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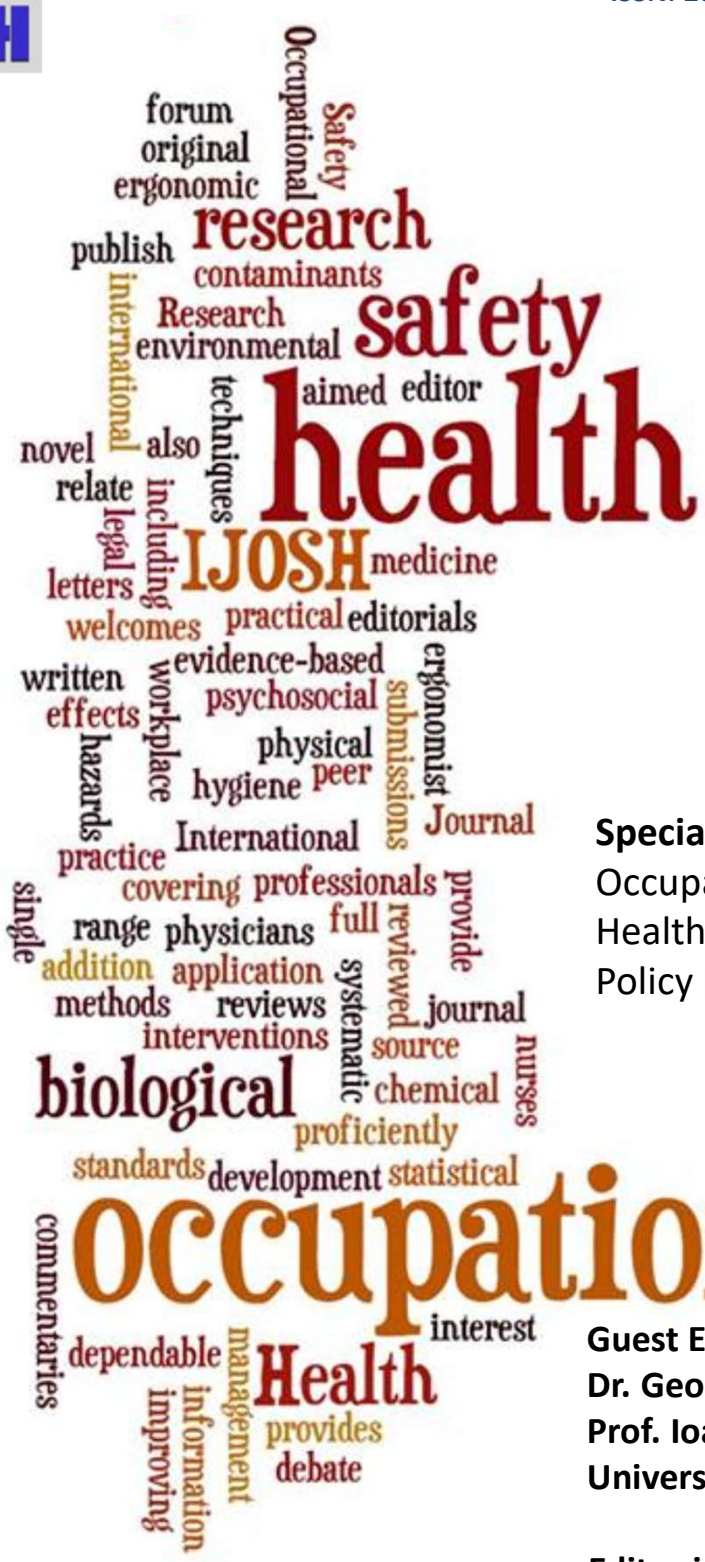

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Original Article

A multi-sensor IoT framework for real-time detection and prevention of sewage gas explosions in domestic and occupational sanitation systems

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ABSTRACT

Introduction: Methane and toxic gases build up in sewer pipes and septic tanks and are extremely dangerous in their ability to cause explosions and poisoning to workers in the confined sewer. The traditional monitoring controls, like infection ventilation and human checking, cannot be used to offer real-time protection.

Methods: In this work, the authors show an Internet of Things (IoT)-enabled cyber-physical system of real-time gas detection and automated mitigation. The system combines the MQ-4 (methane), MQ-135 (CO_2 /NH 3/VOCs), and MQ-136 (H_2S) sensors and place on the ESP32 microcontroller. A moving average-based compensation method is used to stabilize a sensor in contaminated conditions with minimum recalibration requirements. Alerts and ventilation are activated when methane reaches over 25% of the Lower Explosive Limit (LEL) using MQTT, in accordance with OSHA and NFPA safety requirements.

Results: Testing with 250 cases indicated that the system is reliably able to detect hazards, alert, and mitigate without failure. The response time was 8.2 seconds on average, which is a safeguard against gas buildup. Multi-gas sensitivity (±18% was within a reasonable range, and the system was able to run on backup power up to 18 hours.

Conclusion: The offered IoT system would turn the sanitation safety from passive observation to active protection due to real-time multi-gas detection and automated response imposed. It offers an affordable yet scalable way of ensuring occupational safety within dangerous confined spaces.

Keywords: Confined Space Monitoring, IoT Safety System, Methane Detection, Multi-sensor Array, Occupational Hazard Prevention

Introduction

Health and safety in the workplace are critical considerations in urban infrastructure systems, especially for staff who work in confined spaces. The maintenance engineers, utility workers, and sanitation workers have to periodically access sewer manholes, septic pits, and pumping stations, which fall under Permit-Required Confined Spaces (PRCS) because of the possibility of potentially harmful atmospheres. They are likely to accumulate explosive methane (CH_4) and toxic gases like carbon dioxide (CO_2), hydrogen sulfide

(H_2S), and ammonia (NH_3), liable to cause fire, explosion, poisoning, and asphyxiation risks.[1,2]

Traditionally practiced safety measures based on manual inspection and pre-entry gas tests do not offer real-time coverage, exposing workers to unexpected, immediate gas buildup, which is the number one cause of death in sanitation-related occupations.[3] Other domestic sanitation systems are also prone to similar hazards, as accumulation of methane may result in unexpected ignition, as shown in Table 1. The recent reported cases in cities in residential areas, such as methane toilet explosions, indicate that sewage gas is not only restricted to occupational settings but can be life-threatening to the general population as well.[4] These occurrences indicate the systematization of gas accumulation in the available sanitation facilities, especially in congested urban locations. Anaerobic degradation in sanitation systems produces complex gaseous byproducts that put the lives of residential occupants and workers in enclosed environments at risk. Mitigation for sewer gas hazards is primarily passive and structural, involving ventilation pipes, water traps, and plumbing required by the building code.[5]

The processes are inherently prone to failure due to blockages, inadequate maintenance, environmental erosion, or design constraints. More importantly, passive systems are not able to sense in real time or respond automatically to threats and minimize them, which prevents them from predicting an imminent gas buildup or taking mitigation measures. Such a limitation marks a major safety deficiency in both occupational and residential sanitation processes. The Internet of Things (IoT), therefore, has a potential place in filling this gap as it facilitates the process of integrated sensing, actuation, and communication in environments that are of safety concern. Although IoT-based systems for sewage gas monitoring have not been widely implemented, their use has spread widely in general air quality monitoring and gas leak detection in industry. Unique issues in sewage environments include persistent background contamination, humidity, and corrosive conditions, which undermine traditional sensor calibration and reliability.[6]

Such limitations require application-specific system architectures and dynamic signal-processing plans. The tasks of this work were as follows: (i) to design a multi-sense ionic basis system that is appropriate in both domestic and work-situated sanitation correlations; (ii) create a dynamic base compensation algorithm to guarantee a stable real-time gas detection under the continuously contaminated circumstances; (iii) to implement a hybrid local decision-making and alerting based in the clouds to guarantee reliable, and (iv) to experimentally test the system, to measure its accuracy and response time, reliability and effectiveness of mitigation. It is expected that the research will help advance the field of occupational and environmental safety engineering through a proactive, closed-loop cyber-physical technology for real-time monitoring and automated reduction of hazards from sewage gases.

The biochemical production of non-explosive, deadly gases in sanitation systems has been extensively reported. Methane (CH_4) is one of the initial products of anaerobic digestion in septic tanks and sewer pipes, driven by complex microbial activity. [6,7]

Besides methane, other substances likely to be found in the sanitation environment include hydrogen sulfide (H_2S), which is a product of sulfate-reducing bacteria, ammonia (NH_3), and volatile organic compounds (VOCs).[8] Such a mixture poses complex risks, including explosion hazards linked to methane accumulation and acute effects from exposure to gases like H_2S. These dangers are especially great in the workplace. The engineering, maintenance, and sanitation employees often perform their duties inside sewer manholes, septic tanks, and pumping stations, which are regulated by OSHA 29 CFR 1910.146 on permit-required confined spaces (PRCS) due to the risk of unsafe atmospheres. According to reports on occupational safety around the world, sanitation workers continue to

die as a result of asphyxiation, greater amounts of hydrogen sulfide, and ignition of methane.[9,10]

Traditional safety interventions, such as personal protective gear (PPE) and pre-entry gas testing, are only point-in-time measures with a great deficiency in preventing the build-up of the gaseous material during active operation, which is crucial, as there is no follow-up. [11]

The current protectors against sewer gas risks to people in residential and workplace settings are mainly passive. These are plumbing provisions required by codified policies, such as ventilation pipes and water traps on residential properties, and administrative controls, such as routine inspections and procedure checklists used in occupational environments.[4,12] These measures are by their nature prone to failure because of blockages, loss of hydraulic seals, poor maintenance, or environmental degradation. More to the point, passive systems lack real-time sensitivity and automated response, which reduces their usefulness in curbing dangerous gas buildup. The Internet of Things (IoT) has shown considerable promise in environmental and safety factor usage. The development of IoT systems that incorporate sensor nodes, microcontrollers, wireless communication units, and cloud-based systems has enabled continuous monitoring of city air quality and gas leakage detection in industries.[5,13] Metal-oxide semiconductor (MOS) gas sensors, in particular, are known to be low-cost and highly sensitive, and their operating characteristics are well documented in the literature.[14]

Such systems are used to provide a background for real-time data capture and remote monitoring across a variety of settings. These developments notwithstanding, there remains a significant gap in the development and use of IoT technologies for sewage gas hazard management. Although previous research has delved into general air quality monitoring and the detection of isolated fuel gas leaks, little has been done on the sequential sensing of complex sewage gas mixtures in closed sanitation settings. The literature is silent on closed-loop cyber-physical systems that can, at the same time, detect various sewage gases and automatically trigger physical mitigation processes in real-time. Moreover, the problem of maintaining sensor reliability in circumstances of chronic background contamination, where other techniques of sensor calibration are not feasible, has not been adequately tackled. The current paper aims to fill this gap by suggesting and experimentally proving an IoT-based multi-sensor system tailored explicitly to real-time sewage gas detection and automated mitigation of the sewage gas in any sanitation setup.

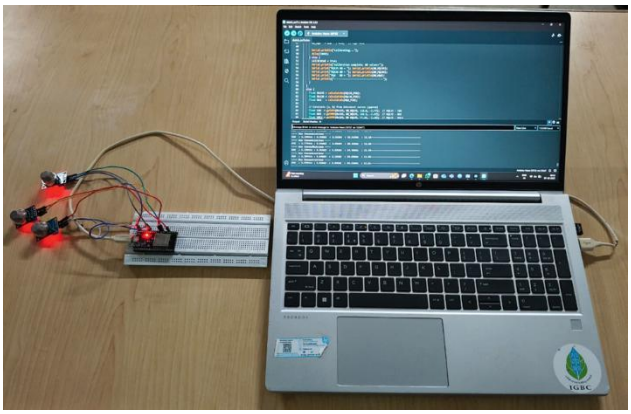

Figure 1: Multi-Sensor IoT Framework for Sewage Gas Detection and Mitigation

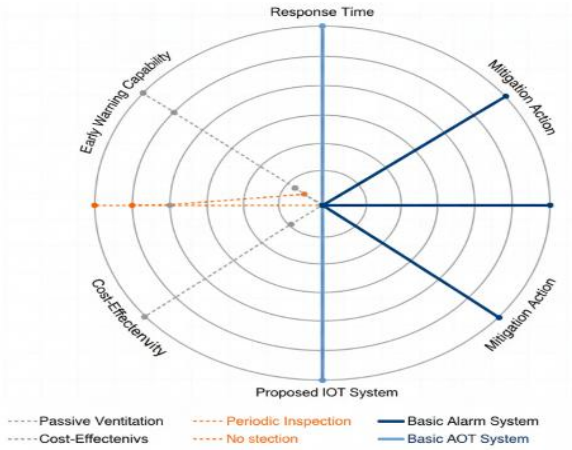

Figure 2: Comparative Analysis Chart

Methods

The suggested system will be built as a stratified cyber-physical architecture that can be deployed in domestic and occupational sanitation setups, such as bathrooms, sewer manholes, and pumping stations. To reduce the risks of gas explosions and toxic exposure in enclosed spaces, the design prioritizes operational reliability, power autonomy, and quick response. Multi-sensor array: This is based on the varied composition of sewage gases, and gas sensing is realized by the multi-sensor array. The array is assembled with Figaro MQ-4, which detects methane; MQ-135, which detects carbon dioxide (CO2), ammonia (NH3), and volatile organic compounds (VOCs); and MQ-136, which detects hydrogen sulfide (H_2S). The reason behind choosing these metal-oxide semiconductor (MOS) sensors is that they have a high level of sensitivity, they are cheap, and can be used in continuous monitoring applications. To ensure longevity in the damp, corrosive environments of the sanitation setting, the sensor assembly is housed in an IP67-rated enclosure. An ESP32-WROOM-32 microcontroller is used as the system's computing component, chosen for its dual-core design, built-in Wi-Fi, and 12-bit analog-to-digital converter (ADC), which enables sensor signal acquisition with appreciable precision (MOS sensor). The actuation layer comprises an opto-isolated 5 V relay module to drive a 280 CFM brushless DC exhaust fan, which enables quick ventilation of small cases. An integrated supply, a primary 12 V DC supply, and a 12 V recent battery, 12 V, 7 Ah LiFePO 4, allows power to be delivered for more than 24 hours during power interruptions, the key to providing safety-critical monitoring systems as shown in Table 2. It is not feasible to clean-air-calibrate MOS sensors during deployment because the sewage environment is always contaminated. Hence, this system is not based on measuring absolute gas concentration but rather uses a relative, threshold-based detection strategy, as is applicable in safety-critical systems. Sensor accuracy is determined relative to manufacturer-provided reference characteristics, rather than laboratory-grade analysis (Figure 1). Also, under experimental conditions, the system showed a ±18% deviation from the manufacturer's reference values, which is sufficient to trigger early warning and automated mitigation. The sensor resistance (R 8) is continuously calculated through the voltage divider equation:

$$\mathbf{Rs = RL * (Vc - Vout) / Vout} \qquad \mathbf{(1)}$$

Where: Rs is the sensor resistance (kΩ), Vc is the circuit voltage (5.0 V), Vout is the output voltage across the load resistor (V), and RL is the fixed load resistance (kΩ).

A multi-step baseline compensation algorithm is used to reduce long-term sensor drift and poisoning effects. A dynamic baseline resistance (Rb) is computed on a sensor-by-sensor basis, just as the moving average at R = of the last N = 500 consecutive Rn samples, enabling the baselines to adjust to slow changes in the environment. The normalized signal deviation S(t) is defined as:

$$\mathbf{S(t) = (R\_b(t) - R_s(t)) / R\_b(t)} \qquad \mathbf{(2)}$$

The rate of change dS/dt is also computed to identify rapid gas-release events that may not immediately exceed absolute thresholds. The two-threshold strategy is used to activate hazard detection and mitigation. The former is an absolute threshold, which is met once the methane concentration reaches 25 percent of the Lower Explosive Limit (LEL) under both OSHA and NFPA confined space safety guidelines. The second condition is a rate-of-change threshold, which is activated when dS/dt exceeds the preset limit and indicates a rapid rise in gas concentration despite a decreasing level of gas concentration in absolute terms. This two-threshold method minimizes false alarms from slow sensor drift, but it is highly sensitive to sudden hazardous gas buildup. The system utilizes a hybrid architecture of communication (Figure 2). Sensor data and alert messages are

remotely monitored and logged, and alerts are transmitted to the ThingSpeak IoT platform using the MQTT protocol. Nevertheless, all critical decision-making and actuation logic is available on the ESP32 to avoid operational disruption in the event of a network outage. Data packets are in JSON format and include the following: timestamp, methane LEL percentage, H2S concentration, and system status. A friend's phone app subscribes to the MQTT stream to deliver live notifications to users and facility administrators. It is a network-independent safety core that ensures mitigation actions are always taken without errors, which is required in the safety of confined spaces (Figures 3 & 4).

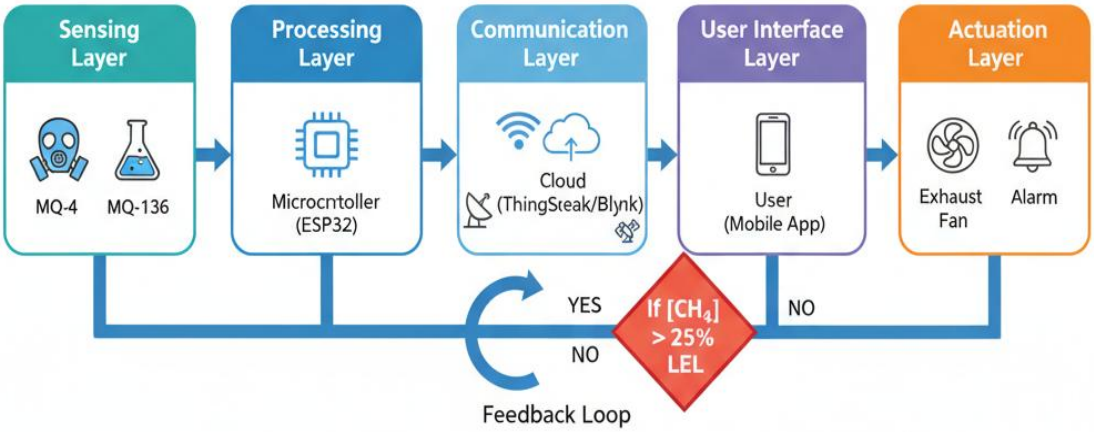

Figure 3: Overall System Architecture Diagram

Table 1: Comparative Analysis of Methane Hazard Mitigation Approaches

Feature / Metric	Passive Ventilation	Periodic Inspection	Basic Alarm Systems	Proposed IoT System
Monitoring Capability	None	Intermittent (Weeks/Months)	Continuous	Continuous & Real-time Multi-gas
Response Mechanism	Passive Diffusion	Manual Intervention	Audible/Visual Alarm Only	Automated Physical Mitigation + Cloud Alerts
Response Time	N/A	Days/Weeks	Minutes (Human-Dependent)	<10 Seconds (Autonomous)
Hazard Prevention	Low (Failure Prone)	Low (Post-Inspection Only)	Medium (Human-Dependent)	High (Active & Immediate)
Environmental Adaptation	None	None	Limited	Dynamic Baseline Adjustment
Cost Efficiency (5-Year)	Low (Initial)	High (Recurring)	Medium	Low-Medium (One-Time)
Early Warning Capability	No	No	At Hazard Point	Predictive Potential + Real-time

Table 2: System Component Specifications

Component	Model / Type	Key Specifications	Role in System
Microcontroller	ESP32-WROOM-32	Dual-core 240 MHz, Wi-Fi, Bluetooth, 12-bit ADC	System processing and communication
Methane Sensor	Figaro MQ-4 [15]	Methane detection, Heater: 5.0V±0.2V	Primary CH_4 detection
Air Quality Sensor	Figaro MQ-135 [16]	CO_2/NH_3/VOCs detection, Heater: 5.0V±0.2V	Multi-gas monitoring
H_2S Sensor	Figaro MQ-136 [17]	H_2S/SOx detection, Heater: 5.0V±0.2V	Hydrogen sulfide detection
Actuation Module	5V Relay Module	Optically isolated	Exhaust fan control
Exhaust Fan	Brushless DC Fan	280 CFM, 12V DC	Physical gas mitigation
Power Backup	$LiFePO_4$ Battery	12V, 7Ah	Operation during outages

Table 3: Experimental Results Summary from 250 Test Cycles

Performance Parameter	Average Value	Standard Deviation	95% Confidence Interval	Minimum	Maximum
Gas Detection Latency	2.1 seconds	± 0.3 s	1.9-2.3 s	1.7 s	2.8 s
Fan Activation Time	4.8 seconds	± 0.7 s	4.5-5.1 s	3.9 s	6.5 s
Total System Response Time	8.2 seconds	± 1.1 s	7.8-8.6 s	6.5 s	10.1 s
Gas Clearance Time	42 seconds	± 8 s	39-45 s	31 s	58 s
Mobile Alert Delivery	1.3 seconds	± 0.4 s	1.1-1.5 s	0.8 s	2.1 s
Multi-Gas Detection Accuracy	±18%	± 3%	17-19%	12%	25%
System Reliability	99.1%	-	97.8-99.8%	-	-

Results

The proposed system was tested with over 250 controlled experiments conducted under simulated sanitation conditions. The reliable functionality of the system was considered to be the effective gas detection, threshold evaluation, automated ventilation actuation, and alert notification under the conditions of no hardware, software, or communication failures. According to this definition, the system achieved 99.1% of the mean reliability, which demonstrates the efficiency of the multi-sensor implementation and internal control logic, as shown in Table 3.

The overall time of the system's reaction was recorded from the start of hazardous gas release until mitigation and alert actions were taken. The average end-to-end response time was 8.2 seconds, which is within the safety range to prevent dangerous levels of explosive or poisonous gases from accumulating. This time frame included an average gas detection time of 2.1 seconds, a ventilator fan turn-on time of 4.8 seconds, and a mobile notification of the alert time of 1.3 seconds (Figure 5).

It was a system that was able to monitor multiple gases at the same time, such as methane (CH_4),

hydrogen sulfide (H_2S), and volatile organic compounds (VOCs). It was experimentally found that the dynamic baseline compensation algorithm was stable in the presence of simulated background contamination, unlike competing experiments, and was able to detect false triggers from long-term sensor drift and effectively respond to rapid gas release events.

The power autonomy testing demonstrated more than 24 hours of continuous system operation under simulated primary power failure conditions, aided by the built-in backup battery. The accuracy of multi-gas detectors had a variation of no more than 18 percent as compared to the reference properties of the manufacturer. This degree of precision will be appropriate for threshold-based safety monitoring and automated mitigation, where early hazard detection and response are more essential than laboratory-scale analytical accuracy. (Figure 6)

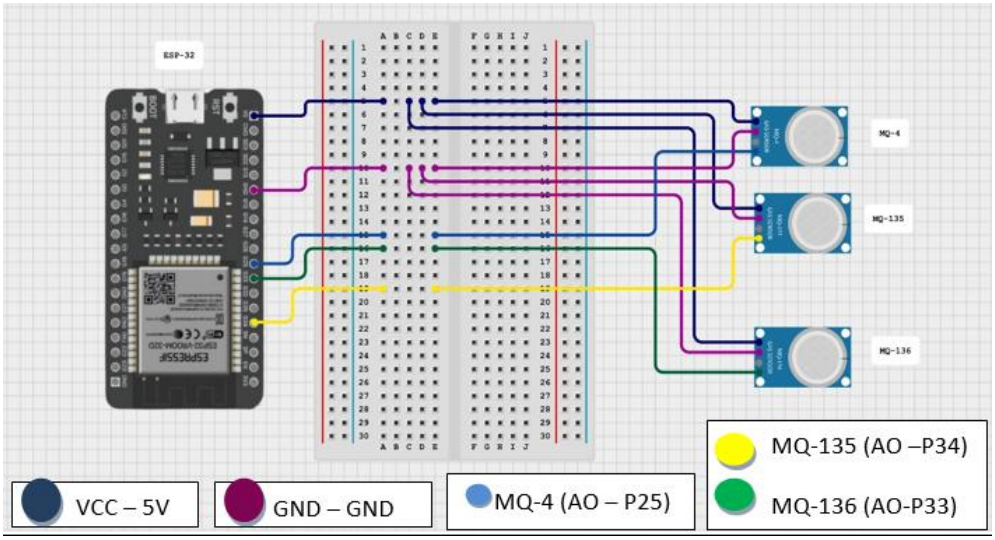

Figure 4: Circuit Integration and Power Management Schematic

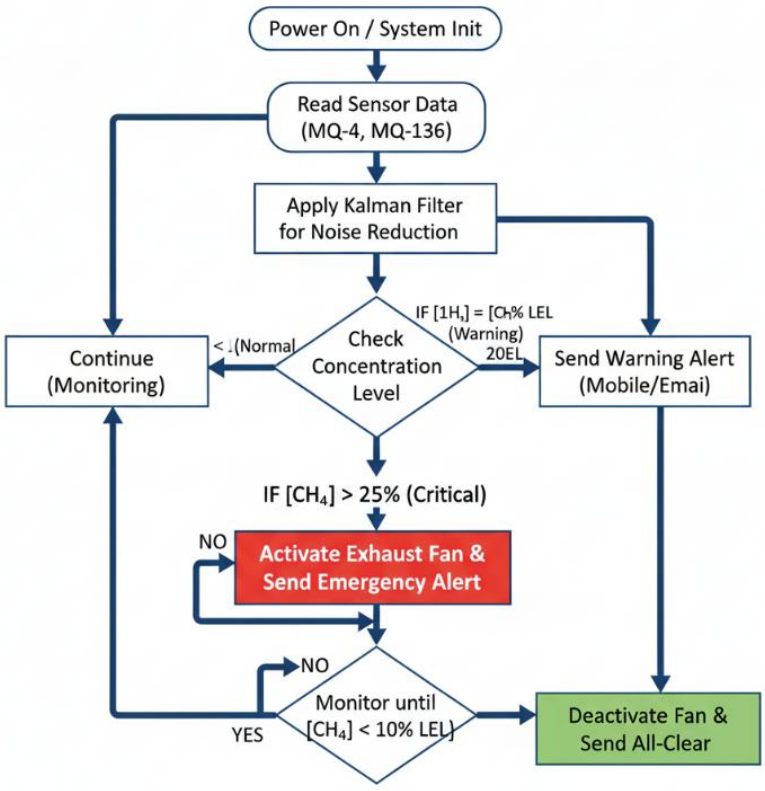

Figure 5: Real-Time Decision Algorithm Flowchart

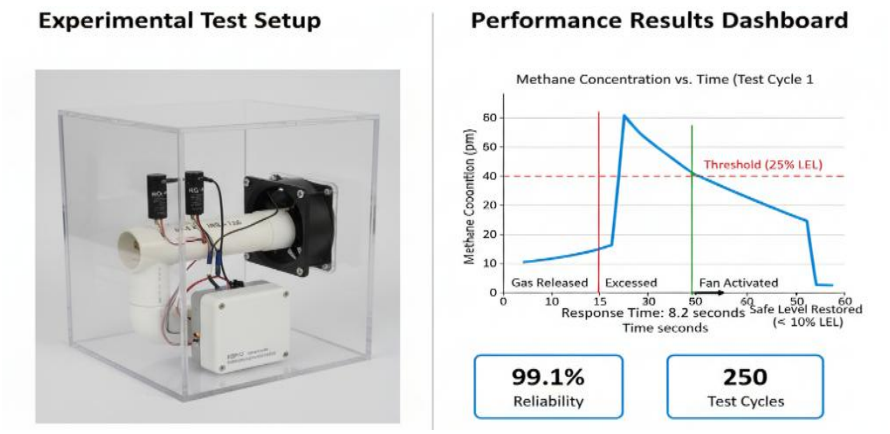

Figure 6a: Experimental Test Setup and Performance Results Dashboard

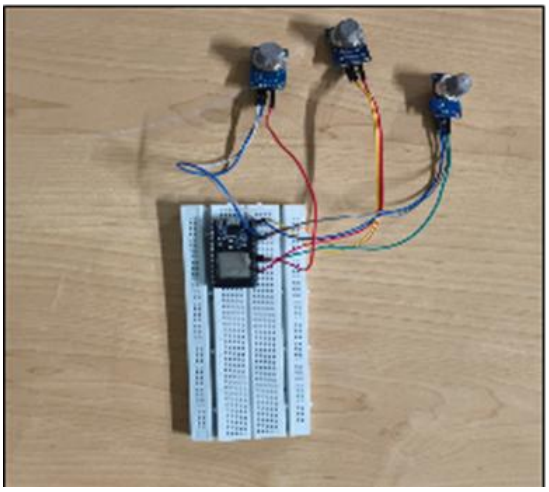

Figure 6b: Physical Prototype of the Multi-Sensor Array on the ESP32 Platform (Experimental Test Setup)

Discussion

The findings of the experiment indicate that the developed IoT-sensitive cyber-physical system can accurately identify and eliminate sewage gas threats in real time when exposed to conditions conducive to sanitation spaces. System reliability of 99.1% through achievement demonstrates that the entire multi-sensor architecture, embedded decision logic, and local actuation are well-suited to chemically volatile and operationally challenging confined spaces.

The performance outcome of the mean end-to-end response time of 8.2 seconds is a critical one, given that it gives the necessary safety margin before gas concentrations can reach dangerous or even explosive values. Even in small sanitary areas, the buildup of a hazardous-to-health gas (methane or hydrogen sulfide) can occur within tens of seconds; hence, an automated response during this period will dramatically reduce the risk of an explosion, poisoning, or even asphyxiation. The localized implementation of mitigation logic also ensures that network failures or cloud delays do not postpone safety operations.

The proposed system will provide greater protection than traditional single-gas methane alarms because it will detect not only methane but also hazardous gases such as hydrogen sulfide and ammonia-containing compounds. The ability is valuable when working in sanitation conditions, as the workers usually die not only because of explosions but also due to acute poisoning by hydrogen sulfide. The system has automated ventilation, so the safety of

sanitation is no longer a passive infrastructure concept but an active engineering control, which is more consistent with the hierarchy of controls in occupational safety and can provide greater resistance than administrative procedures or personal protective equipment used alone.

One of the most important values of this work is the algorithm for dynamic baseline compensation, which enables stable sensor operation under conditions where clean-air calibration cannot be used due to constant background pollution. The system does not attempt to achieve lab-quality gas measurements; instead, it uses a threshold-based safety measurement method. The measured deviation of apparent ±18 percent against the manufacturer's reference characteristics is acceptable; therefore, early hazard assessment and automated mitigation are prioritized, with response as the major criterion rather than analytical accuracy. The given design option reflects a real-life trade-off in engineering and is best suited to actual sanitation implementation.[9]

The proposed system has limitations despite its benefits. The metal-oxide semiconductor sensors used have ageing and cross-sensitivity, and their performance in corrosive conditions is subject to drift; thus, they should be validated or replaced on a periodic basis during the field applications of the product in long-term deployment. Furthermore, Wi-Fi connectivity may be unreliable in areas with limited network infrastructure, although cloud-based monitoring and alerts are possible. Nevertheless, other fundamental safety functions of the system, such as detection and ventilation actuation, operate completely offline due to localized decision-making.[18-21] Occupational safety-wise, the system may be used to supplement the current Permit-Required Confined Space (PRCS) programs, as it would offer ongoing atmospheric monitoring prior to and throughout worker entry, which is one of the most important gaps in current safety practice. Future work will focus on extending communication range using the low-power wide-area network technology LoRaWAN, introducing predictive maintenance and anomaly detection through machine learning models, and enhancing sensor fusion methods to further improve detection robustness. Enhancing cybersecurity by focusing on safety-enhancing infrastructural IoT designs will also be vital as the safety-enhancing structure is scaled to massive levels of municipal and residential deployment.

