprehensive risk management strategies. For example, when cleaning motorcycle undercarriages, the primary causes of musculoskeletal injury include prolonged bending and a lack of ergonomic tools, leading to consequences like chronic back pain and reduced productivity. The prevention strategies outlined, such as using long-handled tools and providing ergonomic training, align with the recommendations of Singh et al. (2024) [17], who emphasized the importance of preventive measures in risk management. The Bowtie analysis highlights the need for a structured approach to risk management, incorporating

prevention, mitigation, and recovery steps, as seen in studies like those of Ispășoiu et al. (2021) [12], which also utilized Bowtie methodology to address ergonomic risks.

3.1. Implications for Future Research and Practice

This study's findings emphasize the urgent need for ergonomic interventions and safety training in vehicle washing operations. Future research should explore the effectiveness of specific interventions, such as task rotation and the introduction of ergonomic tools, in reducing the incidence of MSDs. Additionally, the development of industry-specific safety standards and guidelines, informed by comprehensive risk assessments like the one conducted in this study, could enhance worker safety across the sector.

Further studies could also extend beyond the Mataram area, examining vehicle washing operations in other regions or countries to assess the generalizability of the findings. Cross-industry comparisons, such as those between vehicle washing and other sanitation or manufacturing sectors, could provide valuable insights into common occupational health challenges and best practices for mitigation.

4. Conclusions

This study comprehensively assessed occupational health and safety risks in vehicle washing operations in Mataram, Nusa Tenggara Barat, focusing on motorcycle and car wash workers. Through observational studies conducted on April 6, 2025, and the application of Rapid Entire Body Assessment (REBA) and Bowtie Analysis, we identified critical ergonomic and chemical hazards. Both motorcycle and car wash workers exhibited high REBA scores of 10, indicating a significant risk of musculoskeletal disorders (MSDs) due to non-ergonomic postures, particularly during undercarriage cleaning and car roof scrubbing. Chemical exposure from soap, leading to skin irritation, was another prevalent high-risk issue, exacerbated by inadequate use of personal protective equipment (PPE). The Bowtie Analysis pinpointed key causes, such as lack of ergonomic tools and training, and proposed targeted mitigation strategies, including long-handled brushes, stable platforms, mandatory PPE use, and regular ergonomic training. These findings align with global studies on sanitation workers, reinforcing the urgent need for ergonomic interventions and safety protocols in this understudied sector. By implementing the proposed measures, such as task rotation, improved tool design, and enforced safety training, vehicle washing businesses can significantly reduce MSD prevalence, decrease injury rates, and enhance worker productivity and well-being. This study provides actionable, industry-specific recommendations to improve occupational safety in vehicle washing operations, contributing to safer work environments and sustainable operational practices.

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