Conclusion

The paper has proposed a design, implementation, and experimental validation of an IoT-enabled cyber-physical system for real-time detection and mitigation of sewage gas hazards. A combination of a multi-sensor array, built-in decision-making, and automated ventilation will make the proposed system represent a viable shift toward an active safety model for addressing explosion and toxic exposure risks, rather than a passive sanitation infrastructure.

The reliability of the system and the experimental evaluation showed that the system is stable, with an operational reliability of 99.1 and an average end-to-end response time of 8.2 seconds. These findings mean that the system is capable of developing timely mitigation measures well before it is too late to start, when hazardous gas levels are critical. Dynamic baseline compensation also enables steady performance under continuously polluted conditions where conventional clean-air calibration is not practical, and thus the method is appropriate for real-world use in sanitation field tests.

The fact that the system uses commercially available parts and inexpensive sensing technology also facilitates its adoption in both occupational and household sanitation systems on a large-scale basis. The proposed framework is based on the principles of safety-oriented threshold detection and rapid response, as opposed to laboratory-quality gas quantification, which would be the focus of the proposed system,

and is in line with the established guidelines for well-designed occupational risk mitigation.

In general, the piece bridges a sharp gap between academic research and the practical application of those findings, as it provides an engineering measure that strengthens protection for sanitary workers in tight areas, as well as offering proactive protection for residential sanitary equipment. The proposed solution provides a basis for the further development of smart sanitation safety systems that incorporate continuous monitoring, automated control, and robust functionality in unsafe conditions.

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Original Article

Absenteeism: A retrospective cross–sectional study among employees of the municipality of Keratsini for the year 2022

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ABSTRACT

Introduction: Absenteeism is a multifactorial phenomenon. The aim of the study was to conduct an analysis with specific indicators (Absenteeism rate, Frequency of sickness absence, Cumulative incidence, Duration of absence, Length of sickness absence, Bradford Score) among municipal employees and the comparison through certain variables (gender, position, age, seniority).

Methods: In this retrospective cross-sectional study, the sample was the employees of the Municipality of Keratsini for year 2022. Data were collected through the individual employees' sick leave file, processed with Microsoft Excel and statistically analyzed with Stata (chi-square tests). A comparison of the results between two previous studies with the same sample followed.

Results: Females (n=179/45.8%) received statistically sick leave more frequently (females with at least one sick leave: n=148/82.7%, males with at least one sick leave: n=128/60.4%) ($p<0.005$) and employees with 20-29 years of service (n=117/29.9%) received significantly more likely to take sick leave (employees with 20-29 years of service with at least one sick leave: n=89/76.1%) ($p=0.04$). Regarding the 3 studies' comparison, there was an increase in the number of absentees (2001: n=155/55%, 2007: n=134/40%, 2022: n=276/70.5% ($p<0.001$) and in the granting of sick leave with a medical certificate (2001: n=219/45.7% 2007: n=133/39%, 2022: n=252/30%) ($p<0.001$) and a health board (2001: n=110/23% 2007: n=102/29.9%, 2022: n=304/36.3%) ($p<0.001$).

Conclusion: Absenteeism indicators can reveal groups or individuals with an increased propensity to receive sick leave. Some of the study's results aligned to international literature (category of female employees, category of cleaning employees). Longitudinal comparison revealed an increase in absenteeism that could be justified by a number of factors (increased age, COVID-19 pandemic, periods of economic or health crisis). A number of countermeasures are suggested (close monitoring, return-to-work interviews, vaccination, ensuring personal hygiene in the workplace, upgrade of the role of occupational physicians).

Keywords: municipal employees, absenteeism, sickness absence, sick leave.

Introduction

Absenteeism is an employee's non-presence in the workplace, an action affected by multiple factors, including sick leave.[1-3] There is a separation of the general population based on the risk of absenteeism (general population – working population with insurance – population with sick leave, absenteeism pyramid).[4]

Absenteeism has implications for the employee directly, leading to pay deductions, disruption to career development, psychological deterioration, and social isolation. But it also affects the working organization, by disorganizing it, increasing the cost of substitution and overtime pay and causing productivity loss.[3-8]

There is also a positive outcome, as sick employees recover completely through rest due to sick leave and rehabilitation. This protects the other employees in the event of infectious diseases.[7] This phenomenon, in a certain population sample,[3-4] is thoroughly studied using specific indicators and tools for estimating, apart from variables, such as occurrences, timeline, gender, occupation, age, and education.[5] The indicators aim to examine the phenomenon from the financial, medical, social, or psychological viewpoint.[4-6] There are as many as 40 indicators used; however, only 10 of those indicators are used frequently,[7] and 5 indicators are used in major studies. In this study, the Bradford Score, absenteeism rate, frequency of sickness absence, cumulative incidence, duration of absence, and length of sickness absence are selected.[6]

According to past studies and published literature, health employees and unskilled employees are at high absenteeism risk, while managers, PC technicians and office employees are at low risk.[9,10] Regarding diseases, in the United Kingdom (UK), the most frequent reasons for health conditions were musculoskeletal and psychiatric disorders.[11] Moreover, in India, among female employees, between two groups, the group that was exposed to a higher physical load developed more musculoskeletal disorders and had lower weight, BMI and hemoglobin concentration.[12] Concerning other factors, absenteeism was more frequent with increasing age, involving the female gender (however, with lower mortality), and with lower Education level.[13,14] Also, absenteeism increased in Iceland during the economic crisis of 2008 after an organizational downsizing in the remaining personnel; however, this happened even in departments that were not affected by downsizing.[15]

The aim of this study is to determine whether published studies and data on absenteeism apply to the current study population, and to analyze the similarities and differences between our findings and those of previous studies conducted among similar population groups.

Methods

We conducted a retrospective cross-sectional study. The study sample includes all municipal employees in Keratsini in 2022. The year was chosen because the study took place in 2023 and because of the COVID–19 pandemic, the most recent year with complete data was preferable, in order to have the lowest possible impact from COVID–19 related absences.

The data were collected from the Personnel Records and Procedures Department of the Municipality of Keratsini. Microsoft Word and Excel were used to process files containing lists of employees by tenure and position. The Municipality's STAFF program was used as it includes administrative details of the sick leaves as well as the employee's personal file, where the additional medical details regarding each sick leave were contained. The data are stored and processed in the Municipality's HR department and were accessed with the verbal permission of the head of the department and the Municipality, without exposing employees' personal information. Therefore, no approval from an ethics committee was necessary.

Sick leaves were categorized according to cause, way of granting (three ways, one day justified by the employee himself with a solemn declaration, sick leave granted by a doctor and approved by a health committee) and whether they are related to a weekend or a holiday (bridge effect).

The parameters considered were gender, age, job position, and years of work after obtaining permission from the Municipal Authority and the Infirmary of the Municipality as sensitive personal data, not shared with third parties or the administration. Data entry and analysis were done with Microsoft Word and Microsoft Excel. The statistical analysis was performed using Stata

2013. The method used was chi–square tests. The absenteeism metrics were calculated using the mean value as a measure of central tendency; however, the median was also calculated.

The employees are divided into three categories based on job position and occupational exposure (A: office/administrative employees, B: artisans/craftsmen, C: others). For a more detailed study of the employees, and an easier comparison with the previous works, the category of artisans/craftsmen was further divided into 4 subgroups: (B1 Cleaning, B2 Gardens, B3 Technicians, B4 Drivers)

Many parameters, including the calculation of the specific absenteeism indicators [Absenteeism rate (days of absence/working day x 100%), Frequency of sickness absence (number of sick leaves/employee x 100%), Cumulative incidence (employees that received sick leave/total number of employees x 100%), Duration of absence (days of absence/sick leave), Length of sickness absence (days of absence/employee that received sick leave), Bradford Score [days of absence x (incidents of absence)^2] and the categorization of Bradford Factor (0-300, 300-500, >500 points) despite possible changes that may have occurred in the operation of the Municipality, have been received, categorized and calculated with as much relevance as to the previous studies for the best possible comparison that follows.

Absences were recorded as working days instead of working hours because it was impossible from existing records to know whether the sick leave started before, during or after work. For the year 2022, 251 days were considered as working time. The days lost were calculated as the total sick days of absence of a person, a categorized group of the whole study population during the time of the study chosen, a month, a quarter, or the whole year.

Regarding the reason for sick leave and the month it began, the very high overlap in absences among many people made it extremely difficult to calculate statistical differences between the individual categories. Regarding months, a statistical difference was calculated by quarter using a chi–square test for ratio comparison. Regarding quarters, the first and fourth quarters are the months with the most unfavorable weather and the highest transmission of seasonal infections (influenza and gastrointestinal viruses). The third quarter of the year has mostly good, mild weather and is the leave period, so a reduction in sick leave is logical, since many employees are already absent.

Results

Regarding gender, the employees in the study consisted of males (54.2%) and females (45.8%). The age range was between 26 and 68 years (median 53 - mean 51.77), the prevailing age was 54 years [standard deviation (SD) of 7.44 and a standard error (SE) of 0.38]. The prominent age group among the employees was between 46 and 55 years.

The employment range was 0 - 41 years, (median 18 - mean 16.91), a mode of 4 years, SD 11.3 and SE 0.57, while 0-9 years of service range employees represented the largest group in the study.

A total of 391 employees were considered for the study, with 838 incidents of absence and 3901 days of sick leave (per incident) in the study population. There was a statistically significant association between taking sick leave and gender. Therefore, female employees (n=179/45.8%) were more likely to take sick leave than their male colleagues (females with at least one sick leave: n=148/82.7%, males with at least one sick leave: n=128/60.4%) ($p<0.005$).

Regarding job position, the largest percentage of employees who received at least one sick leave was administrative employees (A), followed by employees in other positions. Cleaning employees (B1) were the most numerous who were absent at least once. There was no statistically significant difference in absence ($p=0.65$).

By age, the largest percentage of employees who received at least one sick leave was in the 56-to-65-year age group, followed by the 46-to-55-year age

group. However, there wasn't a statistically significant difference in absence (p=0.24).

Regarding working seniority, the largest percentage of employees who received at least one sick leave was among those with 20 to 29 years of service (n=117/29.9%), followed by those with 10 to 19 years and 30 to 39 years. There was a statistical significance, meaning that employees with the aforementioned years of employment received sick leave more often compared to the other categories of employees (employees with 20-29 years of service with at least one sick leave: n=89/76.1%) (p=0.04).

The three ways to obtain sick leave are a solemn declaration by the employee, a medical certificate, and approval from a health committee (for leave over 8 days). As leave granting was concerned, there was a statistically significant difference, i.e. a sick leave was more likely to be granted by the relevant health board than by a certificate (p=0.026).

Sick leaves were checked for the bridge effect (leaves up to 3 days related to a weekend or holiday), where a very large proportion was found to be correlated.

There was a separation of sick leave according to the medical reason for which it was granted. The most frequent were Unexcused (36.9%), Respiratory (20.2%), Musculoskeletal (14.9%), and Gastrointestinal (9.8%). The leaves, justified by the employee himself with a solemn statement, were registered as unexcused.

Finally, there was also a distinction regarding the starting month of sick leave and the number of days of leave granted in each month. The most sick leaves were observed to be granted in January, followed by November, February and December of 2022, while the least sick leaves were granted in August and September of 2022. However, in terms of days "lost" per month, the same pattern was not observed. The first month with lost working days was November, followed by June, February, and October of 2022, while the months with the fewest "lost" days were April and August of 2022.

Following the monthly division of sick leave, a quarterly division of absence incidents was also made. The first quarter of the year had the highest percentage of sick leave granted, followed by the fourth quarter, while the third quarter had the lowest percentage. Statistically, using a chi–square test for ratio comparison, a significant difference emerged in sick leave granting ($df = 3$, $p<0.001$), confirming that there is a difference in the granting of sick leave between the first and fourth trimesters and the third trimester.

Of the 391 employees, 276 (70.5%) received at least one sick leave, while 115 (29.5%) did not. Total sick leave days ranged from 0 to 221 (median 2 days - mean 9.97 days - mode 0 days), SD 20.29, and SE 1.02. For employees with at least one absence, total sick leave days ranged from 1 to 221 (median 6 days - mean 14.13 days - mode 2 days), a SD of 22.90, and a SE of 1.38, with a total of 3901 days lost. For employees with at least one absence, absenteeism incidents per employee ranged from 1 to 18 (median 2 incidents; mean 3.03 incidents; mode 1 incident), with an SD of 2.38 and an SE of 0.14, for a total of 838 absence incidents.

Bradford Score for employees with at least one absence ranged from 1 to 17901 (median 34 – mean 476.61 - mode 1), SD of 1729.27, and SE of 104.09.

A calculation of the 6 absenteeism indicators mentioned in the general part as more representative and reliable was performed, both for all employees and for the categories analyzed in the specific part (gender, position, age, seniority).

It is concluded that female employees tend to be absent more frequently and in absenteeism incidents, men are absent for more consecutive days. This is confirmed by the total number of days lost. However, with regard to the Bradford factor, female employees seem to have higher values, especially on the larger scales, which was expected due to the higher number of absence incidents (despite receiving shorter absence leave) (see Table 1).

Table 1: Indicators of absence in total and by gender

Indicators	Total	Male	Female
Absenteeism rate (days of absence/working day x 100%)	3.97%	3.78%	4.21%
Frequency of sickness absence (number of sick leaves/employee x 100%)	214.32%	170.28%	266.48%
Cumulative incidence (employees who received sick leave/total number of employees x 100%)	70.59%	60.38%	82.68%
Duration of absence (days of absence/sick leave)	4.66	5.57	3.97
Length of sickness absence (days of absence/employee who received sick leave)	14.13	15.69	12.78
0<Bradford<300 (points)	78.98%	82.03%	76.35%
0<Bradford<300 (overall) (points)	55.75%	49.53%	63.19%
300<Bradford<500 (points)	4.71%	2.34%	6.75%
300<Bradford<500 (overall) (points)	3.32%	1.42%	5.59%
Bradford>500 (points)	16.3%	15.62%	16.89%
Bradford>500 (overall) (points)	11.51%	9.43%	13.97%
Total days lost (n)	3901	2009	1892
Total incidents (n)	838	361	477
Total population number (n)	391	212	179
Absent (n)	276	128	148
Present (n)	115	84	31

It appears that administrative office employees (category A) have an increased frequency and cumulative effect of absenteeism (as a percentage, more employees have taken sick leave and take leave more frequently), it is the cleaning employees (category B1) who have the longest average length of absence per case and duration of absence, meaning that although leaves are taken less frequently, when they are taken, each absence lasts for more days. Overall, the category of cleaners also has the most lost days (however, as a category, it is the most numerous by quite a margin), while regarding the Bradford factor, administrative/office employees have the highest percentage on the largest scale (see Table 2).

Table 2: Absenteeism Indicators by Job Position

Indicators	A	B1	B2	B3	B4	C
Absenteeism rate (days of absence/working day x 100%)	4.13%	5.23%	3.35%	2.45%	1.87%	3.47%
Frequency of sickness absence (number of sick leaves/employee x 100%)	355.17%	182.76%	196.3%	154.9%	100%	218.6%
Cumulative incidence (employees who received sick leave/total number of employees x 100%)	88.51%	64.14%	70.37%	64.7%	47.37%	83.72%
Duration of absence (days of absence/sick leave)	2.92	7.19	4.28	3.97	4.68	3.99
Length of sickness absence (days of absence/employee who received sick leave)	11.71	20.48	11.95	9.52	9.89	10.42
0<Bradford<300 (points)	68.83%	77.42%	84.21%	93.94%	88.89%	83.33%
0<Bradford<300 (overall) (points)	60.92%	49.66%	59.26%	60.78%	42.11%	69.77%
300<Bradford<500 (points)	7.79%	3.23%	5.26%	3.03%	5.56%	5.56%
300<Bradford<500 (overall) (points)	6.9%	2.07%	3.7%	1.96%	2.63%	4.65%
Bradford>500 (points)	23.377%	19.35%	10.53%	3.03%	5.56%	11.11%
Bradford>500 (overall) (points)	20.69%	12.41%	7.41%	1.96%	2.63%	9.3%
Total days lost (n)	902	1905	227	314	178	375
Total incidents (n)	309	265	53	79	38	94
Total population number (n)	87	145	27	51	38	43
Absent (n)	77	93	19	33	18	36
Present (n)	10	52	8	18	20	7

It is observed that the age groups between 46 and 55 and 56 and 65-year-olds are absent more often, but the age groups between 36 and 45 and 46 and 55-year-olds seem to be having a longer period of absence. The age group 46 to 55-year-old presents more lost days, while it is also the most populous. The 3 middle-age categories (36 to 45 years old, 46 to 55 years old, 56 to 65 years old) have a high percentage of absentees, with the largest category (46 to 55 years old) showing the highest Bradford factor. Therefore, this category of employees appears to be the first in terms of overall employee absenteeism (the only exception is the average duration of absence per incident). Regarding seniority, the middle age categories (10 to 39 years of employment in total) are quite close in terms of the frequency of absence and the percentage of employees who were absent per category. However, the category of employees with 20 to 29 years of service had the highest average length of absence per incident and duration of sickness absence, followed by the category of 0 to 9 years of employment (whose employees were absent more rarely but their sick leaves were longer in duration). Regarding the Bradford factor, the employee group with 20 to 29 years of service is in the highest category first. The same category has the most lost days. Finally, a comparison between the results from previous studies using the same methodology was conducted (see Table 3).[16-17]

Table 3: Comparison of absenteeism in previous years (2001, 2007, 2022)

Categories	**2001**	**2007**	**2022**
Work population (n)	281	329	391
Male (n)	211	231	212
Female (n)	70	98	179
Work group (n)			
A (n)	67	99	87
B1 (n)	84	109	145
B2 (n)	33	37	27
B3 (n)	40	38	51
B4 (n)	29	39	38
C (n)	28	7	43
Mean age (years)	46.12	46.14	51.77
A: sick leave by certificate (n)	219	133	252
B: sick leave by health committee (n)	110	102	304
Γ: sick leave by solemn declaration (n)	150	106	282
1st quarter incidents (n)	131	96	247
2nd quarter incidents (n)	120	65	213
3rd quarter incidents (n)	84	72	151
4th quarter incidents (n)	144	108	227
Percentage % of receiving sick leave (%)	55%	40%	70.5%
Number of receiving sick leave (n)	155	134	276
Did not receive sick leave (n)	126	195	115
Range of duration of sick leaves (n)	1 – 199	1 - 214	1 - 221
Median (n)	1	6	6
Mean (n)	348.97	297.88	476.6

It should be mentioned that the COVID-19 pandemic was a new disease which started as a respiratory disease, in particular, was a factor that affected absenteeism and was not present in the previous studies. Because of that, it is possible that a larger number of sickness incidents occurred in a single year, mostly respiratory tract infections.

Regarding the comparison with the past two studies, the age of permanent municipal employees increased gradually, with a predominance of males (though declining). The largest group is consistently that of cleaning employees. There is a large increase in the average age of employees in the latest study compared to the previous two studies.

In terms of sick leave, there was a large increase in incidences in the latest study, almost twice as much as in the first and more than twice as much as in the second. Regarding the method of receiving sick leave, while all increased in absolute number in the most recent study, there was a statistically significant difference in receiving sick leave with a medical certificate ($p<0.001$) and approval of sick leave by a health committee ($p<0.001$), while receiving sick leave with a solemn declaration did not present a statistically significant difference. The timing of

sick leave also did not differ, with the majority of sick leave received in the first and last quarters of the year (winter and autumn months), and no statistically significant difference in time taken for sick leave across quarters between studies.

Lastly, there was a statistically significant difference in the percentage of employees who were absent from work in one year ($p<0.001$), with a statistically significant increase in the percentage of absentees in the last study. By extension (and due to an increase in the sample in absolute terms), there was an increase in the number of lost working days, sick leave incidents, all forms of sick leave received, and also the mean Bradford Score, which is consistent with the results mentioned above.

Discussion

Comparing the results with the relevant literature, musculoskeletal and psychiatric reasons were found to be less common than reported as reasons for granting sick leave.[11] The female gender was statistically more likely to receive sick leave more often, a tendency that is similar to reported studies and literature.[13-14] Regarding female employees, even if the total number of sick days per sick leave incident was lower than that of their male co-employees, such absences can disrupt the operational flow of the Municipality of Keratsini, especially when they are absent due to illness.

Statistical significance in increased absenteeism among experienced employees was also observed, consistent with the relevant literature.[13]

It is also observed, though not statistically significant, that older employees and administrative employees are more often absent; however, employees aged 36-55 years and those working in the cleaning section (the largest numerical group) received the most long-term sick leave. There is a notable increase in the average age of the workforce compared with the two previous studies (conducted before the economic crisis) and with the results for the cleaning personnel, all of which align with relevant literature.[9,14]

The findings of the present study highlight the significant burden experienced by municipal employees, particularly cleaning workers (category B1), who, despite being absent less frequently, record a longer average absence duration. This observation, combined with the reference to burnout as one of the fundamental root causes of absenteeism, is corroborated by recent literature, which directly correlates exposure to occupational environmental hazards, such as noise, with a decline in quality of life and the onset of occupational burnout.[18]

Furthermore, the present research underscores the impact of external health and economic crises on the aging of the local government workforce and the subsequent increase in absenteeism rates. This systemic vulnerability of organizations to crises is also evident at the broader health policy level, as decision-making during crises decisively influences the operations and political economy of Greek public sector entities.[19]

To address this multifactorial phenomenon, the current study emphasizes the imperative need to closely monitor absenteeism through specialized indicators, such as the Bradford Score, and to implement active intervention by occupational health services. This quantitative approach is fully aligned with modern methodologies, in which the use of Key Performance Indicators (KPIs) has proven fundamental to evaluating and optimizing Occupational Health and Safety systems.[20]

Concurrently, corresponding field studies in other demanding sectors of the Greek public system demonstrate that the institutional and substantial strengthening of occupational health services significantly contributes to the prevention of accidents and diseases.[21] These data strongly support our proposition that the systematic recording of the phenomenon using

quantitative indicators and the support of employees through targeted wellness programs are key to mitigating the negative consequences of absenteeism.

Conclusion

The phenomenon of sickness absence in the workplace, apart from affecting employees as individuals, has social and even greater economic impacts on businesses and social insurance agencies. The reduction of productivity and the increase of health cost, rehabilitation cost and replacement – overtime cost is of a scale that surpasses the businesses and could be a national burden.

Therefore, it is suggested that absenteeism should be closely monitored in every business and organization. This way, the employees who are most absent could be identified and receive help, because some are in need. The root could be poor leadership, burnout, or workplace harassment, all serious problems that can be resolved through organizational intervention. Because employees may not always self-report these issues, return-to-work interviews with supervisors or occupational physicians are vital. Identifying patterns allows for the prediction and prevention of future absences. A pattern of absenteeism can even be spotted, and as a result, work absence can sometimes be predicted and, in many cases, prevented. The role of occupational health services should be upgraded, either in the form of wellness programs in the workplace (e.g. back support program – ergonomic support in businesses that involve heavy lifting, seminars on burnout, sexual harassment or mental illness) or consulting and supporting employees with chronic absenteeism, also using Key Performance Indicators to track progress. Moreover, health monitoring and screening—including blood tests, imaging, and audiograms tailored to job-related risks—should be implemented alongside workplace assessments such as noise-level measurements. Finally, general health measures are not to be neglected, including using face masks when being sick, programmed vaccinations and general workplace hygiene. So, the negative effects can be reduced to a minimum.

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Original Article

Assessing the impact of heat stress exposure on heat strain: An analysis of outdoor and semi-outdoor roof tile workers using the Physiological Strain Index

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ABSTRACT

Introduction: This study evaluates the prevalence and contributing factors of heat strain among roof tile workers exposed to temperatures exceeding occupational limits. Furthermore, it assesses how these heat-related health risks vary between male and female workers in semi-outdoor environments.

Methods: This cross-sectional study involved 107 roof tile workers in Grobogan, Indonesia, utilizing validated questionnaires, WBGT measurements, and the Physiological Strain Index (PSI) to evaluate heat strain. Data were analyzed using Spearman's rank, Pearson correlation, and chi-square tests to identify significant relationships between individual, occupational, and behavioral factors.

Results: The PSI results of roof tile makers had an average score of 5.05 ± 0.40. The results demonstrated that female workers exhibited significantly higher physiological strain than males. This is primarily driven by biological differences in thermoregulatory capacity and greater adipose tissue insulation (p=0,000). Factors associated with heat strain were age (p=0.004), BMI (p=0.023), daily water intake (p=0.014), rest hours (p=0.000), heat stress (p=0.016), and workload (p=0.000).

Conclusion: Despite natural acclimatization keeping overall strain moderate, heat stress, physical workload, female gender, and poor hydration remain critical determinants of physiological heat strain.

Keywords: Gender, Heat Strain, Heat Stress, PSI, Roof Tile Workers

Introduction

Heat stress is the net heat load to which a worker is exposed, arising from the combined contributions of metabolic heat, environmental factors, and clothing worn, resulting in increased heat storage in the body.[1] The heat stress experienced by outdoor workers usually exceeds a WBGT of 32.1°C.[2] Exposure to heat stress is found in those who work in outdoor environments or workplaces that generate

extreme heat. The roof tile industry involves industrial processes that take place in outdoor and semi-outdoor environments with exposure to heat during the production process.[3] Outdoor workers, especially in tropical and subtropical countries, may experience these conditions for several months each year.[4]

Heat stress in the roofing industry exceeds the threshold, with an average heat stress level of 37.59°C, whereas the neutral temperature range comfortably acceptable to humans is between 21°C to 26°C.[3] The human body generates heat when working and has its own thermoregulatory mechanisms. These mechanisms keep the human body cool by dissipating heat, but this is not the case for workers exposed to heat from a hot work environment.

Continuous work processes characterized by high ambient temperature and humidity, physical workloads that generate metabolic heat, and the use of inappropriate work attire combine to create heat stress hazards.[1] Consequently, the accumulation of these three factors as a heat stress load exceeding threshold limit values results in workers experiencing heat strain.[5–8] Heat strain is a physiological response to heat stress (external or internal) experienced by an individual, whereby the body attempts to increase heat release to the environment in order to maintain a stable body temperature.[1] The potential dangers of working in a hot environment depend on several physiological factors, including increased skin temperature, core body temperature, and heart rate.[9] In addition, this exposure can cause heat-related illnesses and injuries, including heatstroke, heat exhaustion, heat cramps, or heat rash, and even death.[10] Other disorders include various physiological and psychological disorders such as heat stroke, fainting, heat rash, heart failure, kidney disease, systolic heart disorders, male infertility, depression, and stress.[9,11,12]

Several studies have been conducted to identify factors contributing to the serious adverse effects of heat. Responses to heat appear to vary across populations. This is influenced by factors including age, clothing, medical history, gender, BMI, physical activity level, and body size.[13] Indeed, measuring the impact of heat exposure by monitoring physiological changes in workers exposed to heat stress exceeding threshold values is essential. Measurements are taken to prevent the body's inability to dissipate heat, which threatens workers' ability to live healthy and productive lives.[7] With the increase in extreme global temperatures, the public health burden of heat-related illnesses is expected to increase dramatically, serving as an important reminder of the importance of this research.[14–16] Therefore, the objectives of this study are to assess the incidence of heat strain in workers, the factors associated with the incidence of heat strain, and the assessment of heat strain based on gender.

Methods

This study was carried out in July 2025 by involving the entire population of roof tile workers in one of the Karangasem Village Areas, Grobogan, Central Java. The total population of roof tile workers in the village was 2,310 individuals, distributed across 20 Neighborhood Units. Due to the high homogeneity of production processes across the region, a single-stage cluster sampling was employed. One group was randomly selected as the study cluster. Within this selected group, all 115 eligible workers were invited to participate (total population sampling within the cluster). This study involved multiple production sites in 33 home industries. Inclusion comprised workers actively involved in physical production, and exclusion comprised workers unwilling to sign an informed consent form. Ultimately, 107 workers (93%) provided informed consent and were included in the final analysis, while 8 individuals declined. This study used a cross-sectional study design. The dependent variable was PSI, while the independent variables were age, work duration, years of experience, daily water intake, rest hours, and heat stress, history of illness and smoking habits, as well as BMI and workload. Written consent was obtained from all

of the respondents in Indonesia. The Ethics Committee for Health Research, Faculty of Nursing and Health Sciences, University of Muhammadiyah Semarang, reviewed and approved all of the study procedures (certificate number 560/KE/07/2025).

All participants were asked to complete a questionnaire to collect information on individual characteristics, occupational factors, and behavioral characteristics, such as age, work duration, years of experience, rest hours, water consumption, history of disease, and smoking habits. BMI with height using GEA Microtoise and weight measurement using Omron HN 289 Digital Scales. Workload was measured using %CVL formula:

$$\%CVL = \frac{100 \text{ x } (HRwork - HRrest)}{HRmax - HRrest}$$

Heat stress was measured using an Extech HT30 Heat Stress WBGT instrument. Measurements using a heat stress meter are used to measure WBGT according to ISO 7243:2017 by calculating the formula WBGT (OC) = 0.7 Tnw + 0.2 Tg + 0.1 Ta. These measurements were taken while workers were working at 1:00 PM. A total of 105 measurement points were taken, with the measurement points located close to the workers work positions, with three measurements taken each point lasting 10 minutes. The environmental conditions during the measurements included several of a home industry engaged in combustion processes during the study. The procedure for measuring heat strain involved measuring a worker's body temperature with Omron MC-720 Thermometer and pulse rate while working with Yuwell Yx301 Fingertip Pulse Oximeter. These results were then entered into the PSI (Physiological Strain Index) formula to obtain the heat strain result. Heat strain was assessed using the PSI method, which measures heart rate and body temperature.[17] PSI formula:

$$PSI = 5\frac{(Tret - Tro)}{(39,5 - Tro)} + 5\frac{(HRt - HRo)}{(180 - HRo)}$$

Data analysis began with univariate analysis, where individual and job characteristic variables were presented in frequency tables with mean values ± standard deviation or median (minimum-maximum). Bivariate analysis was then performed to analyze factors related to heat strain prevalence using the Pearson correlation test and Spearman rank test for numerical data, and the chi-square test for categorical data. The Kolmogorov-Smirnov test was used to assess normality prior to the correlation test. Significance levels of $p > 0.05$ and $p \leqslant 0.05$ were used to define normality with the Pearson correlation test and non-normality with the Spearman rank test, respectively. An independent t-test was used to compare genders and PSI. All statistical tests were conducted using IBM SPSS 21 under an Academic Institutional License.

Results

As presented in Table 1, the age of roof tile workers in this study ranged from 20 to 57 years, with an average of 38 years. The workers' BMI ranged from 17.40 to 37.02 kg/m2, with an average of 27.21 kg/m2. In terms of work factors, the average working hours were 9.27 hours, with a minimum and maximum working hours of 8 hours and 13 hours, respectively. The average length of service was 8.53 years, with the longest being 20 years and the shortest being 1 year. Workers had an average of 1 hour of rest, and the workload measured by %CVL showed an average of 67.76%, with the highest workload reaching 94% in the very heavy category.

Table 1: Individual characteristics, occupational characteristics and behavioral

Variable	$\bar{x}$ ± SD	Me (Min-Max)
Age (years)	38 ± 9	39 (20 – 57)
BMI (kg/m^2)	27.21 ± 0.44	27.73 (17.40 – 37.02)
Work Duration (Hours)	9.27 ± 1.44	9.00 (8.00 – 13.00)
Years of experience (Years)	8.53 ± 0.35	7.00 (1.00 – 20.00)
Rest Hours (hours)	1 ± 0.02	1.00 (0.50 – 1.50)
Workloads (%)	67.76 ± 1.08	68.50 (39.00 – 94.00)
Heat stress (^{o}C)	37.87 ± 2.22	39.00 (32.4 – 39.7)
Heart Rate (bpm)	134 ± 7.43	134 (112 – 148)
Body Temperature (^{o}C)	37.97 ± 0.18	37.90 (37.60 – 38.20)
PSI	5.05 ± 0.40	5.12 (4.0 – 5.9)
Water Consumption (L/days)	3.81 ± 0.12	4.00 (1.00 – 6.00)
n(%)		
History of Disease		
Yes		35 (32.7)
No		72 (67.3)
Smoking		
Yes		44 (41.1)
No		63 (58.9)

Abbreviations: BMI, Body Mass Index; PSI, Physiological Strain Index; $\bar{x}$ mean; SD, Standard Deviation; n, sample size; Me, Median; Min, Minimal; Max, Maximal; C, Celcius; L, Litre; bpm, beats per minute.

On the other hand, heat stress measurements in the working environment of roof tile makers showed an average of WBGT = 37.44°C, with the highest heat stress being 39.7°C. On the other hand, the average heart rate of roof tile makers while working was 134 bpm, with the highest being 148 bpm, and the average body temperature was 37.9°C, with the highest being 38.20°C. It is important to note that the PSI score for roof tile workers, which indicates the incidence of heat strain, showed an average of 5.05, with the highest score being 5.9. Most workers had no history of illness (67.3%), while 32.7% had a history of illness. Meanwhile, 41.1% of roof tile workers smoked, while 58.9% did not smoke. Regarding water consumption habits, roof tile workers had an average consumption of 3.81 liters (Table 1).

The body temperature data peaks sharply at two key points: 37.90 and 38.20. This is known as a bimodal distribution (having two peaks). The results of body temperature measurements of workers, grouped by gender, show that the highest temperature, 38.20°C, occurred in both women and men. In contrast to body temperature, heart rate data spread much more widely, ranging from 112.00 to 148.00. In addition, the maximum heart rate of 148 bpm was observed among male workers.

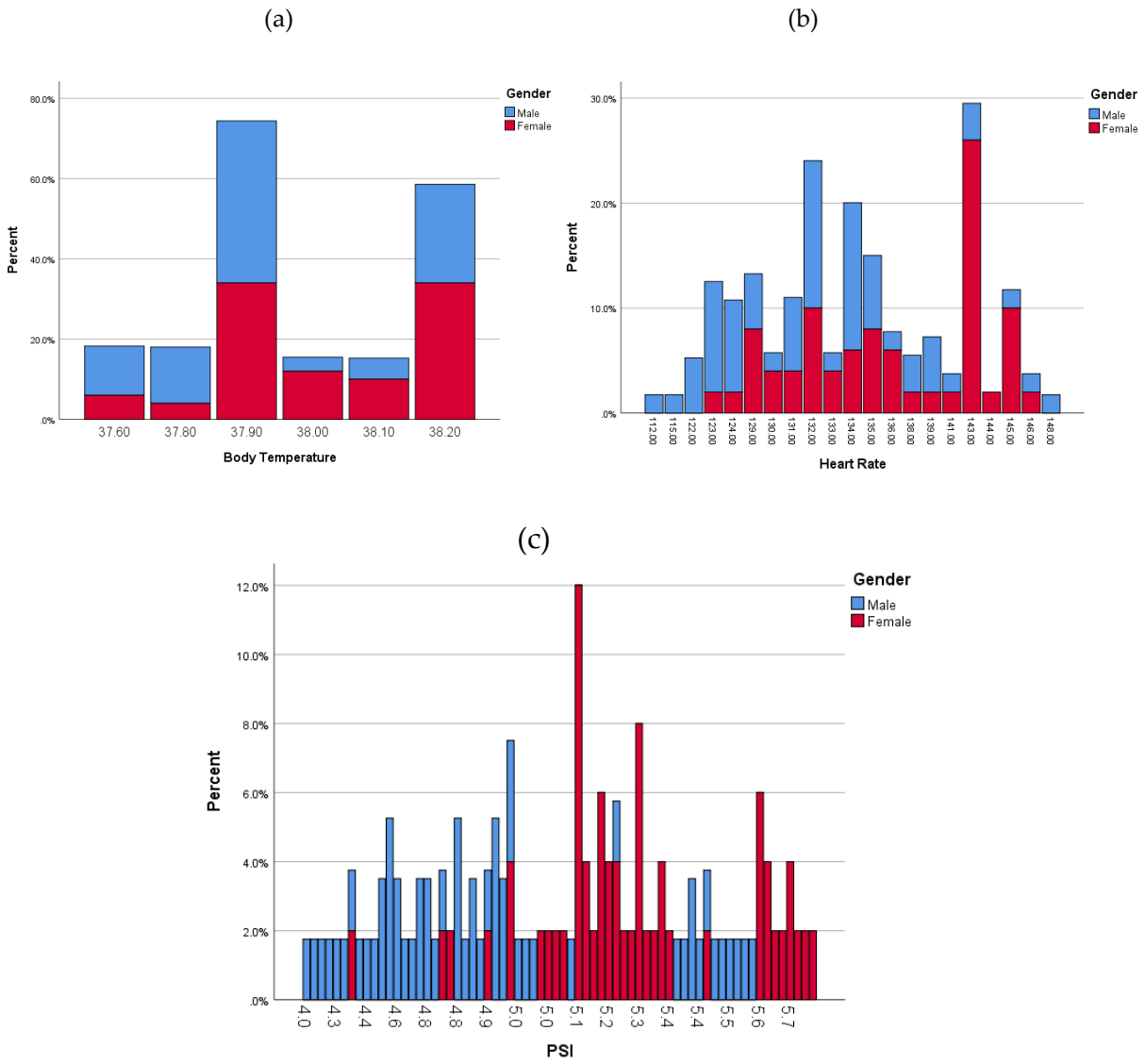

Figure 1: Results of body temperature [(a)], heart rate [(b)], and PSI [(c)] measurements based on gender grouping of roof tile workers

Table 2: Independent Test

Variable	Gender	n	Mean±SD	t	df	p-values
PSI	Male	57	4.86±0.39	-6.16	101.29	0.000
	Female	50	5.27±0.28			

Statistical test performed: Independent t-test

Female roof tile makers were the subject of research due to their low capacity to dissipate heat when exposed to heat stress.[18] This heat exposure can cause fatigue in workers.[10,19] Female workers are at greater risk of fatigue than male workers due to their smaller body size and muscle mass as a result of hormonal influences and the double burden of being a housewife,[20–22] thus, heat exposure exacerbates the condition of female workers (Table 2).

Table 3: Correlation Factors to Heat Strain among Workers

Variables	*r*	*p-value*
Age (Years)	-0.279 [b]	0.004*
BMI (kg/m²)	0.220[b]	0.023*
Work Duration (Hours)	0.180[a]	0.064
Years of experience (Years)	0.065 [a]	0.504
Daily Water Intake (L/days)	-0.238 [b]	0.014*
Rest Hours (Hours)	-0.506[c]	<0.001*
Heat Stress (°C)	0.232 [b]	0.016*
Workload (%)	0.334 [b]	<0.001*

*Abbreviations: BMI, Body Mass Index; PSI, Physiological Strain Index; SD, Standard Deviation; n, sample size; r, correlation coefficient. Statistical test performed: Spearman's rank test for age, work duration, years of experience, daily water intake, rest hours, and heat stress. Pearson correlation test for BMI and workload. *p<0.05. Correlation coefficient: a, very weak; b, weak; c, moderate.*

The correlation analysis results indicated that age, BMI, daily water intake, heat stress, and workload were weakly correlated with the incidence of heat strain. Meanwhile, rest hours showed a moderate correlation. Conversely, work duration and years of experience (work tenure) did not correlate with heat strain among roof tile manufacturing workers in Grobogan (Table 3).

Table 4: The Association between Smoking Habits and History of Disease with Heat Strain among Workers.

Variables	**PSI** n(%)			*p*
	All Respondents (n=107)	**Score 4.0-4.9 (n=48)**	**Score 5.0-6.0 (n=59)**	
History of Disease				
No	72 (100.0)	26 (36.1)	46 (63.9)	0.013*
Yes	35 (100.0)	22 (62.9)	13 (37.1)	
Smoking				
No	63 (100.0)	26 (41.3)	37 (58.7)	0.432
Yes	44 (100.0)	22 (50.0)	22 (50.0)	

*Statistical test performed: Chi-square test for categorical variables. *p<0.05*

Furthermore, the association test for categorical data was conducted using the Chi-square test. The results showed an association between history of disease and heat strain among heat-exposed workers, specifically roof tile manufacturing workers. In contrast, the results indicated no association between smoking habits and the incidence of heat strain (Table 4).

Discussion

This study highlights the severe heat exposure experienced by roof tile workers in Grobogan, both in outdoor and semi-outdoor environments. Outdoor working conditions occur during the initial stages of the process, when workers prepare the soil, dry the roof tiles and transport large quantities of tiles under the hot sun. Meanwhile, semi-outdoor roof tile workers refer to traditional home industry roof tile workers in Indonesia who work in huts with roofs but no

walls or partially shaded walls. This condition usually apply among preparation workers, namely roof tile molders, seset workers, and burners. Several factors tested in this study explain the relationship with the occurrence of heat strain in workers exposed to this heat.

A critical contribution of this study is its empirical validation of thermal dimorphism in an occupational setting. Our findings demonstrate that women are significantly more susceptible to elevated Physiological Strain Index (PSI) than men, which aligns with, yet contextually expands upon, previous thermoregulatory studies.[23] Analytically, this heightened vulnerability is not merely a function of exposure but of inherent physiological capacities: women exhibit a higher core body temperature threshold for the onset of sweating and possess a greater percentage of adipose tissue. In the context of heavy occupational labor, this adipose tissue acts as a formidable insulator, accelerating thermal storage. Furthermore, our findings suggest that the lower baseline aerobic capacity in women exacerbates the relative cardiovascular load. When this biological predisposition is coupled with socio-cultural evaporative resistance (e.g., closed clothing), it creates a compounding effect, resulting in sharper increases in core temperature and heart rate compared to men under identical heat exposure.[23]

Age is a significant determinant of heat strain due to the progressive decline in thermoregulatory function and cardiovascular capacity associated with aging. Older workers exhibit a lower core temperature threshold and a delayed sweating response compared to their younger counterparts when exposed to extreme heat.[24] This is corroborated by findings indicating greater body heat storage and higher core temperatures in older adults compared to younger individuals.[25] Consequently, advancing age is linearly associated with increased vulnerability to heat stress-related health disorders. A high Body Mass Index (BMI) contributes to heat strain through the mechanism of thermal insulation provided by adipose tissue, which hinders the dissipation of internal body heat. Previous studies demonstrate that individuals with an above-normal BMI experience a heavier cardiovascular load and reduced evaporative cooling efficiency.[26] Furthermore, a study emphasizes that obesity increases internal metabolic heat production while simultaneously decreasing the body surface area-to-mass ratio available for heat dissipation.[5] Therefore, workers with a high BMI (obesity) face a significantly greater risk of experiencing a drastic rise in body temperature during physical exertion.

A history of chronic diseases, such as hypertension and diabetes, directly impairs physiological mechanisms for dissipating heat to the external environment via the autonomic nervous system. Patients with non-communicable diseases often experience microvascular dysfunction, which significantly limits cutaneous heat loss.[25,27] These findings are supported by previous studies explaining that certain medical conditions, as well as the side effects of their treatments, can disrupt body fluid balance and cardiac response to thermal stress.[28] In conclusion, a poor medical history serves as a risk factor that compromises a worker's tolerance threshold for occupational heat exposure. In addition, the results of this study show that there is a relationship between daily water intake and heat strain measured using the Physiological Strain Index (PSI) in critical workers. This study explains that the less water workers consume, the higher the risk of their PSI score. Insufficient fluid intake leads to a decrease in blood plasma volume, which results in an increased heart rate and an accelerated rise in core body temperature in response to physiological compensation for heat.[29] Dehydration conditions also reduce the efficiency of sweat evaporation making the body's cooling mechanism becomes less effective and increases the PSI value of.[2]

These findings are in line with a research in outdoor workers that showed that hydration status was directly related to an increase in

physiological heat strain indicators, including PSI.[30] Another study reported that workers with low daily water consumption had a higher risk of developing heat strains despite working at the same level of heat stress.[31] More importantly, our findings robustly validate recent international occupational health guidelines (such as those from NIOSH or ACGIH), which emphasize that proactive, structured fluid replacement protocols, rather than relying solely on the physiological sensation of thirst, are imperative. Thus, adequate fluid intake is an important protective factor in controlling heat strain in jobs with high heat exposure, such as tile.[29] In addition to hydration factors, the results of this study show that rest hours have a meaningful relationship with heat strain in critical workers. Workers with shorter rest durations tend to experience a faster increase in the Physiological Strain Index (PSI), which reflects the body's inability to recover optimally from physiological conditions before being exposed to heat again.[32] Previous experimental research has shown that the effectiveness of physiological recovery is strongly influenced by environmental conditions during rest.[33] The study reported that recovery of core body temperature and heart rate could be optimally achieved within 15–30 minutes when workers rested at a standard effective temperature of around 18.8–24.9 °C, while recovery was slower when rest conditions were less favorable.[33] These findings reinforce the concept of occupational physiology that adequate rest time provides an opportunity for the body to lower core temperature and cardiovascular load before subsequent heat exposure.[33]

We found that the association between PSI and smoking habits, then the correlation work duration, and work experience was not affected. This is because heat strain indicates that workers' physiological responses are more influenced by other factors, such as workload and environmental factors. Workers have naturally acclimatized, and the effects of the hot environment are far more pronounced than the long-term vasoconstriction effects of nicotine. Recent physiological comparisons demonstrate that under acute heat stress, both smokers and non-smokers exhibit similar magnitudes of compensatory vasodilation, rendering baseline arterial differences statistically insignificant during peak exposure.[34] This empirical perspective aligns with the broader occupational physiology consensus: the immediate, acute severity of radiant heat and heavy physical workload dictates physiological strain far more decisively than baseline lifestyle habits. In line with this, research on outdoor workers reports that inadequate management of rest periods contributes to the accumulation of body heat and an increased risk of heat strain. Such event taking place, especially in sectors with high heat exposure and physical workloads, such as construction and manufacturing.[31] In contrast to individual and organizational factors, heat stress is the main environmental factor that is directly related to heat strain in critical workers.

This study shows that the higher the WBGT heat stress, the higher the PSI score the worker receives. The increase in environmental heat stress, which is affected by air temperature, humidity, and heat radiation, causes an increase in the external heat load received by the worker's body.[35] In response to the condition, the body increases blood flow to the skin and heart rate to maintain temperature balance, which ultimately increases the Physiological Strain Index (PSI) value.[8] Recent research shows that in hot and humid environments, the relationship between heat stress and heat strain becomes stronger due to inhibition of the sweat evaporation process.[36] In addition to exposure to environmental heat, workloads have also been shown to be related to heat strain in critical workers. Workers with higher physical workloads exhibit greater Physiological Strain Index (PSI) values, which reflect increased metabolic heat production during work activities.[37] Increased workload leads to an increase in oxygen requirements and heart rate, thereby accelerating an increase in core body temperature and physiological

strain.[30,38] Previous studies have also confirmed that the combination of high workload and environmental heat stress significantly increases the risk of heat strain compared to a single exposure to each factor, making workload control a crucial aspect in preventing heat disturbances.[39]

Despite its significant findings, this study had limitations like methodological limitations. First, the cross-sectional design captures physiological and environmental data at a single point in time, restricting the ability to establish definitive causal relationships or observe dynamic physiological acclimatization over time. Second, the research was confined to a single occupational setting traditional roof tile industries in Grobogan. This specific context, characterized by unique semi-outdoor microclimates and manual workloads, limits the generalizability of the findings to other geographical regions or mechanized industrial sectors.

Furthermore, there are inherent constraints regarding environmental measurement variability. Environmental heat stress (measured via WBGT) in these settings fluctuates continuously, meaning point-in-time readings may not fully capture the cumulative thermal burden experienced by workers throughout their shifts. Finally, we encountered operational challenges typical of extreme field research, including respondent fatigue exacerbated by hot weather and heavy workloads. While mitigating the risk of nonparticipation by educating respondents about the study's occupational health benefits, maintaining absolute procedural consistency in such rigorous, uncontrolled environments remains a practical limitation.

Conclusion

Roof tile workers who work outdoors and in partially shaded environments in this study show high exposure to heat stress. This exposure result in physiological changes in the roof tile workers, as indicated by body temperature and pulse rate measurements with low and moderate PSI results. The results explain that factors not associated with heat strain incidents are length of service, working hours and smoking habits. In contrast, factors such as age, BMI, daily water intake, rest hours, heat stress, and workload are associated with heat strain. Based on gender, the highest PSI scores are observed among female workers, highlighting the need for management of physical workload and duration of heat exposure, particularly for female workers. Based on the current findings, where the Physiological Strain Index (PSI) among workers predominantly falls into the moderate category. More importantly, subsequent studies must transition from observational designs to interventional research. We strongly recommend implementing and evaluating targeted occupational heat management strategies. Future interventions should focus on engineering and administrative controls such as enforcing structured work rest cycles in climatically optimized recovery areas, establishing proactive hydration protocols, and applying localized shading to prevent this moderate physiological strain from escalating into severe, acute heat-related illnesses.

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Original Article

Awareness of farmers regarding pesticides and their effects on health and environment: A cross-sectional study at Chisapani village

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ABSTRACT

Introduction: Over 66% of the population in Nepal is engaged in agriculture, where pesticide exposure is a common issue among farmer. The shortage of personal protective equipment (PPE) and inadequate education on proper PPE use and spraying techniques further increase the risk of pesticide exposure. As pesticides are essential for agriculture and public health, this study aims to assess farmers' awareness regarding pesticides and their effects on health and the environment.

Methods: A cross-sectional study was conducted from 5th August to 5th November 2025 in Chisapani village of Baijanath Rural Municipality using convenience sampling. Ethical approval was obtained from the Institutional Review Committee. A total of 100 farmers who had been farming for more than 6 months were included in the study.

Results: Among the respondents, 74% perceived pesticides as poison; however, more than half (51%) had used them for 5 to 10 years. The highest proportion, 45% used pesticides for growing both vegetables and grains and 95% sprayed two to three times per month. More than half (52%) do not use any personal protective equipment. Only 23% knew the correct use, 30% checked the expiry date and type and 22% followed the proper directions of use. Health effects were reported by 29%, and 20% reported chronic long-term effects. Respondents who agreed that pesticides affect the environment (the pesticides contaminate surface and groundwater and soil, air, and target and non-target vegetables) were 97 %.

Conclusion: The study found a gap between awareness and safe pesticide-use practices among farmers. Most respondents recognize pesticides as poisonous but continue to use them for years, two to three times per month. Although farmers have experienced health issues, many continue to ignore them and still lack safe practices.

Keywords: Chisapani, environmental effects, farmers, health effects, pesticide use.

Introduction

Over 66% of Nepal's population is engaged in agriculture, among whom pesticide exposure is a common issue.[1] Annually, pesticide use increases by 10–20%, with an average application of 396 grams per hectare, and commonly used pesticides are organochlorines (such as Benzene Hexachloride and Dieldrin), organophosphates (including ethyl parathion and methyl parathion),

carbamates, and synthetic pyrethroids in Nepal.[2] However, farmers often lack awareness about types of pesticides, levels of their toxicity, safety precautions, as well as risks they pose to human health and the environment.[1,3] Shortage of personal protective equipment (PPE) and inadequate education on proper PPE use and spraying techniques further make farmers prone to risk of pesticide exposure, as pesticides, these days, are vital for agriculture and public health.[4] A study reports that the majority of participants were well aware of the symptoms of poisoning, such as nausea, vomiting, dyspnea, throat itching, skin irritation, dermatitis, dizziness, headache, eye irritation, burning, and tachycardia affecting the cardiovascular system. They were also aware of chronic effects such as cancer, fetal death, infertility, birth defects and miscarriage because of long-term use of pesticides. Despite this, pesticides are still widely used.[5]

The increasing trend in pesticide use by 10%–20% each year in Nepal, with more than 90% in vegetable products.[6] Although the knowledge of farmers on the use of pesticides is moderate, they have high knowledge of the risks of pesticide use to the environment and health.[7,8] A study from Nepal reports that 66.2% of the participants had a negative attitude toward the use of pesticides, still driven by the aim of increasing vegetable production and income.[9,10] Therefore, the study aims to assess the awareness of farmers regarding pesticides and their effect on health and the environment to fill the gap.

Methods

A descriptive cross-sectional study was conducted from 5th Aug 2025 to 5th Nov 2025 in a rural Chisapani village of Baijanath Rural Municipality, Ward Number One, in Banke District of Lumbini Province of Nepal. Farmers who had been involved in farming for more than six months were included, while those with less than six months of experience were excluded. Convenience sampling was used after obtaining ethical approval from the Institutional Review Committee (Reference number: 07/082-083). Formal permission was obtained from the Chairperson of the ward office. Sample size was calculated using the formula:

$n = z^2 pq/e^2$

Sample size (n) = $[1.96^2 \times 0.61 \times 0.39] / [0.1]^2 = 91.39$

z = 1.96 (within 95% Confidence Interval)

p = Expected proportion of previous studies where farmers knew the harmful effects of pesticides = 61% = 0.61* [4]

q = 1-p (1-0.61=0.39)

d = Allowable error or precision. Usually, it is taken as 10% (0.1).

Therefore, the final sample size was 100.

An interview was conducted among 100 farmers through a face-to-face interview and all those farmers who had been involved in farming for more than six months were included in the study. And those who have just started farming and have not completed six months were excluded. The data were collected and entered into Microsoft Excel 2016 and analyzed using the Statistical Package for the Social Sciences (SPSS) Version 24. Descriptive statistics (mean, standard deviation, frequency, percentage) were calculated.

Results

The highest proportion of respondents, 45 (45%), had attended primary school, followed by 35 (35%) who were illiterate, while only 20 (20%) had completed secondary or higher education. The majority, 86 (86%) were Hindu, by religion, while 7 (7%) were Christian and 7 (7%) were Muslim. More than half, 53 (53%) were female, and 47 (47%) were male. All respondents (100%) were adults aged 19 years or older and married. Most of them were from rural areas 71 (71%) and 24 (24%) were from semi-urban areas, and only a few were from urban areas 5 (5%).

However, among the farmers who have been interviewed, the majority, 85 (85%), practiced commercial farming, and only 15 (15%) practiced non-commercial farming. The majority of them, 41 (41%), had been working for more than 10-19 years, followed by 30 (30%) working for 20-30 years, as depicted below.

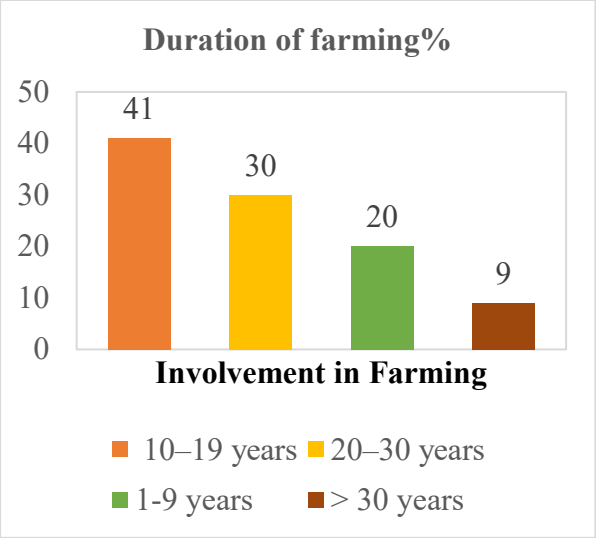

Figure 1: Showing the duration of involvement in farming

According to the respondents, pesticides were perceived as poison by the majority (74%). However, 26 (26%) thought it was a good fertilizer for growing crops. More than half of the respondents (51%) had been using pesticides for 5 to 10 years, as shown in Figure 2 below.

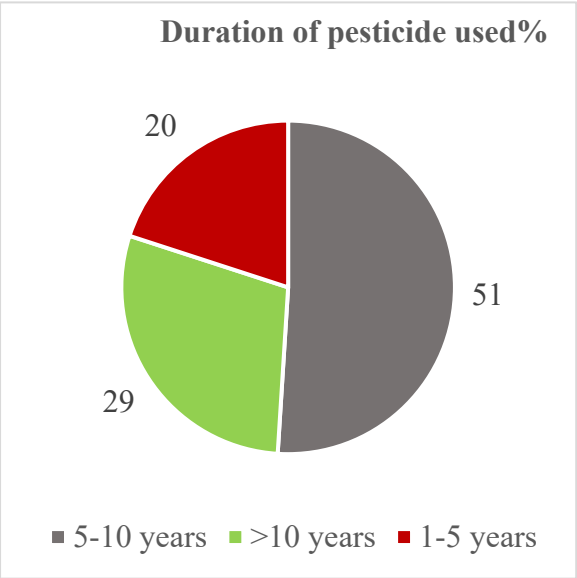

Figure 2: Duration of pesticide use by farmer

The majority of farmers used pesticides for growing both vegetables and grains, 45 (45%), followed by 31 (31%) for all types of crops, as shown in Table 1 below. The farmers usually 95 (95%) sprayed pesticides two to three times per month and 5% sprayed more than three times per month.

Table 1: Types of crops where pesticides are used/time

Types of crops and pesticides use/time	n (%)
Both vegetables and grains	45 (45%)
For all types of crops	31 (31%)
Only grains	20 (20%)
Only vegetables	4 (4%)

More than half 52 (52%) do not use any personal protective equipment (PPE) and 48 (48%) do use PPE to protect themselves from pesticide exposure. Among those who used PPE, 17(17%) used a mask, 19 (19%) used gloves, and the rest, 22 (22%) of respondents, either used two or three of these items, such as a mask, gloves, cap, boots, and spectacles. However, none of them used the proper full PPE. Only 19 (19%) have taken IPM (integrated pest management) training; however, 81 (81%) have not taken it.

Farmers' awareness regarding mode of entry into the human body: 56 (56%) responded that it enters through the skin, 24 (24%) through the mouth, 14 (14%) through the skin, and 6 (6%) through inhalation. According to them, pesticide storage, 74 (74%) agreed that pesticides should not be stored indiscriminately inside the house, and 26 (26%) thought they should not be stored outside the house as rain and air decrease their efficacy. The majority, 77 (77%), of farmers use pesticides incorrectly based on their convenience without reading the label and correct dose and use instructions, and only 23 (23%) knew the correct use of pesticides and also always read the label carefully on the bottle while purchasing pesticides. However, the majority, 70 (70%) do not check for expiry dates and types of pesticides.

When purchasing them, only 30 (30%) check the expiry date and the types of pesticides. In total, 78 (78%) do not follow the proper directions for pesticide use on the label, and only 22 (22%) do.

Health effects were reported by 29% of respondents who fell ill in the last month after they sprayed pesticides. However, the majority have still not noticed 71 (71%). Among those who fell ill, 20 (20%) of them reported more than two symptoms such as headache, skin irritation, burning of the eyes, dizziness and extreme tiredness, and 9(9%) only had skin irritation.

The majority (97%) of farmers agreed that pesticides are harmful to their health; still, they've been widely used, while very few (3%) disagreed. The majority of them, 43 (43%), ignored these signs and symptoms by taking a few days' rest, followed by 26 (26%) who consulted with a healthcare worker nearby, 22 (22%) who consulted with doctors after falling sick, and 9 (9%) who used home remedies/self-medication. Only 20 (20%) agreed that they have experienced chronic health issues due to long-term use of pesticides, and the remaining 80 (80%) have not.

Table 2: Effects of pesticide use on health

Effect on health due to the use of pesticides	n (%)
Fell ill last month after the application of pesticide to crops	29 (29%)
The respondent noticed these multiple signs and symptoms, such as headache, skin irritation, burning of eye, dizziness, extreme tiredness, skin irritation etc.	20 (20%)
Pesticide use is harmful to health	97 (97%)
Ignore the treatment	43 (43%)
Long-term effect	20 (20%)

A total of 97% of respondents agreed that pesticides have harmful effects on the environment, including contamination of soil, water, and air. Also, 98 (98%) respondents agreed that pesticides contaminate the air and target non-target vegetation, and 2 (2%) disagreed.

The majority (97%) responded that pesticides have long-term effects that can undermine the sustainability of farming practices, while three percent responded that they do not. However, all (100%) agreed that pesticide use is harmful to the environment.

Table 3: Effect of pesticide use on the environment

Effect on the Environment due to pesticide use	n (%)
Contaminate the surface and ground water	97 (97%)
Contaminate soil	97 (97%)
Effect on air and target non-target vegetation	98 (98%)
Long-term effects on sustainability	97 (97%)
Pesticides are bad for the environment	100 (100%)

Discussion

The study findings highlight important socio-demographic and occupational characteristics influencing pesticide use and safety practices among farmers as most respondents had low educational levels with 45% completing only primary education, and 35% being illiterate. Similar educational patterns were reported among Nepalese farmers in studies conducted in Tokha Municipality and Bhaktapur, where limited literacy was associated with inadequate knowledge of pesticide labeling and safe handling practices, as in the present study. Also, only 23% knew the correct use, 30% check expiry dates and types of pesticide and 22% follow the proper directions of use.[1,8] Low literacy levels may explain why 77% of respondents in our study reported using pesticides based on convenience rather than label instructions, and 70% did not check expiry dates.

The rural residents seem to have predominance, as 71% of residents and are doing commercial

farming, 85%, suggesting a high level of occupational exposure. Also, a long duration of farming involvement for more than 10–19 years among 41% and pesticide use for five to ten years among 51% suggest chronic cumulative exposure. These findings are comparable to those observed in Panchkhal Municipality and Rupandehi District, where prolonged exposure to pesticides was common among experienced farmers.[5,6] The frequent spraying pattern, 95%(applying pesticides two to three times per month), is consistent with increasing pesticide dependency in vegetable farming reported in the Bharatpur Metropolitan City study.[10]

Although 74% of respondents understood pesticides as "poison," misconceptions still existed, with 26% perceiving them as fertilizers. This gap between perception and practice aligns with findings from Lamatar Village Development Committee, where knowledge did not necessarily translate into safe practice.[9] Furthermore, only 19% had received Integrated Pest Management (IPM) training, similar to studies in Southern India and Malaysia that reported limited formal training.[4,7] The use of personal protective equipment (PPE) was inadequate, with 52% not using any form of protection and none using complete PPE. Similar poor compliance with PPE use has been documented in Nepalese studies, including those in Tokha, Panchkhal, and Lamatar.[1,6,9] The lack of full protective measures increases dermal and inhalational exposure, which corresponds with our finding that 56% correctly identified skin as the major route of entry, yet did not consistently protect themselves.

Health effects reported in the present study include headache, skin irritation, burning eyes, dizziness, and fatigue. These are consistent with the acute pesticide-exposure symptoms described in previous Nepalese and international studies.[2,3,4,9] Although only 29% reported illness in the past month, 20% acknowledged chronic health problems, reflecting potential under-reporting or normalization of symptoms. A concerning observation is that 43% ignored symptoms, opting only for rest rather than seeking medical care, similar to findings in Rupandehi and Bhaktapur where self-medication and neglect were common practices.[5,8,11]

Environmental awareness was notably high in our study. Nearly all respondents agreed that pesticides contaminate water, soil, and air, and negatively impact non-target vegetation and long-term agricultural sustainability. These findings align with national reviews highlighting environmental contamination and ecological imbalance due to excessive pesticide use in Nepal.[2,3,12-14] However, as observed in other Nepalese contexts, awareness of environmental harm does not necessarily reduce usage patterns.[10] Similarly, all of them agreed that pesticide use is not good for the environment. These findings were consistent with those reported from other studies.[12,15]

Conclusion

This study's findings suggest there is a gap between awareness and safe practice regarding pesticide use among farmers, as most respondents recognize pesticides as poisonous but still have been using them continuously for years, two to three times per month, increasing the potential for cumulative exposure. Despite this, the use of PPE and safe handling practices remains inadequate. Although farmers have experienced health issues, many continue to ignore them. Environmental awareness appears to be comparatively higher, as almost all agreed that pesticides contaminate surface and groundwater, soil, air, and affect both target and non-target crops. However, this awareness has not translated into safer practices or reduced their use. So, there is an urgent need for structured training programs on a regular basis and community-based awareness initiatives to promote safe pesticide handling, encourage the use of personal protective equipment, and reduce both health and environmental hazards through mass media (TV, radio, or by use of flip chart, pamphlets), etc.

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Original Article

Community diagnosis of occupational health problems according to informal sector actors working in the city of Ouagadougou, Burkina Faso

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ABSTRACT

Introduction: Occupational health promotes physical, mental and social well-being of all workers in their jobs. In Burkina Faso, however, it hardly covers the informal sector. The study aimed to analyze the occupational health problems perceived by informal sector workers in the city of Ouagadougou in 2024.

Methods: We conducted an exploratory qualitative cross-sectional study through semi-structured individual interviews using an interview guide. It included workers of informal sector coming from trade, services and industrial domains and managers of structures working with them. A thematic analysis was carried out using NVIVO 14 software.

Results: Unhealthy working conditions, occupational hazards and inaccessibility to occupational health services were the problems cited by workers. Deficiency of knowledge on these risks, regulatory obligations and the use of personal protective equipment were cited as causes of occupational hazards. The causes of occupational health services inaccessibility were lack of information on these services, the lack of organization of the sector and the focus on the formal sector. The solutions proposed were legal, medical and technical.

Conclusion: Informal workers are confronted to a range of health problems. Their needs should be highlighted in the country's occupational health and social protection policies and strategies.

Keywords: Burkina Faso, informal sector, occupational health

Introduction

Occupational health is a multi-disciplinary and essentially preventive domain of health sciences which is in charge of social, mental and physical well-being of workers.[1] It is recognized as a right of every worker and contributes to decent work.[2] According to International Labor Organization's statistics, in 2019, more than 395 million workers worldwide had a non-fatal occupational injury and 2,93 million work-related deaths were recorded.[3] Occupational health is therefore a major global concern, especially as almost 70% of

workers don't access to social protection in case of occupational disease or injury.[4]

Informal sector is made up of loosely-organized, small-scale enterprises that create jobs and income through the production of products or services.[5] Employment links, when existing, are essentially based on occasional employment, kinship or personal and social connections, instead of formal contracts.[5,6] This sector represents two billion workers aged 15 and over worldwide.[7] It is not easily regulated by governments, including in occupational health safety.[8]

In Burkina Faso, in 2022, statistics showed 1803 occupational hazards, including 1787 occupational injuries et 16 occupational diseases.[9,10] At the same time, less than 3% of the country's workers were registered with the social security system.[11] Although characterized by a lack of statistics on occupational hazards, this informal sector of the national economy seems particularly confronted with precarious working conditions, and sometimes does not considered occupational health and safety as a priority.[10] The consequences of this include insufficient occupational risk prevention measures within the sector's activities. In addition, poor working conditions and low social protection in the informal sector increase the incidence of occupational diseases, leading to a drop in productivity that impacts both the worker and the company.[12]

Significant efforts are made in this domain at political and operational levels. This includes ratification of international conventions, adoption of laws and creation of structures to govern and regulate the field. However, in the informal sector which represents 70% of all jobs in the country, practical difficulties remain in terms of implementing and monitoring these texts.[10] In this situation, the study of occupational health issue in the informal sector and the taking account of the needs of this sector is of major interest in Burkina Faso. The present study therefore aims to analyze the occupational health problems perceived by the informal sector workers in the city of Ouagadougou in 2024.

Methods

It was a qualitative exploratory cross-sectional study conducted in the city of Ouagadougou from December 2023 to September 2024. It involved workers from informal sector and stakeholders coming from structures working with them found relevant to the study theme. Informal sector workers were those working in an informal enterprise without a tax registration number and/or a trade register number and/or a declaration or voluntary insurance with the national social security fund. They came from the three informal sectors defined in 2018 by the National Institute of Statistics and Demography (trade, industry and services). In practice, the concerned were retail and wholesale for the trade sector, and hairdressing, beauticians, tailoring, catering and mechanics for the services sector. The industrial sector was represented by the building and public works industry with painting and masonry trades. The managers included in the study came from state and two association structures. The state structures were the occupational health and safety directorate, the occupational medical inspectorate, the national fire brigade, the regional directorate of the workers' health office and an occupational health service of the said Directorate, present at the Ouagadougou central market.

The inclusion criteria for workers were to work in the city of Ouagadougou's informal sector, be a member of informal trade organization and not work simultaneously in the both sectors (formal and informal) and agree to participate in the study. The sample size for each of the professions included in the study followed the principle of saturation. This meant that data collection was closed when exchanges with participants no longer provided any significant new information. Using an interview guide, semi-structured individual interviews were therefore conducted with the different participants from April to July 2024. A total of 51 stakeholders, including 44

workers, were interviewed in their preferred language by the principal investigator, and recorded for those who consented. The audio data collected was then translated into French for those in local languages, and fully transcribed. They were then encoded and analyzed according to themes using NVIVO 14 software. The Encoding frequency corresponded to the number of mentions of the problem in all the interviews. The consent of each participant was obtained before the interview.

Results

The study population comprised 44 workers and 7 structural representatives. The workers were drawn from nine informal occupations, and included an equal number of men and women. The average age of the workers was 36.07 years, with extremes of 16 and 67 years.

The analysis identified deleterious working conditions, occupational hazards (occupational injury and disease) and inaccessibility to occupational health services (OHS) as problems perceived by workers in the informal sector (Table 1).

Table 1: Occupational health problems mentioned by frequency of encoding

Problems	Encoding frequency*
Deleterious working conditions	**327 (45, 54%)**
Exposure to biological hazards	
Exposure to chemical hazards	
Exposure to physical hazards	
Exposure to ergonomic hazards	
Exposure to psychosocial hazards	
Occupational hazards	**304 (42, 34%)**
Occupational injury	
Occupational disease	
Inaccessibility to occupational health services (OHS)	**87 (12, 12%)**
Inaccessibility to workers' health office	
No coverage of occupational hazards	

Note: * Encoding frequency: Number of mentions of the problem in all interviews

Table 2: Comments on occupational health problems mentioned by participants

Problems	Comments
Deleterious working conditions	"In terms of paint, there are several qualities, there are qualities where the chemicals are strong or when you rub the coating it releases dust often when you vacuum it remains at nostril level and when you spit you see it there." Painter 3
Occupational hazards	"Catering causes accidents, but I've only been a victim once. My hand was badly burned by hot water." Cook 3 "He does his work informally, (...) a guy got burned on a pole, an electric pole here like this." Head doctor of an occupational health service
Inaccessibility of OHS	"It's the fact that mechanics don't benefit occupational health services." Mechanic 5 "They don't set up occupational health services, nor do they join the workers' health office so that workers can benefit from medical check-ups, workplace surveillance, issues of awareness and education for behavioral change. All these aspects are not taken into account in the informal sector. Manager of the occupational medical inspectorate

The problems identified as priorities by all participants were occupational hazards and inaccessibility to occupational health services. The causes of these priority problems are summarized in table 3. The solutions proposed by participants were medical, technical and legal (table 5)

Table 3: Frequency of encoding evoked causes based on priority problems

Causes	Encoding frequency*
Occupational hazards	**301 (49, 67%)**
Insufficient knowledge of occupational hazards and legal requirements No use of personal protective equipment	
Inaccessibility to occupational health services Lack of information Lack of organization in the sector Emphasise on formal sector	**219 (36, 14%)**

* Encoding frequency: Number of mentions of the cause in all interviews

Table 4: Comments of occupational health priority problems causes mentioned by participants

Causes	Comments
Occupational hazards	"It's like I told you; we don't know what we're doing. As soon as we see the money, we ruch in." Hairdresser 1 "It's difficult for the inspectorate to know that there's a company out that must be check, whereas it's through the labor inspectorate's control that we can obliged employers to apply the laws". Manager of the occupational medical inspectorate
Inaccessibility to OHS	"It's a good thing, but I didn't even know it existed. Retailer 5

Table 5: Solutions to priority problems by number of encoding references

Solutions suggested	Encoding frequency*
Technical Knowledge enhancement Appropriate communication	**173 (51, 18%)**
Legal Formalization Occupational hazard compensation Comfortable and adapted individual protective equipment Coercive measures	**103 (30, 47%)**
Medical Accessibility to workers' health office Occupational hazards management Regular medical checkups	**57 (16, 86%)**

Note: * Encoding frequency: Number of mentions of the solution in all interviews

Discussion

The study permitted to gather the perceptions of informal sector workers on the occupational problems they face. Deleterious working conditions, occupational hazards and inaccessibility of occupational health services were the problems mentioned. Occupational hazards and inaccessibility of OHS were the problems unanimously identified as priorities. Lack of use of personal protective equipment (PPE), insufficient knowledge of occupational hazards and legal requirements were the causes cited for occupational hazards. The reasons given by participants for OHS inaccessibility included a lack of information on these services, a lack of organization in the sector, and a focus on the formal sector to the detriment of the informal. The solutions proposed by participants to resolve the priority problems were legal, medical and technical.

Our study found that working conditions were a health problem for workers in the informal sector. This could be explained by the fact that, although these workers are often aware that their working conditions are deleterious, many of them do not always have sufficient financial resources to make the necessary improvements.[10,13] Furthermore, even among those who do have the financial capacity, some refuse to do so due to the lack of real sanctions, despite legal requirements in our context or because of a lack of culture of prevention. Still others choose the informal sector to avoid tax constraints or because of their low education level, but as mentioned earlier, a large proportion of workers do so because of their insufficient resources. [6,14] They haven't access to conventional credit structures and rely on their own savings, their families or tontines to set up their businesses.[10,15] These funds are often insufficient and the profits minimal. The priority remains meeting daily sustenance.[10] Rossier and al also found in 2021 in Burkina Faso that incomes in small-scale informal sector activities were low and insufficient, and working conditions often precarious.[13] State initiatives to finance the informal sector therefore need to be stepped up.

Occupational hazards were also a health problem in the informal sector. This could be explained by the fear they inspire in workers, due to their frequency and their health and economic consequences.[16,17] In Burkina Faso's informal sector, the majority of workers are self-employed.[10] They live from day to day, with irregular incomes that fluctuate with the clientele. In this context, occupational injuries and diseases represent an immediate loss of income for the worker and his family, due to the resulting days not worked.[18] They can also cause a loss of financial autonomy for workers and their families in case of after-effects or death. This is exacerbated by the cost of medical treatment for workers who often do not benefit from social protection.[6,14,18] These workers should therefore be able to benefit from this protection, including compensation for occupational risks.

Inaccessibility to OHS was the last problem mentioned. This could be explained by the fact that these services are not really present in the informal sector, leading workers to feel abandoned.[10,18] Indeed, they feel that the formal sector is the one that benefits from all the privileges provided by the state, particularly in terms of occupational risk prevention and compensation.[19] At national level, the OHS called OST provides the vast majority of occupational health services, but has few interventions in the informal sector. Afolabi also noted a lack of occupational health facilities in Nigeria, and Traub-Merz and al, in a survey of six African countries, found that improving access to healthcare was the public service most in demand in the informal sector.[16,18] Prevention and control structures should include the informal sector in their priorities, especially as it employs a large number of the country's workers.

Insufficient use of PPE has been cited as a cause of occupational hazards. This could be explained by the fact that many workers don't have this

equipment. Some others wear them when they are forced by their employer, or if they consider that there is risk in the work situation, although their knowledge of such risky situations is insufficient.[20] In Uganda, a study found that the reasons why PPE was not worn were that it was not available and that it was not useful.[21] Improving their knowledge of occupational hazards and the benefits of PPE could therefore increase their use.[22] Another factor is the lack of knowledge and compliance with legal occupational health requirements.[15] In fact, Burkina Faso has ratified International labor organization (ILO) conventions and recommendations and passed legislation to ensure workers' health and safety.[23] In the informal sector, however, companies are often set up outside any regulatory framework, and few workers are therefore aware of occupational health laws. What's more, the control structures that should be raising awareness and forcing companies to comply have few human and financial resources, despite the vast and diverse nature of this sector.[8] The capacity of these structures to ensure compliance with occupational health legislation therefore needs to be improved.[22]

The causes of inaccessibility to occupational health services were dominated in our study by lack of information. Few actors in the informal sector are aware of the existence of occupational health structures. This may be due to the fact that informal businesses are created every day without fulfilling the regulatory requirements and often no fixed address in the sector, making them invisible.[15,16] Moreover, when they are informed and have no idea of the legal constraints in terms of occupational health, many feel that it is the role of workers' health office to contact them. However, the informal sector is vast, present in every neighborhood and poorly organized, with workers and structures that are not all part of the national informal organization, complicating this approach. Prevention and control structures would benefit from working through informal sector associations, which have a better knowledge of this sector, in order to achieve greater impact in their actions. Another reason may be the fact that OHS and control structures often pay little attention to the informal sector, which they consider to be poorly organized and vast, in a context where their human and material resources are already limited.[16] They therefore feel no need to adapt their strategies to the particularities of this sector. And yet, in the informal sector, these are often businesses with small staff who cannot afford to take long hours off for medical check-ups like workers in the formal sector.[24,25] Afolabi also noted in Nigeria in 2019 that the activities of occupational health professionals were fragmented and focused on the formal sector, neglecting informal entrepreneurs.[16] It is necessary for OHS to change their view of the informal sector and focus on these structures in order to motivate them to adhere.

The solutions proposed for the two priority occupational health problems in our study were legal, medical and technical. In legal terms, the focus was put on formalizing the sector.[6,18,19] This should help to improve working conditions and reduce occupational risks, as it implies the implementation of legal occupational health obligations.[6] Formalization should also encourage better supervision by control structures and obliged companies to comply with legislation.[8,15] In 2019, the ILO stated that improving safety, health and working conditions in this sector requires a strategy of transition to formal employment for informal workers.[17] However, this formalization should be mixed with an improvement in resources. Indeed, in Burkina Faso, all employers in the public, formal private and informal sectors are legally obliged to provide occupational health coverage for their workers through occupational health services. However, difficulties remain in its implementation. These are linked, among others things, to a lack of knowledge or interest on the part of beneficiaries and insufficient human, material end financial resources for effective monitoring. The occupational medical

inspectorate responsible for this monitoring and the occupational health services seem to focus more on the structured private sector and still struggle to cover the vast informal and public sectors, with few enforcement measures when violations are identified in the informal sector.

In medical terms, regular medical check-ups of workers have been proposed, and should enable early detection and treatment of occupational diseases. To achieve this, the accessibility of the worker's health office needs to be improved. Many informal sector workers have unstable jobs that ensure their day-to-day survival, preventing them from taking long hours off work.[8,24,25] The health and social promotion centers that exist in all neighborhoods could bring occupational health closer to these workers by constituting front-line structures in the domain.[16]

Improving knowledge is a collective technical solution that has been mentioned. It includes raising awareness and training the workers.[22,26,27] It is the first step to empower workers in occupational hazards prevention. Magoha found in his study that workers with higher knowledge of occupational hazards and safety measures were significantly more likely to have more positive attitudes about safety practices, and were less likely to be victims of occupational injuries.[22]

Conclusion

The aim of this study was to analyze the occupational health problems perceived by informal sector workers in the city of Ouagadougou in 2024. The results show that workers in this sector are faced with deleterious working conditions, occupational hazards and a lack of access to OHS. The priority problems in the sector, however, were occupational hazards and inaccessibility to occupational health services. There were many reasons for this, including insufficient knowledge of occupational hazards and OHS, lack of use of PPE, ignorance of and non-respect of legal requirements, lack of organization in the sector, and a focus on the formal sector. The solutions proposed were legal, medical and technical, and highlighted the need for prevention and compensation for occupational hazards in this sector. The results of this study could serve as a starting point for taking better account of informal sector players in occupational health and social protection policies.

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Original Article

Determinants of worker participation in basic occupational health services: The roles of social capital and motivation among informal tourism workers in Indonesia

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ABSTRACT

Introduction: Informal tourism workers play a vital role in Indonesia's tourism economy but often lack access to occupational health protections, making them vulnerable to workplace hazards. Basic Occupational Health Services (BOHS) provide a preventive and promotive health framework for underserved sectors; however, participation among informal workers remains limited and the determinants of readiness to engage in BOHS are still poorly understood.

Methods: A cross-sectional survey was conducted among 222 informal tourism workers in Yogyakarta, Indonesia. Data were collected using validated questionnaires and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to examine the relationships among health promotion, social capital, motivation, and readiness to participate in BOHS.

Results: Social capital was most strongly associated with health promotion ($\beta = 0.667$, $p < 0.001$) and was significantly affected motivation ($\beta = 0.273$, $p = 0.003$) and readiness to participate ($\beta = 0.234$, $p = 0.001$). Health promotion was significantly associated with motivation ($\beta = 0.240$, $p = 0.004$) and readiness ($\beta = 0.360$, $p < 0.001$). Motivation partially mediated the associations between social capital and health promotion and readiness. The model demonstrated moderate to substantial explanatory power (R^2 readiness = 0.534) and good predictive relevance (Q^2 readiness = 0.283).

Conclusion: Strengthening BOHS participation among informal tourism workers may benefit from strategies that enhance community social capital and motivational engagement rather than relying solely on information dissemination. Participatory health promotion and community-based initiatives may improve the readiness and sustainability of BOHS programs in informal tourism settings.

Keywords: Basic Occupational Health Services, health promotion, motivation, social capital, tourism workers

Introduction

Tourism is a cornerstone of economic and social development, employing over 230 million people, approximately 7.2% of the global workforce, with many more working indirectly in related value chains.[1] In Indonesia, tourism's importance is magnified by the vast informal workforce that sustains local economies, especially in culinary, craft, and management roles in destinations such as Yogyakarta. These workers constitute a substantial and often overlooked segment of the tourism labor force, operating largely outside formal occupational health and safety (OHS) protection systems. These informal tourism workers face numerous occupational health and safety (OHS) risks, ranging from ergonomic strain and foodborne illness to heat stress and infectious threats, often without access to formal protections.[2] Unsafe workplaces claim nearly 2.78 million lives annually and cause hundreds of millions of injuries globally, with informal workers among the most vulnerable due to limited regulation and social protection.[3] Participation in Basic Occupational Health Services (BOHS) is therefore essential not only for safeguarding worker health[4] but also for maintaining service quality[5], strengthening tourism resilience, and promoting community well-being.[6] BOHS represent an inclusive model of occupational health specifically designed to extend preventive and promotive services to underserved and informal sectors.[7]

Evidence from several countries demonstrates that BOHS can improve occupational health outcomes when effectively implemented. Successful examples include community-integrated OHS systems in Thailand.[8] The integration of BOHS into primary healthcare in Iran,[9] and targeted interventions for vulnerable workers in Bangladesh.[10] However, the presence of BOHS programs does not necessarily guarantee active participation by workers. Previous studies have shown that uptake and sustained engagement in occupational health initiatives remain low in many informal-sector settings, even where services are available.[11] In Indonesia, policy efforts have primarily focused on expanding health-center coverage rather than understanding why workers may or may not be ready to participate in BOHS programs.[12]

Yogyakarta, a major tourism hub in Indonesia, has initiated BOHS programs for tourism workers. Nevertheless, preliminary focus group discussions with OHS post managers indicate alarmingly low participation levels.[13] This suggests that the availability of services alone is insufficient to ensure engagement. Instead, workers' readiness to participate becomes a critical determinant of program success. Participation readiness refers to a psychosocial state encompassing willingness, preparedness, and confidence to engage in health programs.[14] Such readiness does not emerge automatically but develops through such as social interaction, information exchange, empowerment, and collective mobilization.[15] Consistent with the pre-adoption stages of the Innovation-Decision Process in Diffusion of Innovations theory, readiness in this study is operationalized as a multidimensional construct comprising awareness (knowledge of BOHS), persuasion (formation of a favorable attitude), decision (intention to participate), and confirmation (perceived reinforcement of the appropriateness of the participation decision prior to sustained action).[16] This conceptualization distinguishes readiness as a precursor to full adoption, focusing on the cognitive and motivational progression that precedes sustained behavioral engagement.[17]

Previous research from low- and middle-income settings, particularly in Southeast Asia, including Malaysia, Thailand, Singapore, Vietnam, Indonesia, and the Philippines, has examined individual determinants of occupational health behavior, such as health promotion exposure, social capital, and motivation.[18,19] However, these factors have rarely been examined simultaneously within a single theoretical framework, particularly in informal tourism contexts. Existing studies in occupational health and safety have largely focused on formal industrial workplaces in high-

income countries, leaving a substantial evidence gap regarding how psychosocial and community-level factors shape readiness to engage in occupational health services among informal workers in low- and middle-income settings.[20] As a result, the mechanisms through which health promotion, social capital, and individual motivation interact to influence readiness to participate in BOHS remain poorly understood.

The present study integrates several complementary theoretical perspectives. First, Diffusion of Innovations theory conceptualizes participation in BOHS as an adoption process, in which individuals move through stages of awareness, persuasion, decision, implementation, and confirmation.[16] Diffusion theory emphasizes that the spread of new practices depends not only on the innovation itself but also on communication processes within social networks and the characteristics of the adopting community.[21] Innovation diffusion occurs through interpersonal networks that transmit information, shape perceptions, and influence behavioral decisions within a social system.[21] Second, Social Capital Theory highlights the importance of trust, social networks, and reciprocal relationships in facilitating collective action and information sharing within communities.[22] In informal tourism settings, where formal institutional support may be limited, social capital can function as a key mechanism for disseminating health information and encouraging participation in health initiatives. Third, Self-Determination Theory provides insight into the motivational mechanisms that drive behavioral engagement.[23,24] According to this framework, intrinsic and extrinsic motivations influence individuals' willingness to adopt new behaviors, including participation in occupational health programs. Together, these theoretical perspectives suggest that social networks may facilitate the diffusion of BOHS information, health promotion activities may enhance awareness and perceived benefits, and motivation may translate these influences into behavioral readiness.

Despite the theoretical relevance of these constructs, empirical research integrating diffusion processes, social capital, and motivational mechanisms in the context of BOHS participation remains scarce. Understanding how these factors interact is particularly important in informal tourism sectors, where occupational health interventions depend heavily on community engagement and voluntary participation.

Therefore, this study aims to examine the structural relationships among health promotion, social capital, motivation, and readiness to participate in BOHS among informal tourism workers in Yogyakarta, Indonesia. By integrating diffusion of innovation, social capital, and motivational perspectives within a structural equation modeling framework, this study seeks to provide a more comprehensive understanding of the psychosocial and community-level determinants of readiness for BOHS participation.

Methods

This study employed a cross-sectional analytical design to investigate the influence of health promotion and social capital on motivation and readiness to participate in Basic Occupational Health Services (BOHS) among informal tourism workers. A cross-sectional approach was selected because it allows the simultaneous examination of relationships among psychosocial constructs within a real-world community setting where experimental manipulation is not feasible.

The analysis examined two exogenous variables (health promotion and social capital) and two endogenous variables (motivation and readiness to participate) within a structural equation modeling framework. In this study, health promotion refers to workers' perceived exposure to and experience of occupational health activities within their work environment.

Figure 1 presents the hypothesized structural model examined in this study. The model includes two exogenous latent variables (health promotion and social capital) and two endogenous latent

variables (motivation and readiness to participate in BOHS). Readiness to participate is operationalized as a higher-order construct comprising four first-order dimensions: awareness, persuasion, decision, and confirmation. Direct paths are specified from health promotion and social capital to both motivation and readiness to participate, and from motivation to readiness to participate. Indirect effects are examined to assess the mediating roles of motivation and health promotion.

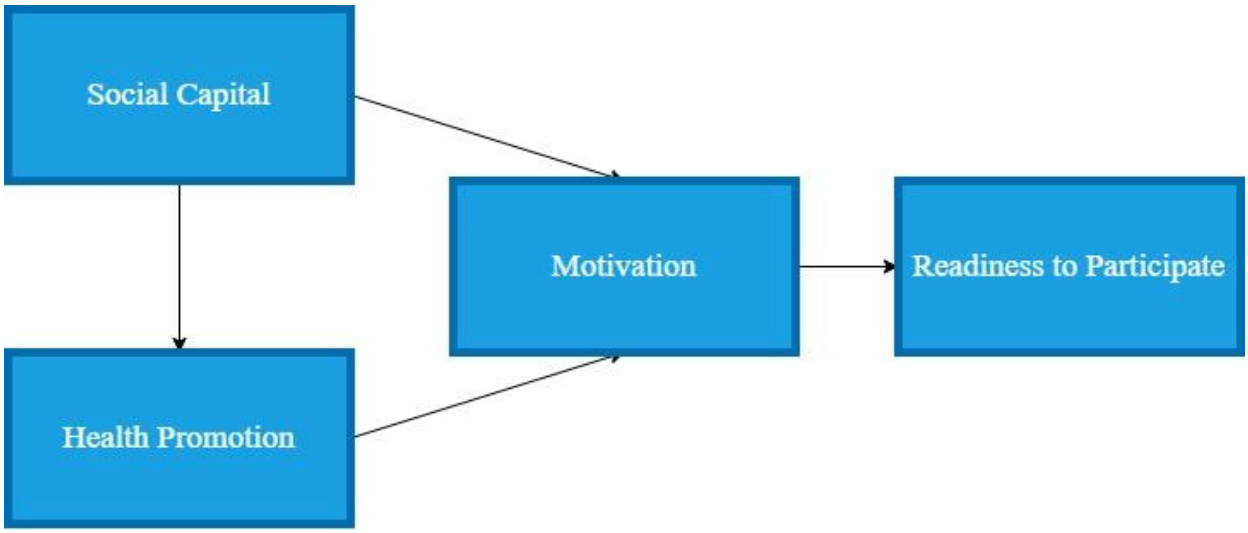

Figure 1. Hypothesized Structural Model of Readiness to Participate in Basic Occupational Health Services

The study population consisted of managers, artisans, and culinary traders working in tourist destinations in Bantul District, Indonesia, who were registered in the Bantul District Health Office's BOHS program database. At the time of the study, the registry contained 487 registered informal tourism workers. Eligible participants were those who were willing to participate in the study, were permanently employed in tourist destinations covered by BOHS, and were able to communicate effectively, either orally or in writing. Participants were selected using a simple random sampling procedure based on the official BOHS participant registry provided by the district health authority. This approach ensures that each registered worker has an equal probability of being included in the study.

A total of 260 workers were randomly selected and invited to participate. Of these, 222 provided complete responses and were included in the final analysis, yielding an 85.4% response rate. The final sample consisted of 222 respondents. The adequacy of this sample size for Partial Least Squares Structural Equation Modeling (PLS-SEM) was assessed using multiple criteria. According to the "10-times rule", the minimum required sample should be at least ten times the largest number of structural paths directed at a latent construct in the model.[25] In the present model, the maximum number of structural paths directed to a single construct was three, indicating a minimum sample requirement of 30 respondents. Recognizing that this rule alone is no longer considered sufficient, the sample size was further evaluated using the inverse square root method, which is specifically recommended for estimating the minimum sample size in PLS-SEM.[26] Based on this method, a sample size of approximately 155 respondents is required to detect path coefficients of at least 0.20 at a significance level of 0.05. The current sample of 222 respondents comfortably exceeds this threshold. The sample size meets the recommendations of Hair et al. (2019), who suggest that for a model with a maximum of three structural paths pointing to a construct, a sample size of approximately 124 is adequate to detect

minimum R^2 values of 0.25 at a 5% significance level with 80% power. The use of PLS-SEM was deemed appropriate for this study given the predictive nature of the research aim, the inclusion of a higher-order construct (readiness to participate), and the non-normal distribution of several indicator variables, conditions under which PLS-SEM offers distinct advantages over covariance-based SEM.[27] Data were collected between June and August 2024.

The research instruments were developed based on the theoretical framework integrating Diffusion of Innovations theory, Social Capital Theory, and Self-Determination Theory, which guided the operationalization of each construct in the study model. Readiness to participate was measured as a higher-order construct reflecting the pre-adoption stages of the innovation-decision process, comprising four first-order dimensions: awareness (knowledge of BOHS), persuasion (perceived benefits and relevance), decision (intention to participate), and confirmation (pre-action conviction in the value of participation). Items measuring readiness to participate were adapted from the Innovation-Decision Process dimensions described by Rogers and Shoemaker (1971).[28] Items for social capital were adapted from the multidimensional framework of social capital proposed by Usman (2018),[29] covering social networks, trust, and reciprocal relationships. Items for health promotion were adapted from the community participation and empowerment dimensions outlined by Obot et al. (2022).[30] Items for motivation were adapted from the Self-Regulation Questionnaires developed by Ryan and Connell (1989),[31] capturing both intrinsic and extrinsic motivational orientations. All items were adapted with wording modifications to ensure relevance to the context of Basic Occupational Health Services and informal tourism work in Indonesia.

The initial item pool comprised 45 items across all constructs. Content validity was assessed using Aiken's V method. The Aiken's V coefficient was calculated based on the following formula: $V = \Sigma s / [n(c-1)]$, where $s = r - lo$, r is the rating score given by each expert, lo is the lowest validity rating score (1), n is the number of experts, and c is the highest validity rating score (5).[32] Seven raters participated in the content validation process, comprising two language experts, two health promotion specialists, two academics with expertise in structural equation modeling, and one practitioner from the District Health Office. Based on a critical value table with RC = 0.05, the minimum acceptable Aiken's V threshold was 0.75. Items with Aiken's V values below 0.75 were removed. Items recommended for revision were modified directly in accordance with expert suggestions. Following this process, 41 items were retained for further psychometric evaluation. The validated items are documented in the supplementary materials.

As the study was conducted in Indonesia, with Bahasa Indonesia as the primary language of participants, the questionnaire was translated from English to Bahasa Indonesia using a forward-and-back-translation procedure. The initial translation was performed by a bilingual researcher, followed by independent back-translation by a professional translator blinded to the original English version. Discrepancies were resolved through consensus discussion between the translators and the research team.

A pilot test was conducted with 30 informal tourism workers from a neighboring district not included in the main study sample. The pilot test assessed clarity, comprehensibility, and average completion time. Minor wording adjustments were made based on participant feedback to improve clarity without altering item meaning. The final questionnaire consisted of statements representing each study variable, with responses recorded on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), with reverse scoring applied to negatively worded items.

The complete list of questionnaire items in both English and Bahasa Indonesia, including the 13 indicators subsequently removed during measurement model evaluation, is provided in the Supplementary Material.

Convergent validity was evaluated using the Average Variance Extracted (AVE) criterion, with a threshold of 0.50 or higher. Reliability was assessed using Cronbach's alpha, rho_A, and Composite Reliability (CR), with acceptable values defined as alpha> 0.60 and CR> 0.70.[27]

Data were gathered through structured face-to-face interviews administered by trained research assistants using the standardized questionnaire. Before data collection, each respondent was provided with a detailed explanation of the study's objectives, procedures, and confidentiality assurances. Written informed consent was obtained from all participants. The interviews were conducted in the respondents' workplaces to ensure convenience and to facilitate accurate responses. To minimize the risk of social desirability bias, interviewers emphasized the voluntary and anonymous nature of participation and assured respondents that there were no right or wrong answers and that their responses would not affect their standing in the BOHS program or their employment. Additionally, the questionnaire was structured such that items measuring the predictor variables (health promotion and social capital) were placed in a separate section from items measuring the outcome variable (readiness to participate), and the order of items within each section was randomized where feasible to reduce the likelihood of consistent response patterning.

Data analysis was conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS version 4.0. The analysis began with an evaluation of the measurement model, which included assessing indicator loadings with an acceptance threshold of 0.60 or higher, confirming convergent validity using AVE, and examining internal consistency reliability using Cronbach's alpha, rho_A, and CR.[33] The structural model was then evaluated by examining collinearity through the inner Variance Inflation Factor (VIF) with a cut-off value below 5, estimating path coefficients, calculating effect sizes (f^2), and determining predictive relevance (Q^2). Bootstrapping with 5,000 subsamples was used to assess the significance of both direct and mediating effects, with a significance level of $p < 0.05$ ($t > 1.96$). Model fit was further assessed through the coefficient of determination (R^2), Q^2 Predict, PLS Predict, and the Cross-Validated Predictive Ability Test (CVPAT). To assess the potential influence of common method bias, Harman's single-factor test was conducted. An exploratory factor analysis with all measurement items entered into an unrotated principal component analysis revealed that the first factor accounted for 31.7% of the total variance, which is below the 50% threshold commonly used to indicate substantial common method bias. While this does not rule out bias, it suggests that common method variance is unlikely to be the primary driver of the observed relationships.[34]

The study was approved by the Health Research Ethics Committee of Doctor Moewardi General Hospital, Indonesia (Approval Number 1.030/IV/HREC.2024). All study procedures were conducted in accordance with relevant ethical guidelines and regulations. Participants were informed about the objectives and procedures of the study prior to data collection. Written informed consent was obtained from all participants before participation. All participants were assured that their identities would remain confidential, and all data were collected and analyzed in anonymized form. All personal identifiers were removed from the dataset prior to analysis and replaced with unique participant codes. No personally identifiable information was retained in any analytical files or shared with third parties. Participants were also informed that their participation was voluntary and that they could withdraw from the study at any time without any consequences.

Results

A total of 222 informal tourism workers participated in this study, consisting of culinary traders (37.84%), tourism managers (36.04%), and artisans (26.13%). Female workers accounted for 52.70% of the sample, indicating a high level of female participation in the informal tourism sector. The age distribution showed that the largest proportion of respondents was aged ≤30 years (26.58%), followed by those aged 31-40 years (24.32%), 41-50 years (25.68%), and >50 years (23.42%). The age range extended from 17 to 75 years, indicating a broad demographic spread. Educational attainment was dominated by high school graduates (62.61%), followed by junior high school or below (30.63%), and undergraduate degree holders (6.76%). Table 1 summarizes the socio-demographic profile of the respondents.

Table 1. Socio-Demographic Characteristics of Respondents

Characteristics	N
Sex	
Women	117 (52.70 %)
Men	105 (47.30 %)
Age (years)	
≤30	59 (26.58 %)
31–40	54 (24.32 %)
41–50	57 (25.68 %)
>50	52 (23.42 %)
Education level	
Elementary school	24 (10.81 %)
Middle school	44 (19.82 %)
High school	139 (62.61 %)
Undergraduate	15 (6.76 %)
Job type	
Culinary traders	84 (37.84 %)
Artisans	58 (26.13 %)
Tourism managers	80 (36.04 %)

The measurement model was evaluated using the hierarchical component model (HCM) with the repeated indicator approach. Thirteen indicators with outer loadings <0.600 were removed during the first-order confirmatory analysis. After respecification, all remaining indicators achieved outer loadings >0.600, satisfying the requirement for convergent validity.

Average Variance Extracted (AVE) values for all dimensions and constructs were greater than 0.50, confirming acceptable convergent validity. Composite reliability (CR) values exceeded 0.70, and Cronbach's alpha values were above 0.60 for all constructs, indicating strong internal consistency. Discriminant validity was assessed using the Fornell-Larcker criterion. As shown in Table 2, the square root of the AVE for each construct (diagonal values) was greater than its correlation with any other construct (off-diagonal values), satisfying the Fornell-Larcker criterion. Inspection of indicator cross-loadings confirmed that all items loaded more highly on their intended construct than on any other construct. Table 3 shows the results of internal consistency reliability and convergent validity.

Collinearity diagnostics showed all inner VIF values were below 5, indicating no multicollinearity among predictor variables. Path analysis revealed that health promotion significantly predicted both motivation ($\beta = 0.240$, $p = 0.004$) and readiness to participate ($\beta = 0.360$, $p < 0.001$). Social capital significantly influenced health promotion ($\beta = 0.667$, $p < 0.001$), motivation ($\beta = 0.273$, $p = 0.003$), and readiness to participate ($\beta = 0.234$, $p = 0.001$). Motivation also significantly affected readiness to participate ($\beta = 0.296$, $p < 0.001$).

Table 2. Discriminant Validity Assessment Using the Fornell–Larcker Criterion

Variable	HP	MOT	RTP	SC
Health Promotion (HP)	0.883			
Motivation (MOT)	0.42	0.79		
Readiness to Participate (RTP)	0.642	0.548	0.746	
Social Capital (SC)	0.666	0.432	0.603	0.8

Table 3. Internal Consistency, Reliability and Convergent Validity of Constructs

Construct	Indicator	Outer Loading	AVE (Dim.)	AVE (Var.)	Cronbach's Alpha	rho_A	CR
RTP	IIN3	0.719	0.587	0.557	0.829	0.829	0.887
	IIN4	0.802					
	INN5	0.859					
	INN6	0.872					
	PER1	0.800	0.743	0.630	0.853	0.855	0.895
	PER2	0.813					
	PER3	0.744					
	PER4	0.817					
	PER5	0.794					
	DEC2	0.822	0.825	0.813	0.772	0.791	0.897
	DEC3	0.921					
	CON1	0.799	0.807	0.711	0.796	0.796	0.880
	CON2	0.853					
	CON3	0.875					
HP	COM3	0.918	0.793	0.853	0.830	0.920	
	COM4	0.929					
	PLA1	0.966	0.940	0.920	0.957	0.957	0.972
	PLA2	0.968					
	PLA3	0.944					
	IMP1	0.913	0.887	0.841	0.812	0.813	0.914
	IMP2	0.922					
	EV1	0.966	0.922	0.934	0.929	0.929	0.966
	EV2	0.966					
SC	NET1	0.897	0.826	0.820	0.781	0.785	0.901
	NET2	0.914					
	TRU1	0.809	0.760	0.726	0.628	0.657	0.841
	TRU3	0.893					
	RR2	0.841	0.839	0.820	0.656	0.665	0.853
	RR3	0.883					

Construct	Indicator	Outer Loading	AVE (Dim.)	AVE (Var.)	Cronbach's Alpha	rho_A	CR
MOT	EX1	0.865	0.791	0.706	0.831	0.866	0.898
	EX2	0.931					
	EX3	0.791					
	INS1	0.750	0.859	0.675	0.843	0.843	0.892
	INS2	0.816					
	INS3	0.898					
	INS4	0.815					

Note. AVE = Average Variance Extracted; CR = Composite Reliability; Dim. = Dimension; Var. = Variable; HP = Health Promotion; SC = Social Capital; MOT = Motivation; RTP = Readiness to Participate; IIN = Introduction of Innovation; PER = Persuasion; DEC = Decision; CON = Confirmation; COM = Communication; PLA = Participative Planning; IMP = Implementation; EV = Evaluation/Monitoring; NET = Social Network; TRU = Trust; RR = Reciprocal Relationship; EX = Extrinsic Motivation; INS = Intrinsic Motivation.

Table 4. Path Coefficients, Significance, and Effect Sizes of The Structural Model

Hypothesis	Inner VIF	β (Original)	Mean	SD	t-value	p-value	f^2	Effect size
H1: HP → MOT	1.800	0.240	0.235	0.083	2.908	0.004	0.041	Low to moderate
H2: HP → RTP	1.874	0.360	0.361	0.067	5.370	<0.001	0.148	Moderate
H3: SC → HP	1.000	0.667	0.670	0.041	16.399	<0.001	0.800	High
H4: SC → MOT	1.800	0.273	0.282	0.093	2.929	0.003	0.053	Low to Moderate
H5: SC → RTP	1.895	0.234	0.240	0.072	3.255	0.001	0.062	Low to Moderate
H6: MOT → RTP	1.281	0.296	0.294	0.068	4.331	<0.001	0.146	Moderate

Note. HP = Health Promotion; SC = Social Capital; MOT = Motivation; RTP = Readiness to Participate.

Table 5. Mediation Effects of Motivation and Health Promotion on Readiness to Participate

Pathway	β (Original)	Mean	SD	t-value	p-value
H7: HP → MOT → RTP	0.071	0.069	0.028	2.501	0.012
H8: SC → HP → MOT → RTP	0.047	0.046	0.019	2.444	0.015
H9: SC → HP → RTP	0.240	0.242	0.048	4.989	<0.001
H10: SC → MOT → RTP	0.081	0.084	0.036	2.268	0.023

Note. HP = Health Promotion; SC = Social Capital; MOT = Motivation; RTP = Readiness to Participate.

Mediation analysis indicated that motivation significantly mediated the relationship between social capital and readiness to participate (β = 0.081, p = 0.023). Health promotion also had a significant indirect effect on readiness through motivation (β = 0.071, p = 0.012).

The model's explanatory power was moderate to substantial, with R^2 values of 0.219 for motivation, 0.445 for health promotion, and 0.534 for readiness to participate. Predictive relevance (Q^2) values were 0.117 for motivation, 0.340 for health promotion, and 0.283 for readiness to participate, confirming acceptable predictive capability.

The Cross-Validated Predictive Ability Test (CVPAT) indicated that the PLS-SEM model outperformed both the indicator average (IA) and the linear regression model (LM) for most variables, as shown by negative and statistically

significant average loss differences in key constructs.

PLS Predict analysis further demonstrated the model's predictive power, with Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE) values for the PLS-SEM model generally lower than those of the LM baseline.

Table 6. Cross-Validated Predictive Ability Test (CVPAT)

Variable	R^2	R^2 Adjusted	Q^2 Predict	PLS-SEM vs IA (Avg. Loss Diff.)	t-value	p-value	PLS-SEM vs LM (Avg. Loss Diff.)	t-value	p-value
HP	0.445	0.442	0.340	-0.338	5.946	0.000	0.049	1.847	0.066
MOT	0.219	0.212	0.117	-0.104	2.619	0.009	-0.020	2.412	0.017
RTP	0.534	0.527	0.283	-0.183	3.786	0.000	-0.015	0.992	0.322
SC	–	–	0.000	-0.229	5.680	0.000	0.021	1.593	0.113

Note. IA = Indicator Average; LM = Linear Model; Avg. Loss Diff. = Average Loss Difference; HP = Health Promotion; SC = Social Capital; MOT = Motivation; RTP = Readiness to Participate.

Table 7. PLS Predict: RMSE and MAE Comparison between PLS-SEM and LM

Variable	Indicator	PLS-SEM RMSE	PLS-SEM MAE	LM RMSE	LM MAE
HP	COM	0.845	0.598	0.813	0.561
	PLA	0.828	0.683	0.800	0.632
	IMP	0.783	0.617	0.760	0.577
	EV	0.815	0.669	0.776	0.621
MOT	EX	0.970	0.614	0.978	0.623
	INS	0.935	0.773	0.947	0.749
RTP	IIN	1.002	0.714	0.944	0.713
	PER	0.884	0.547	0.847	0.501
	DEC	0.894	0.584	0.901	0.596
	CON	0.849	0.648	0.855	0.640

Note. HP = Health Promotion; SC = Social Capital; MOT = Motivation; RTP = Readiness to Participate; IIN = Introduction of Innovation; PER = Persuasion; DEC = Decision; CON = Confirmation; COM = Communication; PLA = Participative Planning; IMP = Implementation; EV = Evaluation/Monitoring; NET = Social Network; TRU = Trust; RR = Reciprocal Relationship; EX = Extrinsic Motivation; INS = Intrinsic Motivation.

Discussion

To the best of our knowledge, this is the first study to empirically examine the interplay among health promotion, social capital, and motivation in relation to readiness to participate in Basic Occupational Health Services (BOHS) among informal tourism workers. Using a validated structural equation model, we found that social capital demonstrated the strongest association with health promotion, with a large effect size, and both social capital and health promotion were significantly associated with readiness to participate. Motivation was

identified as a meaningful mediator in the relationship between social capital and readiness. The model demonstrated moderate to substantial explanatory power, with R^2 reaching 0.534 for readiness to participate, and predictive relevance was confirmed through Q^2 values exceeding zero for all endogenous constructs. The Cross-Validated Predictive Ability Test (CVPAT) indicated that the PLS-SEM model consistently outperformed the indicator average (IA) benchmark, whereas its predictive performance relative to the linear model (LM) benchmark was more equivocal, reaching statistical significance only for Motivation (Table 5). The PLS Predict analysis revealed that the PLS-SEM model yielded lower prediction errors than the LM benchmark for some, but not all, indicators (Table 6). These results suggest that the model possesses acceptable predictive capability, though the evidence of superior performance over simpler benchmarks is mixed. Among the relationships examined, the association between social capital and health promotion represented the most substantial pathway within the model. This finding suggests that in informal tourism settings, community-based social structures may serve as the primary mechanism by which health promotion activities are mobilized and sustained. Given the cross-sectional design, these associations should be interpreted as structural relationships consistent with the proposed theoretical framework rather than as evidence of causal effects or temporal mediation.

The strong association between social capital and health promotion is consistent with previous studies in community-based tourism and occupational health that have highlighted the role of trust, interpersonal networks, and reciprocal relationships in enabling collective health action.[35] Where formal institutional health support is often lacking in informal tourism settings, these social ties may serve as the main conduit for mobilizing resources, disseminating health information, and sustaining participation in BOHS programs.[36] This finding aligns with a study in India,[37] which found that mutual trust and community participation help reduce transaction costs for cooperative initiatives and nurture a sense of collective ownership. This relationship suggests that health promotion in informal tourism communities may not be attributable solely to institutional interventions but rather to socially embedded communication processes within existing networks. The diffusion of occupational health knowledge may occur primarily through interpersonal relationships rather than through formal organizational channels.

Social networks among tourism workers, cooperative vendor groups, and local associations may constitute the backbone of health promotion delivery. These networks could enhance the credibility of health messages, encourage mutual accountability, and create an enabling environment for participation.[38] This pattern is consistent with the diffusion mechanism proposed in the Diffusion of Innovations theory, in which innovations spread through interpersonal communication within social systems. Within such systems, trusted peers may often serve as informal opinion leaders who influence perceptions of program relevance and encourage behavioral adoption.

The significant indirect association between social capital and readiness via motivation is consistent with the principles of reciprocal determinism. In cohesive social environments, individuals are more likely to internalize shared values, develop a sense of collective efficacy, and translate that into personal readiness to engage in BOHS. This mechanism may be especially relevant in informal economies, where interpersonal trust can substitute for limited formal oversight.[39]

These findings can also be interpreted through Self-Determination Theory (SDT), which emphasizes the fulfillment of three basic psychological needs (autonomy, competence, and relatedness) to sustain motivation.[40,41] Social capital is conceptually linked to relatedness, as

networks, trust, and reciprocal relationships foster a sense of belonging among workers.[41] However, relatedness alone may not be sufficient to generate sustained behavioral engagement. Workers likely must also perceive that they have the capability (competence) and the autonomy to act on the information received.

This may explain why the association of social capital with motivation and readiness to participate was relatively limited in the absence of additional structural and internal factors. The present study offers a potential extension of SDT by highlighting that the conversion of social capital into sustained motivation may require not only supportive community networks but also participatory health promotion strategies and structured occupational health management systems. However, the cross-sectional nature of the data precludes definitive conclusions regarding the temporal or causal ordering of these relationships.

Health promotion was found to be associated with readiness through both direct and indirect pathways, the latter involving motivation.[42] This dual association suggests that health promotion efforts in informal tourism contexts may operate not only by raising awareness but also by supporting self-efficacy and perceived behavioral control, which are conceptually relevant determinants of motivation.[43] Evidence from previous workplace health interventions in South Korea is consistent with this view, indicating that effective health promotion is associated with enhanced cognitive and affective determinants of behavior.[44]

Certain forms of health promotion, such as the provision of free first-aid kits, medicines, and health screenings, appear to deliver immediate, personally relevant benefits. Such tangible outcomes may strengthen workers' emotional engagement and foster a sense of ownership over BOHS programs. Nevertheless, the moderate direct association between health promotion and readiness suggests that information-based interventions alone may be insufficient to generate sustained engagement. Health promotion strategies that involve workers directly in program planning, implementation, and monitoring may therefore be more effective in fostering long-term participation.

The findings have important implications for the design and implementation of BOHS programs in informal tourism sectors.[13] Strengthening social capital may be a strategic priority, as community trust and interpersonal networks appear to be powerful enablers of participation.[45] Policy initiatives could therefore benefit from prioritizing community-based engagement strategies, such as peer-led health promotion, participatory planning processes, and recognition systems for workers who actively contribute to BOHS activities.[46] Building on existing social structures within tourism communities may accelerate the diffusion of positive norms regarding occupational health participation.[47]

This study makes several noteworthy contributions. It presents the first empirical model examining associations among social capital, health promotion, motivation, and readiness to participate in BOHS within the informal tourism workforce. The findings contribute to the theoretical literature by demonstrating how diffusion processes, social capital mechanisms, and motivational factors may interact in relation to readiness for occupational health participation in informal-sector settings. Methodologically, it employs PLS-SEM complemented by predictive performance metrics such as Q^2 and CVPAT, providing a level of rigor that goes beyond traditional explanatory modeling. While the evidence for out-of-sample predictive superiority over linear benchmarks is mixed, the model demonstrates acceptable in-sample explanatory power and predictive relevance.

An important limitation pertains to the sampling frame. The sample was drawn exclusively from workers already registered in the BOHS program database maintained by the district health office.

Consequently, the findings may not be generalizable to the broader population of informal tourism workers who are entirely unconnected to the BOHS system. The observed associations may therefore reflect patterns among workers with at least a baseline level of program exposure and may overestimate readiness relative to the completely unengaged informal workforce. The focus on a single district in Indonesia may limit the generalizability of the findings to other cultural and tourism contexts. The reliance on self-reported data introduces the possibility of recall bias and social desirability bias. Future research using longitudinal designs could explore additional contextual factors such as leadership practices, organizational culture, and economic conditions that may be associated with occupational health participation in tourism communities. Longitudinal and comparative studies across diverse tourism regions, ideally incorporating mixed-methods approaches, would further enhance understanding and strengthen the evidence base.

Conclusion

This study provides new empirical evidence on the psychosocial determinants associated with readiness to participate in Basic Occupational Health Services (BOHS) among informal tourism workers. The findings indicate that social capital is the factor most strongly associated with health promotion and participation readiness, while motivation emerged as a key mediating mechanism linking social capital and health promotion to behavioral engagement. These results suggest that readiness to participate in occupational health programs is not solely attributable to exposure to information but is strongly embedded in community social networks and motivational dynamics. From a policy perspective, BOHS initiatives may benefit from prioritizing community-based engagement strategies that strengthen interpersonal trust, peer networks, and participatory health promotion. Leveraging existing social structures within tourism communities could potentially support workers' motivation and contribute to sustained participation in occupational health programs. Given that the sample comprised workers already registered in the BOHS program, caution is warranted in extending these findings to informal tourism workers entirely outside the program's reach. The reliance on self-reported data introduces the possibility of common method bias and social desirability bias. Although procedural safeguards were implemented during data collection (e.g., anonymity assurances, separation of predictor and outcome items) and Harman's single-factor test did not indicate substantial common method variance, the potential for self-report biases cannot be entirely eliminated. Future research would benefit from incorporating objective measures of participation (eg, program attendance records) and multi-source data where feasible. Future research using longitudinal designs should examine how contextual factors such as organizational support and leadership affect the sustainability of BOHS participation among both registered and unregistered informal tourism workers across different tourism settings.

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Original Article

Effectiveness of an ergonomic chair intervention in reducing low back pain among informal garment workers: A Quasi-Experimental Study

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ABSTRACT

Introduction: Garment workers experience low back pain (LBP), which impacts their productivity and health because they sit for prolonged periods and use non-ergonomic chairs. This study aimed to evaluate the effectiveness of ergonomic chairs in reducing LBP among small-scale garment workers.

Methods: A quasi-experimental pretest-posttest control group design was employed, and 102 sewing workers from micro and small-scale garment industries were recruited from Tuban Lor Village, Karanganyar Regency. The sample was divided into intervention (n= 51) and control (n= 51) groups. The intervention consisted of ergonomic chair designed according to the workers' anthropometric measurements. On days 0, 7, and 14, the Oswestry Disability Index (ODI) and Rapid Upper Limb Assessment (RULA) were used to measure LBP intensity and posture. Repeated measures ANCOVA and one-way ANCOVA were used to analyze the data after adjusting for age, gender, BMI, and years of service.

Results: LBP scores decreased significantly over time in the intervention group (F=6.289, p=0.003) with a significant linear trend (p=0.002), but not in the control group (p=0.390). Significant group differences were found on days 7 and 14 (p=0.001) and not at baseline (p=0.731). Covariates did not have a significant effect. There was also an improvement in posture, as evidenced by improved RULA scores.

Conclusion: Within 14 days, the ergonomic chair intervention was successful in reducing low back pain and improving posture among workers in the informal garment sector.

Keywords: Ergonomic chair, garment industry, informal sector, low back pain, working posture

Introduction

One of the most common occupational health issues in the world is work-related musculoskeletal disorders (MSDs), especially in the developing world, where informal sectors and small-scale industries are the major employers. MSDs significantly impact productivity, quality of life, and healthcare expenses.[1,2] MSDs have also been shown to negatively affect worker productivity and quality of life, while significantly increasing the overall burden of healthcare costs worldwide.[3–5] Low back pain (LBP) remains the leading cause of disability worldwide, affecting approximately 568 million people, and is strongly associated with static and non-ergonomic working postures.[6–8] Static, non-ergonomic working positions and the use of equipment that is not adjusted to the anthropometric characteristics of

workers are among the leading risk factors for this condition.[9,10]

Workers in labor-intensive industries such as garment production spend extended hours in a sitting position. To prevent musculoskeletal disorders in such settings, it is important to apply the principles of ergonomics.[11,12] Nevertheless, ergonomic interventions in micro- and small-scale industries are not widespread due to limited resources and a lack of awareness.[13] Garment workers may experience lower back, neck, and shoulder pain due to the use of non-ergonomic chairs, which typically lack adequate back support, cushioning, or proper anthropometric adjustability.[14,15]

This study was motivated by observations from a case study conducted in micro, small and medium enterprises (MSMEs) within the garment industry in Tuban Lor Village, Gondangrejo Subdistrict, Karanganyar Regency, Central Java. An initial evaluation of 10 out of 22 garment workers (45.45%) on January 6, 2025, revealed poor working postures and high levels of subjective musculoskeletal complaints. The workers sat on wooden stools without cushions or a backrest, which were unsuitable for their anthropometric dimensions. Assessment using the Rapid Upper Limb Assessment (RULA) tool revealed a score of 5-6, indicating forward trunk flexion (20-60^{o}), neck flexion (>20^{o}), and elevated arm positions (up to 90^{o}). Workers averaged 8 hours per day, engaging in repetitive tasks. According to the Oswestry Disability Index (ODI), 90% of the workers complained of low back pain.

Therefore, the purpose of this study was to evaluate the efficacy of an ergonomic chair intervention in preventing low back pain among informal garment workers. This study provides practical evidence and addresses the empirical data needed to improve ergonomic conditions in resource-constrained informal sectors. The results of this research can inform the development of simple yet effective ergonomic interventions in informal settings and provide empirical data to support the establishment of industrial hygiene practices grounded in sustainable work design.

Methods

A quasi-experimental pretest–posttest control group design was used in this study to determine the effectiveness of an ergonomic work chair intervention in alleviating subjective complaints of lower back pain in sewing workers in micro and small enterprises. Randomization was not feasible due to operational constraints in the informal workplace setting, which may have introduced selection bias. The study was conducted in Tuban Lor village, Gondangrejo Subdistrict, Karanganyar Regency, Central Java, which represents a typical informal garment production setting in the region; however, the findings may not be fully generalizable to other areas with different working conditions and ergonomic practices. Data collection took place from April to May 2025. The study population consisted of 155 sewing workers, from this population, 102 participants were selected via random sampling and assigned equally to the intervention group (n = 51) and the control group (n = 51). Although the sample size was sufficient to achieve adequate statistical power, the relatively small number of participants may limit the external validity of the findings. The minimum sample size was calculated using G*Power 3.1.9.7 with an effect size (d) of 0.5, α = 0.05, and power (1-β) = 0.80 and corresponded to n = 102 participants in total. The actual statistical power was 0.8059.

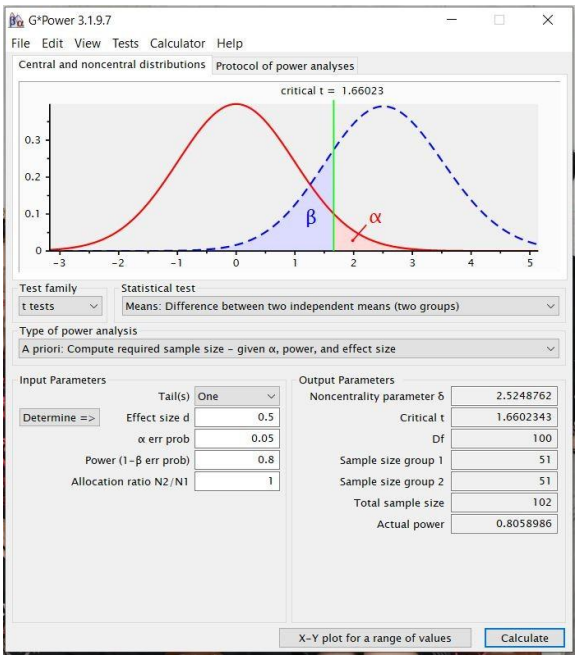

Figure 1: Sample size calculation result using G*Power

The independent variable was the ergonomic chair designed based on individual anthropometric measurements. The outcome was low back pain (LBP), measured with the Oswestry Disability Index (ODI). Workers' posture was measured using the Rapid Upper Limb Assessment (RULA). Data collection occurred at three points: before the intervention (baseline), one week after the intervention (posttest 1), and two weeks after the intervention (posttest 2). Blinding of participants and assessors was not implemented because the ergonomic chair intervention was visible, which may have contributed to observer or reporting bias.

The ergonomic chair intervention was designed based on the anthropometric measurements of the sewing workers. The main anthropometric measures taken were popliteal height, sitting elbow height, and buttock-popliteal length. These measurements were used to determine the appropriate chair size and its adjustments to achieve a neutral sitting position during the sewing process.

The ergonomic chair featured an adjustable seat height, a contoured backrest with lumbar support, and an appropriate seat depth. Seat height was adjusted to the workers' popliteal height to ensure complete foot contact with the floor, while the lumbar support was aligned with the natural lumbar curvature to minimize excessive flexion of the trunk. The backrest was adjusted to maintain an upright sitting position, as advised by ergonomic guidelines for prolonged seated work.

Participants in the intervention group used the ergonomic chair continuously during their working hours for a 14-day observation period, whereas the control group continued using their existing work chairs without ergonomic modification. The rationale for selecting a 14-day intervention period was based on evidence indicating that short-term ergonomic interventions are sufficient to observe early postural adaptations and initial reductions in musculoskeletal discomfort. Accordingly, this follow-up duration was designed to capture short-term postural adaptation and early musculoskeletal responses, rather than to assess the long-term sustainability of the ergonomic chair intervention.

The data collection instruments included anthropometric tools, the ergonomic chair, the RULA and ODI questionnaires, a demographic questionnaire, a posture documentation camera, and Angulus software for measuring sitting

angles. Data were analyzed with SPSS version 27. A repeated-measures ANCOVA was employed to compare groups over time on ODI scores with age, sex, BMI, and years of service as control variables. Statistical significance was set at $p < 0.05$.

Results

Repeated-measures ANCOVA was used to evaluate the impact of ergonomic seat usage on low back pain complaints among garment workers by taking three measurements: before the intervention (LBP_Pre), after the first intervention (LBP_Post1), and after the second intervention (LBP_Post2). Moreover, a one-way ANCOVA was conducted to assess differences in low back pain scores between the groups at each time point. Age, years of service, body mass index (BMI), and gender were used as covariates in both analyses to control for potential confounding factors and ensure that the observed effects could be attributed to the ergonomic chair intervention. Table 1 shows the descriptive statistics for the variables studied.

Table 1: Demographic Characteristics of Respondents (N = 102)

Characteristic	Description
Group 1: Intervention Group (n = 51)	
Gender	
Male (Number, %)	25 (49.0)
Female (Number, %)	26 (51.0)
Age (mean ± SD)	38.49 ± 8.1
Years of Service (mean ± SD)	12.69 ± 4.9
BMI (mean ± SD)	22.9 ± 3.5
LBP (mean ± SD)	
Pretest (Baseline)	19.16 ± 4.5
Posttest1 (1 week)	14.73 ± 3.3
Posttest2 (2 weeks)	8.24 ± 6.7
Group 2: Control Group (n = 51)	
Gender	
Male (Number, %)	26 (51.0)
Female (Number, %)	25 (49.0)
Age (mean ± SD)	39.06 ± 8.9
Years of Service (mean ± SD)	12.00 ± 4.8
BMI (mean ± SD)	22.71 ± 3.4
LBP (mean ± SD)	
Pretest (Baseline)	19.35 ± 3.5
Posttest1 (1 week)	19.61 ± 3.4
Posttest2 (2 weeks)	19.92 ± 3.5

Work posture improved, consistent with the RULA questionnaire results, and the score improved from 5 to 4. The changes in the posture are described in detail in Figures 2, 3, and 4.

Figure 2: RULA Score Before the Intervention (Score 5)

Figure 3: RULA Score After 7 Days of Intervention (Score 4)

Figure 4: RULA Score After 14 Days of Intervention (Score 4)

Repeated-measures ANCOVA was employed to assess differences in low back pain (LBP) scores across three measurement points (baseline/pretest, posttest 1, and posttest 2), controlling for covariates such as age, years of service, body mass index (BMI), and gender. The Mauchly's test indicated that the assumption of sphericity was met for both the intervention group ($W = 0.968$, $p = 0.478$) and the control group ($W = 0.987$, $p = 0.747$), as both p-values exceeded 0.05. Thus, the repeated-measures ANCOVA output was interpreted using the F-statistic with the assumption of sphericity. The findings indicated that low back pain scores decreased significantly across time points in the intervention group ($F = 6.289$, $p = 0.003$), whereas the covariates had no significant effect ($p > 0.05$). Conversely, the control group did not exhibit any significant difference across measurement times ($F = 0.951$, $p = 0.390$). Table 2 shows the detailed results of the analysis.

Table 2: Repeated Measures ANCOVA Results on Low Back Pain Scores across Time Points, Controlling for Age, Years of Service, BMI, and Gender

Source of Variation	Differences across time		Covariates							
			Age		Years of Service		BMI		Gender	
	F	p-value	F	p-value	F	p-value	F	p-value	F	p-value
Group 1: Intervention Group (n = 51)	6.289	0.003	0.011	0.917	0.210	0.649	0.303	0.584	0.345	0.560
Pre-test Post-test1 Post-test2										
Group 2: Control Group (n = 51)	0.951	0.390	0.005	0.945	0.008	0.930	0.227	0.636	0.155	0.695
Pre-test Post-test1 Post-test2										

A trend analysis was then performed to investigate the direction of change in low back pain (LBP) scores over time and to establish whether the trend was linear or quadratic. The within-subjects effects test showed that the linear trend was statistically significant in the intervention group ($p = 0.002$), whereas the quadratic trend was not significant ($p = 0.534$). In the control group, however, there was no statistically significant pattern of change, as neither the linear trend ($p = 0.840$) nor the quadratic trend ($p = 0.160$) was significant. These results suggest that the change in LBP scores in the intervention group showed a strong linear pattern ($p < 0.05$); specifically, the scores declined steadily over time.

The differences in low back pain (LBP) scores between the control and intervention groups at each measurement time point—baseline (pretest), posttest 1 (day 7), and posttest 2 (day 14)—were analyzed using a one-way ANCOVA. This comparison was conducted while controlling for potential confounding factors, including age, years of service, body mass index (BMI), and gender, to ensure that the identified differences could be attributed to the ergonomic chair intervention. The findings showed no significant difference in LBP levels between the intervention and control groups at baseline ($p = 0.731$), suggesting the two groups had similar LBP levels before the intervention. Nevertheless, on day 7 (posttest 1) and day 14 (posttest 2), statistically significant differences were observed between the two groups ($p = 0.001$ for both), with LBP scores showing a sharp decrease in the intervention group but no significant changes in the control group.

Moreover, the results of the analyses showed that covariates, including age, years of service, BMI, and gender, did not significantly affect changes in low back pain scores at any time point. This supports the observation that the decrease in pain complaints was mainly attributable to the ergonomic chair itself. Table 3 presents the results of the one-way ANCOVA analysis at each measurement time point in detail.

Table 3: Results of One-Way ANCOVA of Low Back Pain Scores in Intervention and Control Groups at Three Time Points, Adjusting for Age, Years of Service, BMI, and Gender

Source of Variation	MSDs Baseline pre-test ($\bar{x} \pm SD$)	MSDs Day 7 post-test1 ($\bar{x} \pm SD$)	MSDs Day 14 post-test2 ($\bar{x} \pm SD$)
Group			
Intervention	19.16 ± 4.5	14.73 ± 3.3	8.24 ± 6.7
Control	19.35 ± 3.5	19.61 ± 3.4	19.92 ± 3.5
F	0.119	49.377	263.519
p-value	0.731	0.001	0.001
Covariates			
Age			
F	1.719	0.514	1.344
p-value	0.193	0.475	0.249
Years of Service			
F	0.541	0.481	0.208
p-value	0.464	0.490	0.649
BMI			
F	0.168	0.075	0.789
p-value	0.683	0.785	0.377
Gender			
F	0.119	0.361	0.038
p-value	0.512	0.549	0.846

Discussion

The findings of this research indicate that the ergonomic chair intervention approach provided substantial value in reducing low back pain (LBP) complaints among workers in the informal garment sector. The repeated-measures ANCOVA confirmed this reduction, demonstrating a significant linear trend in pain scores across time points in the intervention group ($p = 0.002$) but no significant difference in the control group. This indicates that consistent use of the ergonomic chairs led to a positive change in alleviating low back pain in only two weeks. In addition, the One-Way ANCOVA findings also supported these results, revealing that the difference in LBP scores between intervention and control groups became significant after the first week ($p = 0.001$) and even more pronounced in the second week ($p = 0.001$), whereas the difference at baseline was not significant ($p = 0.731$). That is, the group using ergonomic chairs had a significantly larger reduction in pain than the group receiving no intervention.

Age, length of service, body mass index (BMI), and gender were not statistically significant, indicating that the reduction in pain complaints was more likely attributable to the ergonomic intervention itself than to the participants' demographic or anthropometric characteristics. The positive impact of ergonomic chairs on working ergonomics, as evidenced by a reduction in RULA scores from 5 (high risk) to 4 (medium risk), indicates an improvement in working posture, though the RULA score of 4 corresponds to a medium risk level, suggesting a need for further ergonomic modifications or supplementary interventions. Overall, these findings suggest that anthropometrically designed ergonomic chairs are effective in the short term in reducing low back pain and improving posture, although they may not be sufficient on their own to achieve an acceptable postural risk level.

The reduction in low back pain can be attributed to the ergonomic chair's design, which enhances postural support. In this study, the chair was designed to optimally accommodate the lumbar curve, discourage excessive slouching, and enable height adjustments to align it with the

worktable.[16,17] This aligns with established principles of static ergonomics, whereby maintaining a neutral posture and using adequate lumbar support helps decrease pressure on the intervertebral discs and reduce muscular load on the lower back on the lower back.[18,19]

These findings are consistent with previous research indicating that modified work chairs, as an ergonomic intervention, can potentially reduce the prevalence of low back pain among garment workers.[20–22] Adjustable lumbar support chairs were shown in a longitudinal study to reduce musculoskeletal complaints by half after the second week of intervention.[23]

Moreover, the posture rating score based on RULA (Rapid Upper Limb Assessment) also improved, decreasing to 4 (from an earlier score of 5). Although the difference was not significant, it shows that working postures can be corrected with an ergonomic chair, particularly by reducing excessive lumbar flexion.[24,25] More favorable working conditions are reflected by a lower RULA score. This is supported by studies that revealed a positive correlation between the risk of musculoskeletal disorders and RULA scores.[26–28]

As indicated by the between-subjects analysis, the covariates did not significantly affect LBP scores. This confirms that changes in pain were more attributable to the ergonomic chair intervention than on individual factors.[29–31] However, the influence of these factors cannot be dismissed entirely, as several studies have shown that age and BMI may increase the risk of LBP, especially among manual laborers.[32,33]

From a scientific perspective, this study expands the body of empirical evidence that even simple ergonomic interventions—like adopting suitable ergonomic chairs—can make a considerable difference in a very short time, even in an informal industry like garment workshops.[34–36] It should be noted that most prior research was conducted in formal industrial or office environments, whereas garment workers have received little to no attention regarding ergonomic measures.[37]

Although the current research makes significant contributions to the overall knowledge of how ergonomic interventions with chairs can be used to alleviate low back pain among garment industry workers, a number of limitations must be noted. First, the intervention is relatively short (14 days), which could limit the assessment of long-term outcomes of using ergonomic chairs. To evaluate the long-term sustainability of the intervention's effects, longer-term follow-up studies are warranted. Second, self-reported pain scores are prone to subjective bias, such as intentional or unintentional over- or underreporting.[38,39] Third, the geographic location of the study site, limited to one garment industry in Indonesia, might also limit the generalizability of the results to other populations that have different conditions in the workplace and different ergonomic cultures.

Future research should address the limitations identified in this study. Specifically, longitudinal or longer follow-up designs would be more effective for evaluating the long-term effects of ergonomic interventions, as suggested by Konradt and Wiben.[40,41] Additionally, the validity and robustness of the findings could be strengthened by incorporating objective measurements, such as spinal load analysis, muscle activity (EMG), or sitting duration. Applying these methods to other industries and geographic locations, especially in Southeast Asia, would provide a broader perspective and enhance the generalizability of ergonomic interventions in high-risk work environments.

Conclusion

The ergonomic chair intervention showed improvements in working posture and a consistent decrease in low back pain over 14 days among informal garment workers. These results are novel and contextually appropriate for this industry in Southeast Asia, where ergonomic research is limited. The findings illustrate the need for even simple ergonomic interventions, especially when incorporating chair designs that fit the anthropometric characteristics of the

intended users, to mitigate the risk of developing MSDs in occupations with high ergonomic stress.

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Original Article

Investigating the prevalence of work-related musculoskeletal disorders among ICU nurses in the Sultanate of Oman

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ABSTRACT

Introduction: Intensive Care Unit (ICU) nurses are increasingly exposed to work-related Musculoskeletal Disorders (MSD), making them among the most vulnerable healthcare workers globally. This study aims to investigate the prevalence of MSD among ICU nurses in Oman. It further examines the relationship between nursing activities and the prevalence of MSD among ICU nurses.

Methods: This study deployed a cross-sectional research design and a concurrent observational ergonomic assessment. A Nordic Musculoskeletal Questionnaire was completed by a random sample of 171 nurses to assess their perception of MSD pain. Subsequently, 48 nurses were observed using the Rapid Upper Limb Assessment (RULA) tool to evaluate the impact of various nursing activities on nurses' MSD.

Results: The findings reveal a high prevalence of MSD symptoms among ICU female nurses. Significant associations were identified between adherence to safe work procedures and shoulder ($p = 0.014$), low back ($p = 0.037$), and foot/ankle pain ($p = 0.022$). Moreover, adults (heart Center) ICU were found to have the highest RULA score of about (6.6), followed by adults main, and pediatrics heart center (6.4) and (6.2) respectively.

Conclusion: This study highlights the prevalence of Musculoskeletal Disorders among ICU nurses. It underscores the need for healthcare organizations to strengthen ergonomic training, patient-handling strategies, and workplace safety measures to support nurses', safety, health, well-being and improve overall healthcare performance. The integration of occupational health and safety practices into ICU work environments enables policymakers, safety practitioners, and regulators to promote safety among ICU nurses.

Keywords: ICU, Nurses, Oman, Work-related Musculoskeletal Disorders (MSD),

Introduction

Intensive Care Unit (ICU) nurses are essential healthcare professionals who spend more time with patients than any other healthcare staff. The extensive dependence of critically ill patients on nurses for complex daily care activities increases nurses' exposure to work-related Musculoskeletal Disorders (MSD). Activities such as patient repositioning, manual handling, transferring patients, prolonged standing, repetitive movements, bending, and twisting expose ICU nurses to high ergonomic and occupational risks.[1-7] These physically and psychologically demanding working conditions make ICU nurses among the most vulnerable healthcare workers globally. [6,8–12]

Work-related MSDs among healthcare workers account for nearly 50% of occupational injuries and contribute substantially to global healthcare costs.[13–18] MSDs are highly prevalent among ICU nurses and commonly affect the lower back, neck, shoulders, wrists, legs, and feet.[19–21] Previous studies reported that ICU nurses experience higher MSD rates than many other healthcare professionals due to frequent patient-handling activities and awkward working postures. In addition to physical pain, MSD negatively affects nurses' psychological well-being, contributing to stress, anxiety, depression, absenteeism, poor job satisfaction, and reduced nurse retention.

Several ergonomic, organizational and sociodemographic factors influence the prevalence of MSD among ICU nurses. Common risk factors include age, gender, years of service, night shifts, workload, stress, and unsafe patient-handling practices.[12,22] The nature of ICU departments may also influence ergonomic exposure. For example, nurses in pediatric intensive care units frequently switch between tasks and experience high multitasking demands, increasing physical and cognitive workload.[10] These findings highlight the importance of identifying ICU-specific occupational risks to support the development of targeted ergonomic and safety interventions.

Moreover, manual patient transfers, bedside procedures, repetitive movements, and prolonged standing are common ICU activities that generate physical strain, particularly affecting the lower back and shoulders.[23–25] In addition, MSD are associated with disability, spinal disorders, osteoporosis, anxiety, depressive symptoms, and reduced well-being among nurses. [20,21,26]

Despite extensive international evidence on the burden of MSD among ICU nurses, limited research has examined nurses' perceptions of MSD risks, body pain, and safe work practices in Oman. Therefore, this study aims to investigate the prevalence of MSD among ICU nurses and the body parts most affected. In addition, this study aims to investigate the most common risk factors in the ICU work environment that influence the spread of MSD. Hence, the following research questions were developed:

1. What is the prevalence of musculoskeletal disorders (MSDs) among intensive care unit (ICU) nurses?
2. How do nursing activities affect different body regions among ICU nurses?
3. What are the risk factors that are associated with the development of MSD among ICU nurses?

Understanding the risk factors associated with the development and prevalence of MSDs enables policymakers, safety practitioners, and regulators to promote occupational health and safety among ICU nurses. The findings of this study can support the development of ergonomic interventions and safer patient-handling practices.

Methods

This study deployed a cross-sectional research design and a concurrent observational ergonomic assessment to investigate the prevalence of MSD within ICU units with particular focus on nurses at the Royal Hospital. Being one of the pioneering healthcare entities, the Royal Hospital is one of the largest tertiary healthcare institutions in the Sultanate of Oman that was established in 1987.[27]

The study integrated two methods, a questionnaire and observational ergonomic assessment methods, to provide a more comprehensive understanding of the prevalence of MSD among ICU nurses.[28] The data collection took place concurrently between 15 January and 8 February 2024 by self-administered questionnaire and direct observations of routine nursing activities. The questionnaire explored the perception of nurses of the symptoms and the risk factors of MSD, whereas the Rapid Upper Limb Assessment (RULA) tool was used to evaluate physical demands and postural risk factors.[29]

A convenience sample of (n=4) ICU was selected from a total of sixteen ICU based on accessibility, administrative approval, and willingness to participate in the study. The four departments in

this study are: adult ICU, adult heart center ICU, pediatrics ICU, and pediatrics heart center ICU. Following department selection, participant recruitment within each selected ICU was performed using random sampling to reduce selection bias and enhance representativeness. Lists of eligible nurses were obtained from each participating department, and participants were randomly selected using a simple random sampling (fishbowl) method.

The sample questionnaire size was determined in two stages. First, the required sample size for an infinite population was calculated and then adjusted based on the number of eligible nurses in each ICU. The lists of eligible nurses were obtained from the ICU head nurses. Eligibility criteria included full-time ICU nurses with at least two years of work experience and who are directly involved with patients' care. Nurses on leave or those in administrative roles were excluded from study. The final adjusted sample size was proportionally allocated across the four ICU departments. Details of the eligible population, adjusted sample size, completed responses, and response rates are presented in Table 1. The questionnaire was shared with 171 individuals, and 107 responses were returned, yielding a response rate of about 63%.

Table 1: Eligible population, sample size, responses, and response rates

ICU departments	Eligible population (N)	Adjusted sample size Sample	Completed responses (n)	Response rate (n/ adjusted sample size%)
Heart center (Adults)	58	36	29	80.5
Heart center (Pediatric)	63	38	10	26.3
Pediatric (main building)	98	49	37	75.5
Adult (main building)	96	48	31	64.58
Overall Total	***315***	***171***	***107***	***62.6***

For the RULA, a purposive sample technique was used to select observees from the list of nurses based on availability, meeting the study eligibility criteria, and agreeing to be observed. The sample included individuals with different demographic and work characteristics, including age, gender, service years, marital status, and shift work patterns, to ensure variability in observed nursing activities. The observations of a variety of activities, based on availability, were conducted in the three shifts. Observations were concluded after assessing 48 nurses, as data saturation was achieved and all major nursing activities had been recorded. Each session was task-based and lasted for the duration of the activity being performed. The scores were reported according to their corresponding action levels to ensure consistent interpretation of ergonomic risk severity. All observation sessions were photographed and later reviewed using a standardized RULA scoring procedure to enhance scoring consistency.

The questionnaire comprised two sections: participants' demographics and the prevalence of work-related MSD using the Musculoskeletal Disorders Nordic Musculoskeletal Questionnaire (NMQ-E). This study adapted the NMQ-E to assess nurses' perceptions of musculoskeletal pain or discomfort across nine body regions, including the neck, shoulders, upper back, elbows, lower back, wrists/hands, hips/thighs, knees, and ankles/feet.[18,30] To evaluate the questionnaire clarity, readability, and suitability for this study, it was pilot tested on a small group of ICU nurses, and no issues were raised.

The RULA instrument is an observational ergonomic assessment method used to evaluate postures and ergonomics in nurses' routine activities, such as patient repositioning, patient transfers, bedside care and equipment handling. Each nurse was observed during a certain activity, and the postures associated with the highest ergonomic load were scored. Prior to the

observation sessions, the researchers received training with the RULA to ensure consistency in posture evaluation and scoring. To minimize disruption to workflow, the study objectives and RULA procedure were explained individually to participants before observations. Participants provided informed consent for observation and video recording using a phone camera to support accurate posture assessment and scoring.

The data from the questionnaire and RULA were analyzed using the Statistical Package for the Social Sciences (SPSS) version 26 and Microsoft Excel. Descriptive statistics were used as graphical displays and numerical summaries of quantitative data, such as means, percentages, and frequencies, to present data categories, and standard deviations were used to present continuous data.

To identify factors associated with MSD, Chi-square tests were conducted using IBM SPSS Statistics to examine the relationships between demographic and MSD symptoms across the nine body parts. The assumptions of the Chi-square test were assessed prior to analysis. Fisher's Exact Test was applied when expected cell counts were low or zero-frequency cells were identified.

The reported RULA mean scores indicate the level of ergonomic risk and priority for intervention. For example, a score of 7 or higher indicates that an immediate ergonomic intervention is required; scores of 5-6 suggest implementing intervention as soon as possible; and scores of 3-4 indicate the need for further investigation. Following similar studies,[31,32] the results from both methods were integrated during the results discussion and interpretation to provide insight into the prevalence of MSD risks among ICU nurses.

At the beginning of the questionnaire, researchers clearly indicated that participation in this study was voluntary and that participants could withdraw without consequences. At the beginning of each observation session, researchers thoroughly explained the study to participants and obtained their consent to take and use their photos, in accordance with research ethical guidance, without compromising participants' confidentiality. Ethical approval for this study was obtained from the Center of Studies and Research, Ministry of Health, Sultanate of Oman (MoH/CSR/23/27637).

Results

The sociodemographic characteristics of ICU nurses, including gender, age, service years, marital status, and rotations shifts, are summarized in Table 2. Most participants were female nurses across all ICU departments, ranging from 90% to 100%. The participants are mostly between 30-49 years, with service years ranging between 5-16+ years. While 80% of the participants were married, around 38.6% work night shift.

Table 2: Sociodemographic characteristics of ICU nurses

		Department			
		Adults -ICU	**Adults Heart canter ICU**	**Pediatrics - ICU**	**Pediatrics Heart Center ICU**
Gender	Female	28 (90.3%)	27 (93.1%)	36 (97.3%)	10 (100.0%)
	Male	3 (9.7%)	2 (6.9%)	1 (2.7%)	0 (0.0%)
Age	20-29	3 (9.7%)	8 (27.6%)	8 (25.8%)	2 (20.0%)
	30-39	16 (51.6%)	6 (20.7%)	16 (51.62%)	0 (0.0%)
	40-49	12 (38.7%)	11 (37.9%)	10 (32.3%)	8 (80.0%)
	50-59	0 (0.0%)	4 (13.8%)	3 (9.7%)	0 (0.0%)
	60 and above	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Service years	11-15 years	12 (38.7%)	4 (13.8%)	6 (16.7%)	2 (20.0%)
	16 years and above	8 (25.8%)	12 (41.4%)	10 (27.8%)	2 (20.0%)
	5-10 years	11 (35.5%)	9 (31.0%)	21 (55.6%)	5 (50.0%)
	Less than 5	0 (0.0%)	4 (13.8%)	0 (0.0%)	1 (10.0%)
Marital status	Divorced	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

	Married	31 (100.0%)	23 (79.3%)	31 (83.8%)	9 (90.0%)
	Single	0 (0.0%)	6 (20.7%)	6 (16.2%)	1 (10.0%)
Rotations	Afternoon	6 (20.0%)	7 (25%)	10 (28.1%)	4 (44.4%)
shift	Morning	10 (32.0%)	11 (39.3%)	13 (34.4%)	2 (22.2%)
	Night	15 (48.0%)	10 (35.7%)	14 (37.5%)	4 (44.4%)

Musculoskeletal disorders (MSD) prevalence among ICU nurses

Figure 1 presents the prevalence of Musculoskeletal Disorders across different body regions and ICU departments. Overall, the highest prevalence of MSD symptoms was reported among nurses in the adult ICU, followed by the pediatrics ICU. Shoulder, hand/wrist, and lower back pain were the most frequently reported complaints across the investigated ICU.

In the adult ICU, shoulder pain showed the highest prevalence (84.8%), followed by hand/wrist pain (77.8%) and elbow pain (75.0%), while hip/thigh pain was the least reported symptom (50.0%). Among nurses in the adult heart center ICU, hip/thigh pain was the most reported complaint (57.1%), whereas knee pain showed the lowest prevalence (27.3%). In the pediatrics ICU, shoulder pain (73.3%) and hand/wrist pain (70.0%) were the most frequently reported MSD symptoms. Nurses in the pediatrics heart center ICU reported the highest prevalence of lower back pain (66.0%), followed by upper back and knee pain (60.0% each).

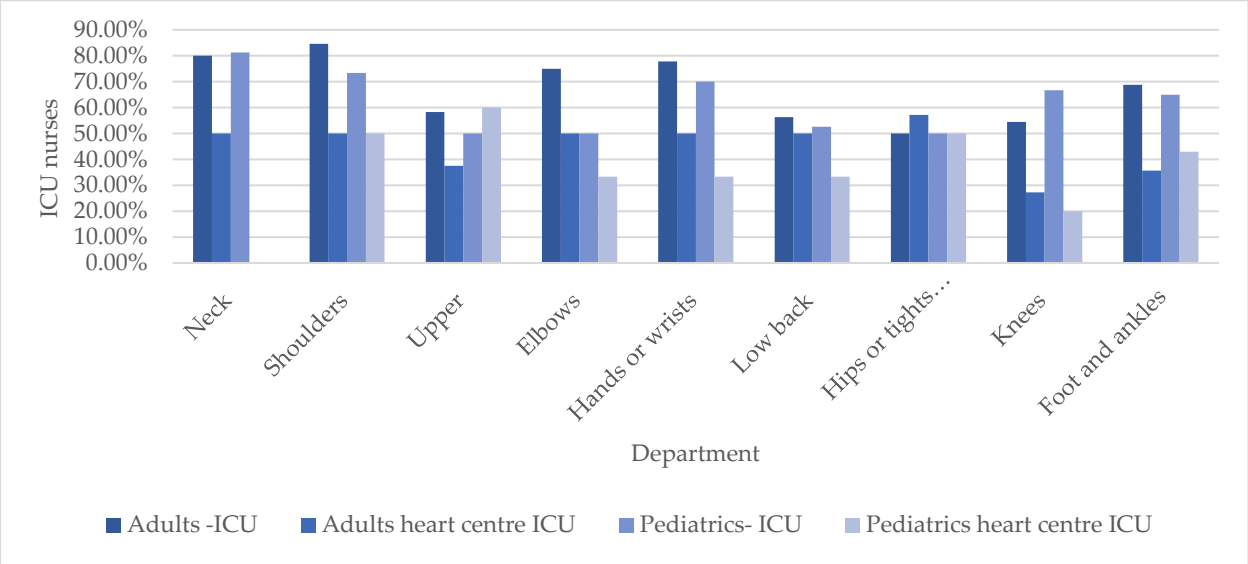

Figure 1: Prevalence of MSD across the four ICU departments.

Figure 2 shows that the nurses aged 40–49 years reported the highest prevalence of MSD symptoms, followed by nurses aged 30–39 years. Surprisingly, nurses aged 50–59 years reported the lowest prevalence rates. The highest symptoms of pain reported by nurses aged 40–49 were observed in the hands, wrists, shoulders, lower back, and feet and ankles.

The female nurses reported higher prevalence rates of MSD symptoms compared to male nurses across all body parts. The highest prevalence was reported in their hands, wrists, feet, ankles, shoulders, and knees. However, this finding should be interpreted with caution, as the number of male nurses is much lower than that of female nurses.

Figure 3 presents the distribution of safe work practices and training related to Musculoskeletal Disorders prevention across the four ICU departments. Overall, a high proportion of nurses across all ICUs reported following safe work procedures when handling patients, with the highest adherence observed in the adult heart center ICU and adult ICU. In contrast, the

proportion of nurses reporting training on reducing MSD was lower in most departments. The adult heart center ICU had the highest percentage of nurses receiving MSD-related training, whereas pediatrics and pediatrics heart center ICU showed the lowest training levels.

Finally, several nurses reported that they received treatment for MSD conditions, underwent surgical procedures, changed their jobs or considered early retirement because of MSD pain.

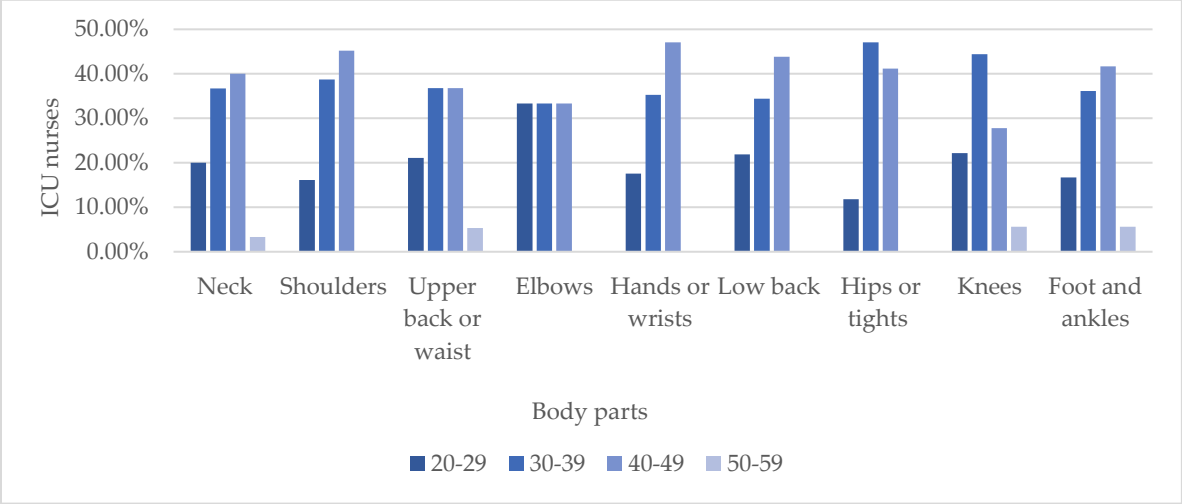

Figure 2: Prevalence of MSD symptoms by body parts and age groups

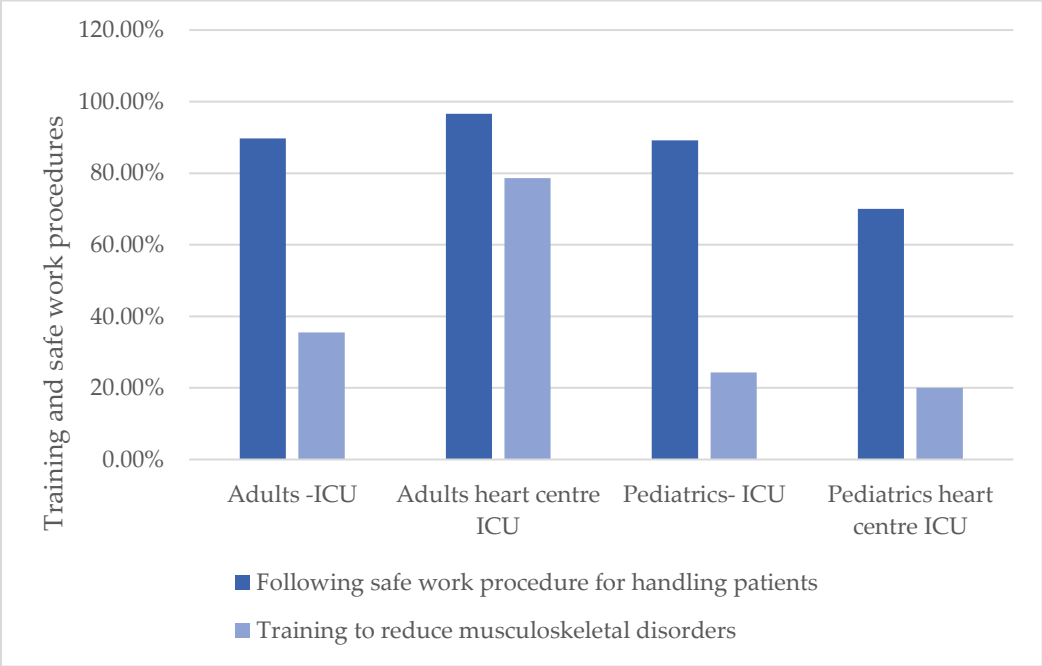

Figure 3: Perception of training and safe work procedure.

Risk Factors associated with musculoskeletal disorders

The Chi-square analysis reveals several significant associations between work-related MSD symptoms and demographics. See Table 3. For example, department type, service years, and rotating shift are significantly associated with neck, foot, and knee pain, respectively. Affecting one body part. Age and manual handling affect two body parts simultaneously. While the age of a nurse is found to have an association with the increase in shoulder pain and lower back pain, manual handling is linked to shoulder and foot pain. On the other hand, following safe work procedures is found to be significantly associated with lower pain in nurses' shoulders, backs, feet,

and ankles. However, the p-values presented in Table 3 should be interpreted as an exploratory study, given the multiple Chi-square comparisons performed. Therefore, emphasis was placed on overall patterns of association rather than isolated statistically significant findings.

Table 3: Summary of Chi-square test

Likelihood Ratio	Neck pain, numbness or discomfort	Shoulder pain, numbness or discomfort	Low back pain, numbness or discomfort	Knee pain, numbness or discomfort	Foot and ankle pain, numbness or discomfort
Department	***0.004***	0.080	0.131	0.233	0.087
Age	0.071	***0.003***	***0.034***	0.616	0.211
Service years	0.204	0.518	0.073	0.095	***0.046***
Rotating-shift	0.074	0.336	0.519	***0.004***	0.099
Manual handling procedure	0.337	***0.014***	***0.037***	0.186	***0.022***

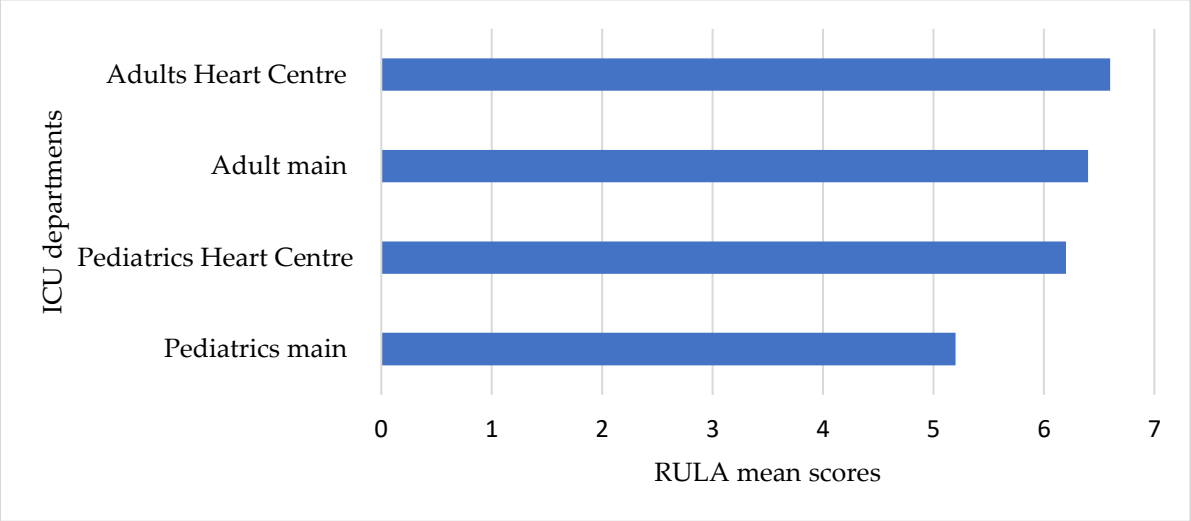

Figure 4: Mean score across 4 ICU departments.

The impact of nursing activities on different body parts

The distribution of RULA scores observed during different activities across the four ICU departments is grouped into five main categories. Namely: bedside treatment, bed preparation and patient transfer, medication preparation, treatment procedures, and patient care. The bedside treatment activities included inserting urinary catheters, medication and medical rounds. Bed preparation involved transferring and repositioning patients between beds, chairs, and departments. Treatment procedures included suctioning, blood collection, emptying urine bags, handling oxygen cylinders, and raising bedside rails, while patient care activities mainly involved holding and feeding babies. Out of the 48 nurses observed, 19 were involved in bedside treatment tasks, 11 in bed preparation and patient transfer, 9 in patient repositioning, 5 in medication preparation, and 4 in infant care activities. The RULA average mean score of the nursing activities across the four ICU depicts that the adult heart center unit is the highest (6.6), followed by the adult main (6.4) and pediatrics heart center (6.2). The main ICU pediatrics scored the least among the four departments (5.2) RULA score. See Figure 4. The reported mean RULA scores across the ICU

tasks indicated moderate-to-high ergonomic risk levels. In particular, the adult heart center ICU recorded the highest mean RULA score, followed by the adult and pediatric ICU. According to RULA action levels, scores above 5 indicate that the observed postures are likely to place nurses at increased risk of developing Musculoskeletal Disorders and require further ergonomic investigation and prompt intervention. These findings suggest that several routine ICU nursing activities involve awkward postures, repetitive movements, and physical strain that may contribute to MSD development if corrective ergonomic measures are not implemented.

Discussion

To the authors' knowledge, limited studies have examined the prevalence of Musculoskeletal Disorders (MSD) among ICU nurses in Oman. The findings of the cross-sectional study and the concurrent observational ergonomic assessment highlight the substantial burden of MSD symptoms among ICU nurses. The study also emphasizes the importance of ergonomic and occupational health interventions within ICU settings in Oman and similar healthcare environments.

The findings demonstrated varying associations between sociodemographic factors and MSD symptoms among ICU nurses. It indicates that the duration of occupational exposure associated with ICU activities varies by nurse age and years of experience. The results indicate that MSD affects nurses to the extent that they receive regular treatment and surgical procedures. Some nurses report considering a job change or early retirement due to their MSD experience.

However, the MSD problem is not without a solution. The results indicate that effective safety procedures, training that raise nurses' awareness, and safety communication are associated with lower levels of pain across body parts. These results highlight the importance of proactive safety management practices in reducing MSD symptoms among ICU nurses. Differences in MSD exposures were observed in the ICU departments. These differences may be related to variations in activities and workload demands. However, although nurses in the pediatric ICU appeared to report lower MSD exposure, previous literature studies indicated that they are exposed to frequent task changing and multitasking demands.[10] The Rapid Upper Limb Assessment (RULA) findings were generally consistent with the questionnaire results and indicated moderate-to-high ergonomic risk levels across several ICU nursing activities.

Observed tasks commonly involved awkward postures, prolonged standing, repetitive movements, and manual patient handling, which may increase ergonomic strain among ICU nurses. The results of this study show that although adherence to safe patient-handling procedures is high among ICU nurses, formal ergonomic and MSD prevention training may be insufficient in some ICU departments. The variation across departments may reflect differences in workplace safety practices, training availability, or organizational emphasis on ergonomic risk management.

Given that the effective implementation of safety management practices, including risk assessment, safety training, effective communication, workers' involvement and leadership commitment, is associated with reduced occupational incidents and enhanced workplace safety performance.[33] It is crucial that the ICU departments adopt a variety of proactive safety management practices to manage workers' exposure early. It is essential to raise awareness among nurses about the impact of MSD on health, safety, well-being and the quality of nurses' lives. The findings of this study will support the integration of occupational health and safety practices into ICU work environments, aiming to reduce physical strain and prevent long-term MSD. It further enables policymakers, safety practitioners, and regulators to promote occupational health and safety among ICU nurses.

Limitations

The findings of this study suggest that specific demographic and workplace factors are associated with the prevalence of Musculoskeletal Disorders among ICU nurses and highlight the importance of targeted ergonomic interventions to reduce pain and discomfort in ICU settings. However, several limitations should be considered when interpreting the findings. The cross-sectional design and relatively small sample size may limit the generalizability of the results.

Although the sample met the minimum recommended for both methods, it may not fully represent the diversity of participants. Secondly, the study was conducted in a single hospital in Oman, which may limit the generalizability of the results to other healthcare institutions or ICU settings. The use of self-reported symptoms may introduce recall and response bias, as participants' perceptions of pain and discomfort may vary. Therefore, future research should use longitudinal designs with larger, more diverse samples drawn from several hospitals. Only then can results be robust, valid and generalizable.

Conclusion

This study highlights the prevalence of Musculoskeletal Disorders among ICU nurses. It also emphasizes the importance of ergonomic and occupational safety interventions within ICU settings.

Among several nursing activities, safe patient-handling practices are linked with lower levels of shoulder, low back, foot and ankle pain, indicating the potential value of reinforcing safe work procedures in critical care environments. The study underscores the need for healthcare organizations to strengthen ergonomic training, patient-handling strategies, and workplace safety measures. These proactive safety practices will support nurses' safety, health and well-being and improve overall healthcare performance. The integration of occupational health and safety practices into ICU work environments enables policymakers, safety practitioners, and regulators to promote safety among ICU nurses.

Declaration of Competing Interest

The authors used Grammarly to assist with grammar, spelling, punctuation, and language editing of the manuscript. The authors confirm that Grammarly was used solely for linguistic refinement and did not contribute to the study's scientific content, data analysis, interpretation, or conclusions. Otherwise, we declare that there are no known competing personal relationships or financial interests that could have influenced the work reported in this study.

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Original Article

Musculoskeletal discomforts among young nurses: A foreshadowing and the reasons behind

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ABSTRACT

Introduction: Musculoskeletal discomfort in nurses is becoming more common. Studies have revealed that age and exposure to causative factors over the years might trigger symptoms. The goal of this study was to evaluate the prevalence and factors influencing the work-related musculoskeletal discomfort indications among young female nurses.

Methods: This cross-sectional study was performed between August, 2020 to November 2022. Maintaining the inclusion and exclusion criteria of this study, female registered nurses were chosen with an age limit of 29 years. Modified Nordic Questionnaire, Physical Activity Level (PAL) questionnaire, Copenhagen Psychosocial Questionnaire (COPSOQ), and Rapid Entire Body Assessment (REBA) tool were used. Percentage analysis, Correlation analysis, and Binary Logistic Regression tests were performed.

Results: 79.4% of participants reported the presence of musculoskeletal discomfort in at least one body region, and the most frequent among them was lower back pain (LBP) with a percentage of 51.4%. Quantitative Demand, General Health, and Vitality displayed a significant relation with LBP. Posture analysis exhibited high bending angles.

Conclusion: Musculoskeletal discomfort complaints among young nurses disclosed an alarming prevalence. High work demand and frequently unfavorable postures contributed to the outcomes. Addressing the discomfort among young workers is of the utmost priority to ensure good health and forestall deteriorating symptoms in the future. Amelioration of work-related discomforts can lead to improved performance, enhanced job quality, and improved physical and mental health. As health sectors play a vital role in society and embrace a large number of young workers, assessing the workers' discomfort leads to a better and flourishing tomorrow led by healthier individuals.

Keywords: Health care sector, Musculoskeletal diseases, nurses, occupational health, occupational stress

Introduction

Musculoskeletal disorders (MSDs) include pain, discomfort, numbness, stiffness, and inflammation of nerves, muscles, bones, and related issues. In severe cases, degeneration in bones, joints, nerves, and muscles may occur with compression of nerves, reduced blood flow, swelling, and restricted and reduced movements. Work-related musculoskeletal disorders (WMSDs) received considerable scholarly attention in almost all working sectors. Concerning other workplaces, hospitals and nursing homes are expected to be more secure, but, in most instances, the conditions contradict the perception. Practically, hospitals and nursing

homes, as workplaces, can source various WMSDs.[1] Aggravation of these discomforts leads to absence from work, sick leave, and burnout. These in turn affect the overall productivity, organisational expenses and workers' well-being.[2]

Several factors can contribute to the onset and magnification of musculoskeletal discomfort. There is evidence from prior research linking musculoskeletal discomfort to morphological variables,[3] degree of physical activity,[4] and psychosocial aspects in the workplace.[5] Though individuals' morphological and genetic factors are unalterable, the biomechanical and psychosocial dimensions of the discomforts are amenable to intervention. Notably, young nurses in India have remained an underexplored demographic in this context, despite being critical to the country's growing healthcare sector. Assessing these risk factors of the discomfort is very crucial as there are multiple factors involved simultaneously, and among them, the age of the nurses appears to be an important factor to consider, as it was found that the prevalence of MSDs and areas of discomfort varies with age.[6,7] With the rising population and increased patient load, more young nurses were assigned to jobs in the health sector in India. In this study, the subjects have been chosen with work experience of less than 10 years, with the maximum age being 29 years.[8]

Prior research conducted worldwide has demonstrated that young nurses encounter a range of emotional stressors in the workplace, including bullying, blaming, intergenerational hostility, lack of respect, need to prove competence, etc.[9,10] As they are in their early decades of life, constant discomfort and underlying causes can affect their quality of life and can lead to persistent ailments in the future. This study seeks to explore the prevalence of WMSDs among young nurses in West Bengal, India, and to critically examine the multiple factors, ranging from physical activity and body posture to psychosocial elements at work, that contribute to their discomfort. These findings aim to inform interventions and policies that could mitigate the risks of WMSDs while enhancing the overall well-being and professional longevity of young nursing personnel.

The objectives of the study are to observe the prevalence of work-related musculoskeletal discomfort among young nursing personnel of West Bengal, India, and to assess the daily physical activity levels (PAL) of the young nursing population and their relation to musculoskeletal discomfort. Along with these, evaluation of the possible psychosocial factors relating to the musculoskeletal discomforts and analysis of the postures of the young nursing personnel while performing the tasks allotted were also the goals of this study.

Methods

This observational study cross-sectional in nature and was performed between August, 2020 to November 2022. The study was conducted in eleven hospitals in West Bengal, India, where female nursing personnel under the age of thirty were recruited. Appointments or hospital email IDs on official websites were used to contact hospital and nursing home administrators. After permission and introduction to the nursing staff, the research details were explained, and interested volunteers were recruited. Taking the confidence level of 95% with a 10% margin of error and a 50% population proportion, using Cochran's formula, the calculated sample size was 96. The sample size of the study was attained by randomly selecting and contacting 123 registered nursing personnel who were within the specified age range of this study. Among them, 4 nursing personnel were engaged in major patient and ward-related activities, and 119 participated in the study. Finally, 107 were selected, maintaining the inclusion criteria of the study. The inclusion criteria of this study were female registered nurses employed in different wards of hospitals and nursing homes, and with an age limit of 29 years. The exclusion criteria were nurses with histories of major accidents and injuries in the past, chronic musculoskeletal diseases, pregnancy, histories of recent major surgery, clinically diagnosed psychological

disorders, and having taken sick leaves of 7 days or more within the previous month from the day of the study.

The ethical clearance of the study was obtained from the Institutional Human Ethical Committee (IHEC) from the Department of Physiology, University of Calcutta in December, 2019 (IHEC/SM/P93/2019). Participants were given the consent forms at first, mentioning the particulars of the study and only the nurses who consented and approved the measures were taken to the procedures.

At first, the body height and weight of the subject were measured using an anthropometer (Martin's Anthropometer) and a weighing machine ("Crown" weighing Machine, Mfg. by Raymon Surgical Co.) and noted down along with the age of the subject. Modified Nordic Questionnaire,[11,12] Physical Activity Level (PAL) Questionnaire,[13,14] and Copenhagen Psychosocial Questionnaire (COPSOQ),[15] were used in this study. In the Modified Nordic Questionnaire, various body parts like neck, shoulder, elbow, hand, upper and lower back, thigh, knee, and feet were mentioned, and there was also a whole-body schematic diagram with approximate positions of the areas present in the questionnaire, which aided in better understanding. There were questions about the presence of pain or discomfort in any of the mentioned body parts in the questionnaire within the last 12 months and also within the last 7 days. Participants were asked to point out appropriate body areas with discomfort by tick-marking the checkboxes. As it emerged from previous studies that health sectors are workplaces with extensive workloads and responsibility, to assess their effects on nursing personnel, seven scales from the COPSOQ, Quantitative Demands, Cognitive Demands, Emotional Demands, Demands for Hiding Emotions, General Health, Mental Health, and Vitality were chosen for this study.[16,17] The Demand scales and General health scale questions had 5 options ranging from 0 to 100, where a score of 100 meant the highest response value or the highest level of the criteria being measured, and 0 was the lowest. The Mental Health and Vitality scale questions had 6 options ranging from 0 to 100, with the previous scoring manner. In the PAL questionnaire, various daily activities like sleeping, dressing, eating, domestic work, etc., were mentioned, and the subjects were asked to select the appropriate activities as per their daily chores and state the approximate duration of those specific works in a whole day of 24 hours duration.

After that, the most frequent activities of the nurses were noted down in various wards, and the subjects were asked to mention the tasks they found to be exhausting to perform or caused discomfort in body parts after performing. To observe the daily duties of the nurses, video recordings were done at different wards in different hospitals, maintaining the privacy of the patients and their family members. The nurses had to perform comparable tasks daily, but their workstations and task frequency varied between wards and hospitals. The video recordings were analyzed for the working posture of the nurses. The specific tasks were chosen from the recording, considering the highest frequency found and subjects' reports on discomfort. The frames were split and extracted from the videos for posture analysis, and the Rapid Entire Body Assessment (REBA) tool was used for the investigation.[18,1]

SPSS 23 version was used to analyze the data. Descriptive statistics were used to estimate the percentages of discomfort reports in different body areas, along with the age, body height, weight, Body Mass Index (BMI),[19] and PAL. Spearman's correlation was used to evaluate the relationship between work-related musculoskeletal discomfort with BMI and PAL categories. Binary logistic regression was used to assess the psychosocial factors. Locating the neck, trunk, legs, upper arm, lower arm, and wrist positions from the selected postures of the subjects and considering the other factors like force, coupling score, activity score, etc., the final REBA scores were calculated.

Results

The mean age of the participants was 25 years, and the mean height and weight were 156 cm and 57 kg, respectively (Table 1). According to the BMI classification,[20] 64.5% of participants belonged to the normal BMI category, 18.7% were overweight, and 8.4% of participants belonged to the underweight and obese categories each. Analysis of the PAL questionnaire depicted that 49.5% of subjects were in sedentary lifestyles, 46.7% in moderately active ones, and 3.7% in vigorously active lifestyles.

Table 1: Demographics of the subjects

Variables	Minimum	Maximum	Mean (SD)
Age (years)	20	29	25.21 (±2.69)
Height (cm)	130	172	156.18 (±6.29)
Weight (kg)	31	94	57.33 (±11.21)
BMI (kg/m^2)	15.52	35.38	23.44 (± 4.11)
PAL	1.45	2.38	1.71 (± 0.15)

In this present study, it was found that among the total participants (N=107), 79.4% of respondents reported the presence of musculoskeletal discomfort in at least one body region. The most frequently reported discomfort was in the lower back region, and 51.4% of subjects reported the discomfort since last year. Subjects with a percentage of 40.2% described that the lower back pain (LBP) prevented them from performing daily tasks, and 32.7% reported the presence of discomfort in the last week (Table 2).

Table 2: Percentage of subjects with discomfort in different body areas

Discomfort In Body Areas	Percentage of Participants (%)
Neck	
Since Last 12 Months	25.2
Prevented From Work	18.7
Last 7 Days	15.9
Shoulder	
Since Last 12 Months	22.4
Prevented From Work	14.0
Last 7 Days	14.0
Elbow	
Since Last 12 Months	2.8
Prevented From Work	1.9
Last 7 Days	0.9
Wrist/ Hand	
Since Last 12 Months	11.2
Prevented From Work	8.4
Last 7 Days	8.4

Upper Back	
Since Last 12 Months	14.0
Prevented From Work	13.1
Last 7 Days	12.1
Lower Back	
Since Last 12 Months	51.4
Prevented From Work	40.2
Last 7 Days	32.7
Hip/Thigh	
Since Last 12 Months	15.9
Prevented From Work	10.3
Last 7 Days	12.1
Knee	
Since Last 12 Months	20.6
Prevented From Work	15.9
Last 7 Days	16.8
Ankle	
Since Last 12 Months	20.6
Prevented From Work	15.9
Last 7 Days	15.0

With BMI and PAL, musculoskeletal discomforts revealed nonsignificant correlations here with r_s values of 0.054 and -0.092 with p values of 0.584 and 0.343, respectively.

As LBP was found to be the most recurrent one, the subjects were categorized into two groups, with the presence and absence of symptoms. The distribution of subjects' responses on the COPSOQ scales taken in the study was presented individually in Figure 1. For each scale response, subjects with and without LBP were depicted discretely.

In binary logistic regression, seven psychosocial factors from COPSOQ analysis were incorporated as independent variables and the LBP as the dependent variable. The full model containing all the predictors was statistically significant with $\chi 2(7, N=107) = 48.713$, $p < .001$. In this model, the Cox & Snell R Square value was 0.366, and the Nagelkerke R Square value was 0.488. Quantitative Demand, General Health, and Vitality showed statistically significant influence on the model. In the case of Quantitative Demand, the OR value was 1.074. (Table 3).

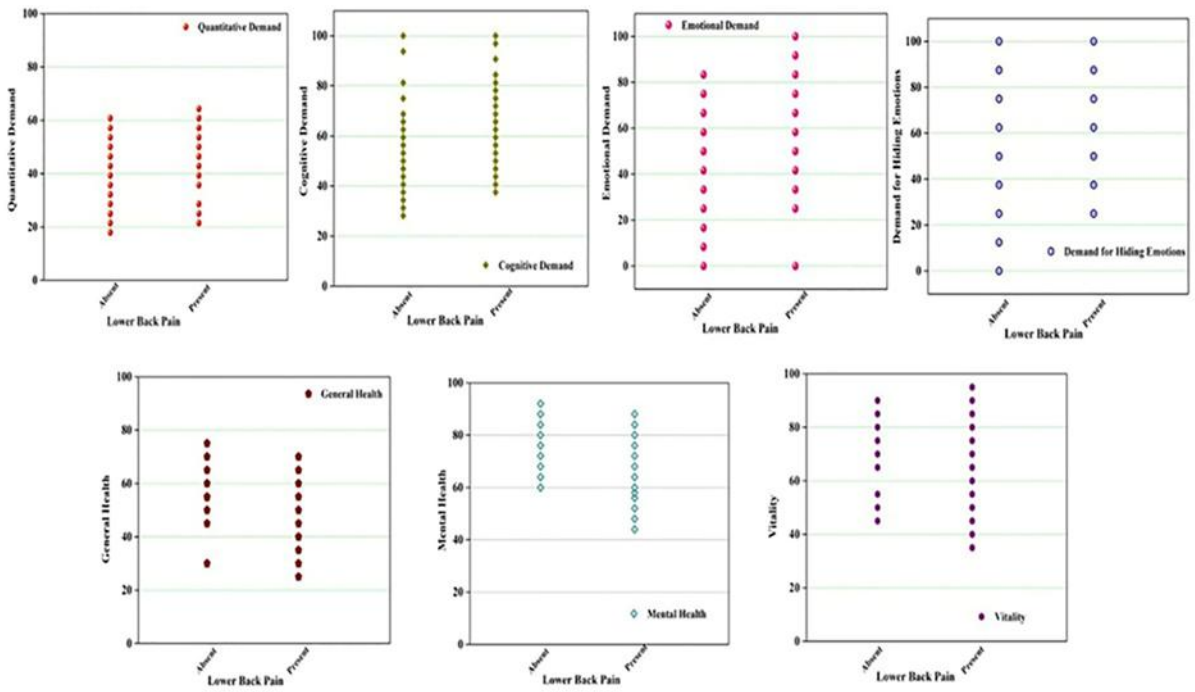


Figure 1: Distribution of individual scales of COPSOQ with the LBP reports

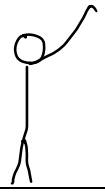
Table 3: Logistic regression model of LBP with scales of COPSOQ

	B	S.E.	Wald	df	p	OR	95% CI for OR	
							Lower	Upper
Quantitative Demand	.071	.027	7.064	1	.008	1.074	1.019	1.132
Cognitive Demand	.038	.020	3.492	1	.062	1.038	.998	1.080
Emotional Demand	-.007	.016	.181	1	.670	.993	.963	1.025
Demand for Hiding Emotions	.003	.014	.053	1	.817	1.003	.976	1.031
General Health	-.070	.034	4.271	1	.039	.933	.873	.996
Mental Health	.046	.035	1.708	1	.191	1.047	.977	1.122
Vitality	-.047	.023	4.154	1	.042	.954	.912	.998
Constant	-1.526	2.808	.295	1	.587	.217		

S.E.= Standard Error, OR= Odds Ratio

Most frequent and fatiguing daily activities were inspected, reviewed, and assessed with the REBA tool. Tasks with low REBA scores were eliminated, and only tasks with medium and high-risk levels were taken into further analysis. In Table 4, the eight tasks with long duration or high frequency and high REBA scores were mentioned with the scoring and stick diagrams of the postures.

Table 4: Working posture analysis using the REBA tool

Serial No.	Figure	Assessment	Task Description	Neck Score	Trunk Score	Legs Score	Upper Arm Score	Lower Arm Score	Wrist Score	REBA Score
Task 1		Long Duration	Holding and supporting the patient in maintaining an upright seated posture during a meal	1	**4**	1	**5**	1	3	**9**
Task 2		Long Duration	Pulling the patient's bed by rotating the lever handle	1	**5**	2	2	1	2	**7**
Task 3		Long Duration	The procedure of Ryles tube feeding	2	1	1	**4**	1	2	4
Task 4		Long Duration	Writing on a table during the duty handover	2	2	2	1	1	2	5
Task 5		High Frequency	Arranging instruments and medicines on a table	1	**4**	1	2	1	1	4
Task 6		High Frequency	Arranging instruments on a shelf	2	2	2	**4**	1	1	**7**
Task 7		High frequency	Administering an injection	2	2	1	2	1	**3**	4
Task 8		High Frequency	Changing the saline bottle	2	1	1	**4**	1	1	4

Discussion

In this study, all the subjects (N=107) were in their first few years of working life. They were a young platoon of workers with ages below 30 years and with a mean age of 25 years. In this study, 64.5% of subjects had normal BMI, and 18.7% were overweight. In both the underweight and obese categories, there were 8.4% of subjects. Almost half of the subject population were in sedentary lifestyles, with only 3.7% in vigorously active ones and 46.7% in moderate levels. Among them, 79.4% of participants reported musculoskeletal discomfort in at least one body region. The most prevalent one among them was LBP with a percentage of 51.4%. Discomfort in the neck, shoulder, knee, and ankle constituted percentages of 25.2%, 22.4%, 20.6%, and 20.6%, respectively. This present study is supported by the findings of Yasobant and Rajkumar (2014), who depicted young health workers with a greater chance of developing musculoskeletal discomfort [21]. In the study by Heiden et al. (2013), age groups exhibited disparities in MSDs complaints among nurses. From young to old, MSD incidence increased, as did physical discomfort [22]. As this present study showed a considerable percentage of young workers facing musculoskeletal discomfort, and prior studies demonstrated age-related symptom prevalence [22], there is an invariable likelihood of worsening discomfort with advancing age. Nurses reported the extent of discomfort and their outlook, and when discussing the presence of discomfort with them, the following responses were found.

"After the night duty, I feel pain in the waist area and legs."

"It happens sometimes that the patient is so critical we don't have the chance to sit"

"Sometimes the pain hurts, but what I am doing is of greater importance. This helps me go."

In this study, work-related musculoskeletal discomforts showed a non-significant correlation with BMI and PAL. While some researchers [6], contrary to this present study, have linked BMI to an increased risk of MSDs, other studies [23] have found that other work-related factors, such as posture and hours worked, have a more substantial impact than BMI. In this study, PAL showed a non-significant relationship with the presence of work-related musculoskeletal discomfort. However, it is important to highlight that 49.5% of the participants of this study led sedentary lifestyles, and 46.7% of the subjects were moderately active. Some research showed the beneficial effect of recommended physical activity on reducing discomfort symptoms [24] while others showed aggravation of symptoms with work-related physical activity [25]. Since earlier studies showed contradictory results and this study found a non-significant correlation between PAL and symptoms, yet 79.4% of musculoskeletal discomfort was found in the present study, more research is needed to recognize the causal factors here.

As LBP was found to be the most prevalent discomfort among the others, the contribution of different psychosocial factors was assessed here, taking LBP as the dependent variable. In binary logistic regression, seven factors from COPSOQ were incorporated as independent variables. The full model containing all the predictors was statistically significant with $\chi 2(7, N=107) = 48.713$, $p < .001$. The model as a whole explained between 36.6% (Cox & Snell R Square) to 48.8% (Nagelkerke R Square) of the variance in LBP and classified correctly in 81.3% of cases. Three predictors, Quantitative Demand, General

Health, and Vitality, showed a statistically significant influence on the model. Quantitative Demand showed the strongest contribution with OR 1.074. This 'Quantitative Demand' scale reflects the problem-oriented dimension of a workplace and imparts information about the tasks workers must perform. This study reinforced the study performed by Choobineh et al. (2010), where operating room (OR) nurses depicted a very high physical and mental demand. Activities of direct material handling were found to be associated with reported symptoms.[26,27] During the interview process, several questions were asked. Some examples of the responses have been highlighted. To the questions of COPSOQ, "Do you have to work very fast?" and "Do you have to keep your eyes on lots of things while you work?" the following types of responses were found in most cases, respectively.

"Most of the time, I have to work fast, depending upon the work pressure in the ward."

"We must check various aspects during duty hours. There are different types of patients with different needs. We must cater to everything and act according to the individual needs of each patient."

In this study, General Health and Vitality showed a negative association with LBP, which was analogous to previous studies where LBP was found to be positively associated with poor general health and could also alter the quality of life.[28,29]

As the nursing personnel had to perform wearing tasks during their entire working hours and the effects of some distinct activities could impact their health, the tasks performed by them were evaluated thoroughly using the REBA tool. The tasks scored 2 to 3 were designated as the low-risk tasks and removed from the analysis. Tasks scored 4 and above were selected for evaluation. Eight tasks were taken here and represented in Table 4. Among the activities taken into consideration, multiple tasks showed difficult posture scores with side bending or twisting and high bending angles (Table 4). The neck score of 2 depicted >20° flexion to the front. Trunk score ≥ 4 depicted forward flexion of >60°, and in the case of score 5, there was the twisting or side-bending posture. The upper arm score with a score of 4 showed a 90° upward position, and the score of 5 added the condition of raised shoulders in the posture. Wrist score 2 showed 15° up and downward movement, and with a score of 3, there was a side-bent wrist position. Twisted and bent postures for an extended period were able to cause pain and discomfort in musculoskeletal areas, which may lead to work-related musculoskeletal discomfort. These findings were supported by a study performed by Asghari et al. (2019) on nurses showing frequent and prolonged bending postures of the neck and trunk, and the type of task they performed demanded that the participants maintain those positions for a long time.[30] Sagittal inclinations ranging from 0° to 20° are in an acceptable range and are categorised as erect postures. In this position, the pressure on the spinal disc is minimal. It rises in tandem with increasing sagittal inclination. Sagittal inclinations ranging from 20° to 60° are deemed conditionally permissible, while those exceeding 60° are considered unacceptable. Nurses were subjected to complex and often risk-prone tasks, with varying percentages of time spent in extreme positions according to their wards. Studies unveiled that varied degrees of trunk forward bending are associated with LBP reports.[31] Patient transfer is merely one of the numerous responsibilities that comprise nurses'

daily work; they spend a significant portion of their workday on duties that do not involve direct patient contact.[32] Sagittal inclinations exceeding a 60° angle were most frequently induced by bed making (22%), tidying up/cleaning (16%), and basic care chores (16%).[32] However, among the 8 tasks evaluated here, only 3 tasks showed trunk scores ≥4, which depicted forward flexion of >60° with side bending and twisting. Although the largest proportion of study participants reported LBP, REBA analysis revealed concerning scores in other body regions as well, including the upper arm, wrist, neck, and so forth, alongside the trunk.

In another study, it was found that a large number of nurses reported that they had their first symptoms of work-related musculoskeletal discomfort in the first five years of their work life.[33] This was surely an important issue to discuss, as a vast number of workers reported the onset of symptoms at a young age. Though it was discussed previously that the frequency and aggravation of discomfort symptoms increase with age in nursing staff, contradictory findings also surfaced. After the age of 50 years and with 20 or more years of service, the prevalence of work-related musculoskeletal discomfort reports weakened.[33] According to previous research, it is possible that in very senior nursing personnel, there were fewer patient handling duties and amplified administrative work, also, they might avoid damaging work tasks or exhausting physical loads, and had better knowledge and experiences of injury prevention and coping strategies and were more used to with getting more staffs and supports to conduct an injurious workload, handling patients, executing alteration of procedures and positions of patients to dodge an injury or re-injury.[33] As the young group of nursing workers was assumed to be called for most of the vigorous tasks that emerged, their responses here could be enlightening in this aspect. To the question of the Modified Nordic Questionnaire, "Have you at any time during the last 12 months been prevented from doing your normal work because of the trouble?" the following responses were found.

"When there is a need for long-duration tasks to be performed, we are asked for."

"Some critical patients need repeated inspection, and some ask for the nurses repeatedly. We go and check them mostly. It happens."

According to studies, awkward working postures, stressful task demands, inadaptable work methods, and faulty workstation designs can lead to discomfort and incapability, which in turn leads to psychosocial stress, a shortfall in competition, and difficulty in matching the demand, which can again play some vital roles in the aggravation of physical symptoms.[34-37] This flawed loop must be broken to improve the overall physical and mental health of workers. This study sheds some light on the incidence of work-related musculoskeletal discomfort and the work-related factors responsible for young nursing workers in the health sectors of India.

Given the focus of this research on young nurses' musculoskeletal discomfort and the possible determinants of symptoms' onset and severity, addressing the underlying causes is advisable. Many studies illustrate the implementation of diverse preventive measures for nursing personnel to decrease the prevalence of symptoms.[38,39]

Multiple considerations might be taken into account when proposing safety measures like reducing the workload on each nurse, allocating the workload more equitably, increasing the

workforce, ergonomics and safety training, educating the nurses on the detrimental effects of MSDs, advocating for their willingness to disclose their discomfort without apprehension of criticism or harassment and finally consistent follow-up by the management.[40-42]

This study contributes to the growing body of research on the social and occupational health of young working nurses, a demographic often overlooked in existing literature. The findings provide a platform for interdisciplinary debate, opening avenues for future studies at the intersection of sociology, health policy, and workplace ergonomics. Given the increasing reliance on young nurses in India's growing healthcare sector, these insights hold significant implications for policymakers, healthcare administrators, and scholars in the fields of social health and labor studies. This study contributed to designating some probable causal factors for MSDs among this population (Figure 2).

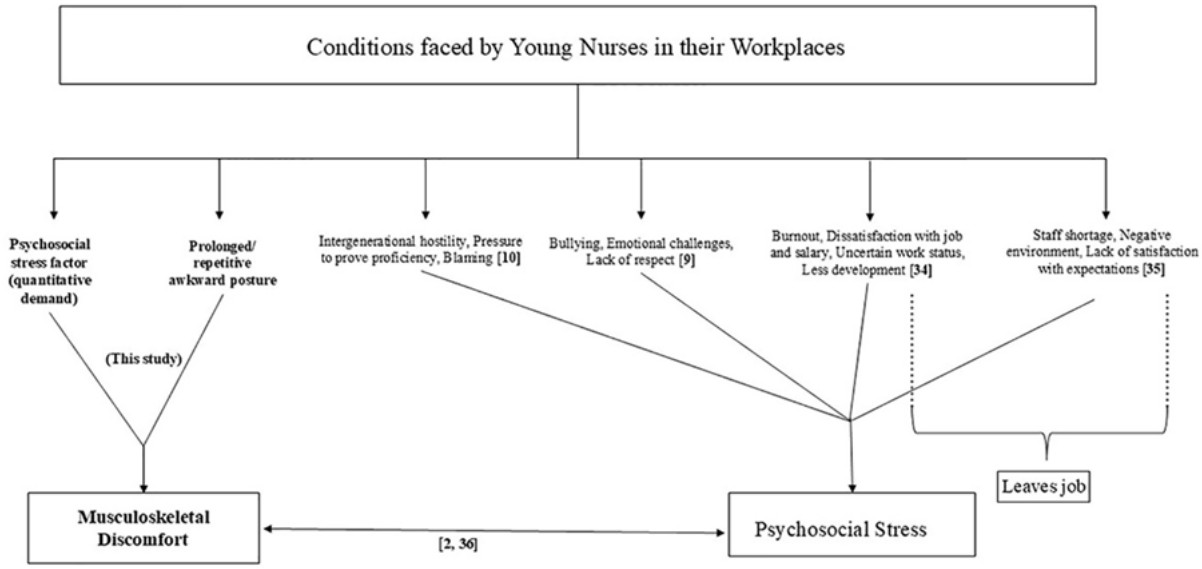


Figure 2: The contribution of this study to the evaluation of the circumstances faced by young nurses in workplaces

Conclusion

Musculoskeletal discomforts, with LBP being the most prevalent, were reported by a significant proportion of young nurses under the age of thirty. The musculoskeletal symptoms of nursing personnel may be adversely affected by increased quantitative demand and frequent injurious working postures associated with general nursing duties. The hindrance of a nurse's ability to perform due to discomfort symptoms can lead to a significant decline in the efficiency of health resources. Beyond the individual experience of pain and discomfort, these conditions have systemic implications for the healthcare sector, where the diminished functional capacity of nurses can lead to inefficiencies and increased strain on already overburdened health systems. It is necessary to conduct more detailed investigations to alleviate the symptoms, as the number of young nurses entering the health industry continues to rise. This research underscores the need for a more integrated approach to workplace health—one that critically considers not only ergonomic interventions but also the underlying social and institutional structures that shape the working conditions of young nurses. Future studies

should adopt a broader sociocultural lens to investigate how structural and policy-level factors influence the well-being of young healthcare professionals.

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Original Article

Occupational and environmental exposures of overhead distribution lineworkers and environmental impacts of creosote: a cross-sectional study

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ABSTRACT

Introduction: Workers in overhead electrical distribution networks (OEDNs) face numerous physicochemical hazards. In Greece, wooden poles (WPs) used in OEDNs are typically treated with creosote, a complex mixture containing polycyclic aromatic hydrocarbons (PAHs), heteroaromatic compounds and tar acids/bases. Creosote is a probable human carcinogen and a skin and eyes irritant and can result in environmental contamination from creosote "bleeding".

Methods: A cross-sectional study of the health effects on workers in OEDNs in Northern Greece was conducted between January-September 2024. Fifty-six workers (70% response rate) completed a structured questionnaire on demographics, personal protective equipment (PPE) use, and perceived health and environmental risks associated with creosote-treated WPs. Data were analyzed using SPSS 23.0. Kolmogorov–Smirnov, chi-square, Mann–Whitney U and Spearman correlation tests were applied. A p-value < 0.05 was considered statistically significant. Ethical approval was obtained from the University of West Attica Ethics Committee (Ref. No. 4608, 24 Jan 2024).

Results: Frequent contact with creosote-treated poles was reported by 66.1% of participants. While climbing newly creosote-treated poles, workers reported skin burns (46.4%), eye irritation (32.1%) and dermatitis (25%). Symptoms were described as more intense during summer. Of the sample group, 66.1% recognized creosote-related health hazards, 42.9% were aware of potential for soil contamination and 30.4% for water contamination.

Conclusion: Based on the study findings, creosote remains a tangible occupational and environmental hazard for lineworkers, especially when climbing newly creosote-treated poles. Environmental contamination from treated WPs was mainly localized in the surrounding soil driven by creosote seepage and PAHs leaching.

Keywords: Creosote, Environmental impact, Occupational exposure, Overhead distribution networks

Introduction

Lineworkers primarily work at heights and in direct contact with electricity, using a portable ladder, basket vehicles, or climbing harnesses/climbing shoes in combination with PPE (work position, suspension and anti-fall safety belts). Due to the high risk of the work, specialized training is required before taking on duties, which includes theoretical knowledge and practical training on safe work procedures, proper use and maintenance of PPE, as well as escape and

rescue protocols. In Greece, legislation also mandates periodic retraining (at least every three years) to maintain the necessary skill level and ensure continued adherence to safety rules.[1] Most of their work is done on WPs impregnated with chemical preservatives, such as creosote.[2]

Creosote is the most widely used wood preservative in Greece for WPs of OEDNs due to its high penetration ability and strong toxicity against microorganisms, as well as its fungicidal, insecticidal and sporicidal properties.[3,4,5] A dark brown to yellow-green viscous liquid with a characteristic strong tar-like odor and pungent aroma, creosote is classified as a restricted-use pesticide.[4,6] Creosote consists primarily of PAHs (up to 85%), and high concentrations of PAHs persist in creosote-impregnated wood decades after application.[7] Other components in creosote include heterocyclic aromatic substances and certain tar acids and bases.[8] Creosote is genotoxic and has been shown to cause skin cancer in animal studies. Studies in occupationally exposed groups indicate potential human carcinogenicity.[7] Additionally, creosote can cause eye irritation.[9]

While exposure through inhalation can occur during the production stages,[10] occupational exposure of overhead lineworkers occurs primarily through skin absorption from frequent direct contact with impregnated poles, during handling, maintenance, repair and installation of new poles and placement of fittings.[8] Epidemiological and toxicological studies have shown increased risks of cancer, respiratory, eye, and skin diseases in workers exposed to creosote.[5] Prolonged or repeated skin contact can also cause allergic reactions, changes in skin pigmentation, and benign skin lesions.[11]

Outdoor workers are increasingly facing prolonged exposure to high temperatures and intense ultraviolet (UV) radiation due to climate change, which can intensify both chemical absorption and physiological strain. Concurrent exposure to heat, humidity, and chemicals affects thermoregulation and enhances dermal absorption of chemicals.[12,13] Despite potential health problems from exposure, PPE (e.g., long sleeves, hats, sunscreen) is often considered uncomfortable, unsafe, or inconsistently worn due to workplace culture.[13]

Exposure to creosote is intensified by exposure to UV radiation. Simultaneous exposure to sunlight can lead to phototoxic or photoallergic reactions and long-term skin damage.[5,7,14] Lineworkers are among the professions with the highest exposure to UV[13] and workers exposed to both creosote and UV radiation develop photosensitivity, as UV radiation increases the toxicity of creosote, causing dermatitis in sun-exposed areas of the body.[14] This phenomenon is attributed to the photo-reactivity of PAHs, which leads to the formation of intermediate compounds that can cause irritation, redness, eczema and hyperpigmentation.[7]

Creosote also poses environmental concerns due to the "bleeding" phenomenon (Figure 1) observed in wood treated with creosote or its mixtures, in which the oil leaks or drips from the surface after application. The dark color of the stained wood leads to the absorption of a large amount of heat, resulting in the surface temperature, under direct sunlight, reaching up to 60 °C or higher. Bleeding is influenced by temperature, solar radiation, the injection method, the type and amount of preservative and the presence of air in the wood pores.[3]

Figure 1: Bleeding phenomenon

(Source: Authors' photograph)

The losses of creosote preservatives from the WPs are difficult to predict. Laboratory findings indicate that PAHs and heterocyclic compounds are primarily washed out within the first 24–48

hours following application.[15] Subsequent leaching rates are affected by treatment quality, pole age and environmental conditions and are temperature dependent. Creosote preservatives that remain in a liquid state within the wood cells move downward (due to gravity), resulting in the accumulation and darkening of the soil around the pole.[16]

The variability of PAH concentrations in soil around the poles is high and is influenced by many factors (e.g., soil, topography, pole age). Contamination is highest near the base of the pole, with PAHs concentrations up to 24.000 mg/kg. Highest concentrations are found at medium depths, particularly near the edge of the pole due to the direct deposition of creosote from the buried section of pole 3–8 inches underground. Concentrations of lighter PAHs (e.g., naphthalene, acenaphthylene) increase steadily with depth due to their increased water-solubility and lower soil adsorption coefficients (K_{OC}), while concentrations of heavier PAHs (e.g., indenopyrene) decrease steadily with depth due to their lower solubility and higher K_{OC} values.[17,18] Multiple contamination pathways such as direct deposition of preservatives from the surface of the WPs, volatilization, leaching from rain, runoff of preservatives from the edge of the pole, highlight the complexity of creosote migration in the environment. While at 4 °C up to 85% remain on the wood surface, at temperatures above 30 °C certain PAHs, such as acenaphthene and phenanthrene, are volatilized.[8] The main environmental sinks for PAH are sediments and soil.[19] The hydrophobic nature of PAHs,[10] as indicated by high octanol-water partition coefficient (K_{ow}) values, predicts a stronger affinity to organic matter compared to water and a slow groundwater migration.[20] In aquatic environments they migrate slowly through the co-transport of adsorbed colloidal pollutants.[19] Migration is influenced by various factors, such as the type of soil, hydrogeology, and the amount released.[5]

Although contamination decreases with distance from the pole, high PAH concentrations can still occur, posing risks to both soil and groundwater. Elevated levels of PAHs have been detected in trench water near railway lines with creosote-impregnated WPs, with an average concentration of 606.9 μg/L, raising concerns about chronic exposure to aquatic organisms despite non-lethal toxicity levels[21] due to their persistence and bioaccumulation potential in benthic organisms.[8]

Given these occupational and environmental concerns, the present study aimed to evaluate the exposure of lineworkers to OEDNs in creosote as a WPs preservative and its environmental impact. It examined the awareness and perceptions of lineworkers about the relevant occupational and environmental hazards. The findings aim to identify gaps in protection practices and to support preventive strategies in occupational and environmental health.

Methods

A cross-sectional study was conducted with the source population consisting of all active lineworkers in the country aged 18 and over. Data collection took place between January and September 2024 using convenience sampling. The research was based on a questionnaire created for the needs of the study and was formulated after a bibliographic review, author communication with lineworkers, and a trial test. Questions were closed-ended, with the option of either two "Yes/No" answers or more than two answers, including the five-point Likert scale that indicates the degree of agreement or disagreement with the following gradation: "not at all", "slightly", "moderately", "somewhat" and "very much", along with the additional option "I don't know". In collaboration with HEDNO SA services and a contractor in Northern Greece employing lineworkers, approximately 80 questionnaires were distributed. Due to the limited number of active lineworkers in the study area, the sample size was determined by accessibility to the available workforce during the study period. The study response rate was 70% (56/80). The questionnaires were either distributed in person to the respective employers or via email to ensure

they were properly forwarded to all lineworkers. The questionnaire was accompanied by an introductory note that fully explained the purpose of the research and the importance of participation, informed consent, the right to withdraw, and included the researcher's contact information for additional information or clarification.

Dependent variables included participants' beliefs of the health and environmental risks associated with creosote-treated WPs and the rational PPE use score, which ranged from 5 to 25, with higher scores indicating more appropriate use. Independent variables included demographic and occupational characteristics such as age, marital status, education level, employment status and years of service.

For nominal variables, univariate analysis was performed by presenting the absolute (n) and relative frequencies (%), while for quantitative variables, measures of position and dispersion were presented, specifically mean, standard deviation, median, minimum and maximum. The Kolmogorov–Smirnov test was applied to assess the normality of quantitative variables. Age followed a normal distribution, whereas years of service and the rational PPE use score did not; therefore, non-parametric statistical tests were applied where appropriate.

Associations between two dichotomous variables were examined using, a χ^2 test. The Chi-square test for trend was used to assess associations between dichotomous dependent variables and ordinal independent variables. The Mann–Whitney U test was applied to examine associations between dichotomous variables and non-normally distributed quantitative variables. Spearman's correlation coefficient was used to assess associations between quantitative variables when at least one did not follow a normal distribution. The two-tailed significance level was set at 0.05. The data analysis was performed using IBM SPSS Statistics 23.0.

The study did not present any ethical or deontological issues. Participation of lineworkers was voluntary, anonymous and without coercion. All data were used solely for research purposes and written informed consent was obtained from all participants. Ethical approval for the study was granted by the University of West Attica Ethics Committee (Approval No. 4608, 24 January 2024). Permission for data collection was also obtained from HEDNO KILKIS S.A. and BALKAN ELECTRIC S.A. and the questionnaire was completed anonymously.

Results

The study population consisted of 56 participating lineworkers, all of whom were Greek citizens aged between 20 to 62 years old (mean age 40.6 years). In terms of education, 60.7% (n=34) had completed upper secondary education (Lyceum), 21.4% (n=12) were graduates of public IEK/OAED/private school, 7.1% (n=4) had completed lower secondary education, 8.9% (n=5) were university/TEI graduates and 1.8% (n=1) were elementary school graduates. A majority of 60.7% (n=34) were married/cohabiting, 33.9% (n=19) were single, 3.6% (n=2) were divorced, and 1.8% were widowed (n=1). 67.9% (n=38) worked for a contractor, while 32.1% (n=18) worked for HEDNO and 66.1% (n=37) were contract workers, compared to 33.9% (n=19) who were permanent employees. The average years of service were 9.4 years, with a minimum of 2 months and a maximum of 43 years.

A very high percentage of lineworkers reported adequate provision and use of PPE. Specifically, 82.1% (n=46) stated that they received the appropriate PPE, 14.3% (n=8) reported moderate provision and 3.6% (n=2) reported limited provision. Similarly, 80.3% (n=45) reported that they received sufficient information from their employer on the proper use of PPE, 16.1% (n=9) stated that the information was provided to a moderate extent and 3.6% (n=2) answered that none/little was provided. The use of PPE was

considered very important by 96.4% (n=54) of the participants, while 91.1% (n=51) said they use it "a lot/very much". 89.3% (n=50) performed regular equipment checks. Among HEDNO employees, 100% (n=18) reported adequate PPE provision and 88.9% (n=16) reported adequate information on PPE use, while among contractor employees, the corresponding percentages were 73.7% (n=28) and 76.3% (n=29), respectively.

To further assess PPE practices, a composite score for rational use of PPE was calculated. The PPE score ranged from 5 to 25, with higher values indicating more rational use of PPE. The mean PPE score was 22.3 (S.D. = 2.6), with a median of 23, a minimum value of 15 and a maximum value of 25, indicating overall high adherence to recommended PPE practices among participants.

Bivariate associations between demographic and occupational characteristics and PPE rational use scores are presented in Table 1. No statistically significant associations were observed between PPE scores and age (Spearman's ϱ, p = 0.430), educational level (Mann–Whitney U, p = 0.422), marital status (Mann–Whitney U, p = 0.200), employer (Mann–Whitney U, p = 0.347), employment status (Mann–Whitney U, p = 0.746) or years of service (Spearman's ϱ, p = 0.948).

Creosote was ranked as the second most dangerous occupational hazard by 39.3% (n=22) by respondents after work under voltage. A total of 66.1% (n=37) of participants believed that creosote used as a wooden pole-impregnator had a negative effect on their health, while 30.4% (n=17) reported that they did not know whether such effects existed. Contact with creosote-treated WPs was reported as "fairly frequent" by 26.8% (n=15) of participants and "very frequent" by 39.3% (n=22). Symptoms reported after climbing newly creosote-treated poles are presented in Table 2. The most frequently reported symptom was skin burns (46.6%, n=26) followed by eye irritation (32.1%, n=18) and skin rashes (25%, n=14). Less frequently reported symptoms included difficulty breathing (8.9%, n=5) and headaches or dizziness (5.4%, n=3). The majority of 76.7% (n=43) of respondents reported that symptoms were more intense during the summer months, while 23.3% (n=13) reported that symptom intensity remained the same throughout the year.

Table 1: Bivariate associations between demographic and occupational characteristics of lineworkers and rational personal protective equipment use score.

Characteristic	Mean rational PPE use score (SD)	p-value
Age		0.430[a]
Educational level		0.422[b]
Up to high school graduates	22.4 (2.5)	
Higher/University education graduates	21.8 (2.9)	
Marital status		0.200[b]
Unmarried/Divorced/Widowed	21.6 (2.9)	
Married	22.6 (2.4)	
Employer		0.347[b]
HEDNO		
Contractor	22.9 (1.7)	
Employment status		0.746[b]
Permanent	22.6 (2.1)	
Contractor	22.1 (2.9)	
Years of service		0.948[a]

[a]Spearman correlation coefficient
[b]Mann–Whitney U test

Marital status was associated with perception of health risk related to creosote exposure. Married lineworkers (76.5%, n=26) reported that creosote-impregnated WPs pose a health risk more frequently compared with unmarried/divorced/widowed workers (χ^2 (1) = 4.175, p = 0.041; n = 56) (Table 3). Years of service were also significantly associated with perceived health risk, with workers having ≥5 years of service more frequently recognizing health risks

compared with those with ≤4 years of service (80% vs. 54.8%; χ^2 (1) = 3.908, p = 0.048; n=56) (Table 4).

Table 2: Reported symptoms after climbing newly creosote-treated poles.

Characteristic	N (%)
Skin burns	26 (46.6%)
Eye irritation	18 (32.1%)
Skin rash	14 (25%)
Difficulty breathing	5 (8.9%)
Headache/Dizziness	3 (5.4%)

Table 3: Association between lineworkers beliefs about the health risks creosote-impregnated wooden poles and their marital status.

3a Association between knowledge of health risk of creosote-impregnated WPs and marital status					
			Creosote health risk		
			Yes	No/I don't know	Total
Marital status	Unmarried/ Divorced/ Widowers	Measurement	11	11	22
		% in marital status	50%	50%	100%
	Married	Measurement	26	8	34
		% in marital status	76.5%	23.5%	100%
Total		Measurement	37	19	56
		% in marital status	66.1%	33.9%	100%

3b Chi-Square Tests					
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.175	1	.041		
Continuity Correctionb	3.078	1	.079		
Likelihood Ratio	4.144	1	.042		
Fisher's Exact Test				.050	.040
Linear-by-Linear Association	4.100	1	.043		
N of Valid Cases	56				

Table 4: Association between lineworkers beliefs about the health risks of creosote-impregnated wooden poles and their years of service.

4a Association between knowledge of creosote-impregnated WPs and years of service					
			Creosote health risk		
			Yes	No/I don't know	Total
Years of Service	Up to 4 years	Measurement	17	14	31
		% in years of service	54.8%	45.2%	100%
	5 years and above	Measurement	20	5	25
		% in years of service	80%	20%	100%
Total		Measurement	37	19	56
		% in years of service	66.1%	33.9%	100%

4b Chi-Square Tests					
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.908	1	.048		
Continuity Correctionb	2.867	1	.090		
Likelihood Ratio	4.038	1	.044		
Fisher's Exact Test				.087	.044
Linear-by-Linear Association	3.839	1	.050		
N of Valid Cases	56				

Over half of the respondents (58.9%, n=33) reported that creosote used as a WPs impregnator may have negative environmental effects. Specifically, 42.9% (n=24) identified soil as potentially affected, 30.4% (n=17) identified the water table, 23.2% (n=13) identified biodiversity and 8.9% (n=5) air. A significant percentage (41.1%, n=23) reported that they did not know whether creosote had environmental impacts, while none of the respondents considered creosote to be environmentally harmless (Figure 1). A statistically significant association was observed between years of service and perception of environmental risk (χ^2 (1) = 8.285, p = 0.004; n=56). Workers with ≥5 years of service more frequently perceived creosote as posing an environmental risk compared with those with ≤4 years of service (80 % vs. 41.9% (Table 5).

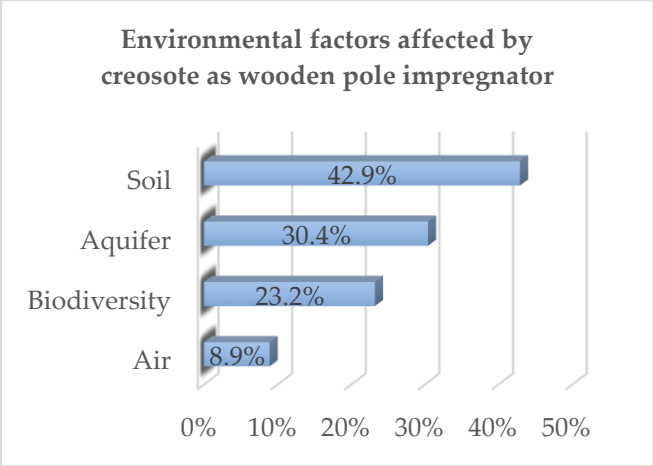

Figure 1: Environmental factors perceived by lineworkers as affected by creosote used as a wooden pole impregnator.

Table 5: Association between lineworkers beliefs about the environmental risks of creosote-impregnated wooden poles and years of service.

5a Association between knowledge about environmental risks of creosote-impregnated WPs and years of service

			Creosote danger to the environment		
			Yes	No/I don't know	Total
Years of service	Up to 4 years	Measurement	13	18	31
		% in years of service	41.9%	58.1%	100%
	5 years and above	Measurement	20	5	25
		% in years of service	80%	20%	100%
Total		Measurement	33	23	56
		% in years of service	58.9%	41.1%	100%

4b Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	8.285	1	.004		
Continuity Correctionb	6.787	1	.009		
Likelihood Ratio	8.652	1	.003		
Fisher's Exact Test				.006	.004
Linear-by-Linear Association	8.137	1	.004		
N of Valid Cases	56				

Discussion

The findings of the present study showed a high degree of correlation with the references in the studied literature. Although it provides significant benefits in extending the service life of WPs,[22] creosote also carries critical challenges for the environment and human health, primarily due to the presence of PAHs in its composition.[23]

Assessing the effects of creosote in occupational exposure is challenging, as workers are frequently co-exposed to various other

carcinogens. Furthermore, exposure measurements are often inconsistent, with available data being predominantly qualitative. Consequently, research tends to focus on individual constituents, which may lead to generalized conclusions.[10,5]

This is the first study in Greece to assess the opinions and attitudes of OEDNs lineworkers regarding the use of PPE and the perceived health and environmental impacts of creosote-impregnated WPs and may serve as a foundation for future research in this field. There are limited studies regarding exposure of lineworkers, generally indirectly mentioned in some related studies as part of the groups exposed to creosote. Most studies focus on other occupations such as workers in impregnation plants or railroad ties.

Although lineworkers in OEDNs were not explicitly referenced among the occupational groups identified in the 2024 ILO global report as being simultaneously exposed to thermal stress and chemical substances, they clearly fall within this category. Their work is performed outdoors, often under high ambient temperatures, particularly during summer and involves direct contact with creosote-impregnated WPs.[13] As a result, lineworkers experience elevated occupational exposure, including thermal stress, intense UV exposure, exposure to chemical pollutants such as creosote, and an increased likelihood of parasitic diseases due to field conditions.

The findings of the present study, in which participants reported skin burns and eye irritation as the most frequent symptoms while climbing newly creosote-treated poles, are in agreement with the literature on the effects of creosote on lineworker health. During the summer months, exposure increased; workers reported that while working on impregnated creosote poles, a strong odor was released and oil secretion was observed,[2] and symptoms increased (this study).

The observed associations between marital status, years of service, and perceived health and environmental risks indicate that both personal and occupational experience may influence risk awareness among lineworkers. Greater recognition of risks among more experienced workers may reflect cumulative exposure and enhanced hazard awareness developed over time. Similarly, higher health risk awareness among married participants may be associated with increased concern for long-term health and family responsibilities. These findings are consistent with previous occupational health research showing that work experience and life circumstances shape risk perception and safety awareness.[24,25,26,27]

Despite the relevance of these findings, several limitations should be considered when interpreting the results. The convenience sampling used limits the generalizability of the findings to the broader population of lineworkers in Greece. The relatively small sample size (n=56) resulted primarily from practical constraints in recruiting potential participants, given the outdoor, highly mobile nature of linework. Nevertheless, because the total number of active overhead distribution line workers in Greece is limited, the number of questionnaires collected may be considered broadly representative of this occupational group. The sample size, determined by accessibility during the study period, was adequate for exploratory analysis but limits statistical power and the generalizability of the findings. Selection bias may be present, as participants who agreed to take part in the study may differ systematically from non-participants. In addition, reliance on self-reported measures may have introduced recall bias and limited objective verification of reported responses. Finally, an inherent limitation of self-reported instruments is the absence of mechanisms to ensure the objectivity of participants' answers.

Regarding infrastructure alternatives, while materials such as steel, concrete, composite poles, and underground cabling are available, each presents practical, economic, or technical limitations.[28] Underground networks entail

substantially higher construction costs, reinforced concrete poles are suitable only for specific structural conditions and more environmentally friendly alternatives often involve higher costs and shorter service life. Consequently, WPs and creosote remain widely used in OEDNs due to their cost-effectiveness, durability, ease of installation and insulating properties, with regulatory approval for creosote use extending until 31/10/2029.[22,29]

Conclusion

The main cause of the negative effects on both line workers' health and the environment is the presence of PAHs in creosote. Ensuring their health and safety, as well as protecting the environment, requires a holistic and systematic approach. Greater emphasis needs to be placed on the use of PPE in conjunction with continuous retraining of employees to enhance awareness of risks and compliance with safety practices. At the same time, information and training on environmental protection during the execution of the works could represent an integral part of professional training. The findings highlight the importance of exploring more sustainable infrastructure solutions and less hazardous preservatives. Further scientific research is also needed on soil contamination caused by creosote-impregnated poles. Additionally, further studies should examine the health effects of occupational exposure to creosote among lineworkers, not only during contact with newly creosote-treated WPs, as assessed in the present study, but throughout the full duration of their work. Future research should account for additional modifying factors such as age, habits, medical history, daily work practices, occupational environment and climatic conditions, and should investigate the combined effects of all chemical constituents of creosote to enable comprehensive risk assessment and targeted preventive measures.

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Original Article

Occupational health conditions and personal protective equipment utilization among women waste workers in Kathmandu: A cross-sectional study

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ABSTRACT

Introduction: Women Waste Workers (WWWs) face significant occupational health risks due to minimal safety practices, limited access to vaccinations, and inadequate use of Personal Protective Equipment (PPE). These factors contribute to respiratory diseases, injuries, and musculoskeletal disorders (MSDs).

Methods: A cross-sectional study was conducted from February to March 2024 among 90 WWWs in Kathmandu Metropolitan City (Wards 10, 12, and 32) using purposive sampling. Data on demographics, work conditions, occupational health status, and PPE use were collected through semi-structured interviews and analyzed using descriptive statistics, Pearson's chi-square test, and multivariable logistic regression.

Results: Most participants were aged 30–40 years (47.8%), illiterate (55.6%), and married (87.8%). The majority handled dry waste (61.1%) and had ≤7 years of work experience (65.6%). Only 12.2% had received occupational health and safety (OHS) training. Vaccination rates were low for tetanus (48.9%) and Hepatitis B (28.9%). MSDs (71%) were most common, followed by mental health-related issues (45.6%), skin diseases (42.2%), and respiratory diseases (41.1%). Despite 92.2% reporting PPE use, concerns remained over quality and effectiveness. Multiple binary logistic regression showed that workers earning ≤17,000 rupees had 6.7 times higher odds of skin disease ($p = 0.038$), while those with >7 years of experience had 85% lower odds ($p = 0.002$). Visiting a clinic once a year reduced the odds by 90% ($p = 0.003$), but never visiting showed no significant impact ($p = 0.374$).

Conclusion: WWWs face severe occupational health risks, highlighting gaps in OHS training, vaccinations, health-seeking behavior, and workplace policies. Strengthening OHS programs and improving PPE utilization are essential to protecting their health.

Keywords: Musculoskeletal Disorders, Occupational Health and Safety, Personal Protective Equipment, Tetanus Toxoid, Women Waste Workers

Introduction

Informal Waste Workers (IWWs) in Nepal generally have inadequate awareness of occupational health and safety issues.[1] Inadequate protection against workplace and environmental hazards puts workers at significant risk of health problems. The workers faced challenges in accessing and correctly using PPE, making them more susceptible to infections and long-term health issues. Waste management jobs are often socially stigmatized, and the majority of workers have reported experiencing mental health issues.[2]

Waste workers are the individuals who are responsible for the collection, sorting, recycling, and disposal of waste to manage and process it effectively.[3] Municipal Solid Waste (MSW) collection and handling are considered among the riskiest jobs. Laborers working as collectors have fatal and nonfatal musculoskeletal problems.[4] MSW workers are also exposed to several pathogens, toxic substances, and chemicals originating from waste decomposition, vehicle fumes, noise, extreme temperatures, and ultraviolet radiation.[5] The rapid increase in fatalities among waste collectors has been attributed to their inadequate awareness and poor compliance with OHS safety measures.[6]

Municipal waste collectors are regularly exposed to physical, chemical, and biological hazards due to the nature of their work. In low- and middle-income countries such as Nepal, inadequate use of personal protective equipment, low vaccination coverage, and limited health monitoring may increase the risk of occupational illnesses and injuries. Despite their essential role in public sanitation, evidence on their occupational health and safety remains limited.[7] Sociodemographic factors, occupational lifestyle, and personal hygiene behaviors were all linked to health outcomes, safety awareness, and safety practices among e-waste workers. Thus, improving safety awareness, alongside these factors, is essential for fostering sustainable safety behaviors.[8]

Women in the informal sector face poor working conditions, low income, safety risks, and minimal decision-making power. In waste management, unregulated work exposes women to crime, violence, and hazardous conditions. They earn lower wages than men, who typically handle heavier, more skilled tasks. Limited PPE use increases health risks like respiratory issues, skin infections, and injuries, which are worsened by poor hygiene and inadequate healthcare access.[9]

This study aims to assess the occupational health conditions of WWWs in Kathmandu Valley, focusing on the utilization of PPE and its impact on the prevalence of occupational diseases.

Methods

A cross-sectional study was conducted between February and March 2024 among women waste workers (WWWs) in selected wards (10, 12, and 32) of Kathmandu Metropolitan City using convenience sampling. The major waste collection and processing sites in Baneshwor, Teku, and Koteshwor, were purposively selected. Women engaged in both formal and informal waste management sectors were recruited through convenience sampling techniques and were approached directly at their workplaces for data collection.

Study sites were purposively selected based on predefined criteria aligned with the research design. Because the eligible population within the selected sites was small and finite, a census (complete enumeration) approach was adopted, whereby all eligible women waste workers present during the study period were invited to participate (N = 90).

The required sample size for the cross-sectional study was initially estimated using Cochran's formula, assuming a 95% confidence level (Z = 1.96), a margin of error of 10% (d = 0.10), and an expected prevalence of 50% (p = 0.5) due to the

absence of prior local estimates.[10,11,12] The calculated minimum sample size was 96 participants. However, as the total number of eligible workers available at the selected sites during the data collection period was 90, all eligible individuals were included. All approached participants consented to participate, resulting in a response rate of 100%, and no adjustment for non-response was required. A total of 40 participants were recruited from Baneshwor, 30 from Koteshwor, and 20 from Teku. Data were collected through face-to-face structured questionnaires administered at dumping sites and waste management organizations.

Descriptive analyses were performed on demographic and occupational health data, while chi-square and multivariate logistic regression analyses were used to examine relationships and health impacts. Occupational health outcomes, such as skin, respiratory, musculoskeletal, eye, gastrointestinal, and chronic diseases, were assessed. PPE use, clinic visits, job type, and training were considered, while income and work experience, originally quantitative, were grouped as ⩽17,000/>17,000 NPR and ⩽7/>7 years. The adjusted odds ratio (AOR) and 95% confidence intervals (CI) were reported, with a significance level of 5% ($p < 0.05$). The multicollinearity among the explanatory variables was assessed using the variance inflation factor (VIF)13, with values kept within acceptable limits (VIF ⩽ 3, Tolerance ⩾ 0.1). Data analysis was conducted using SPSS version 26.

WWWs aged 18–60 years with a minimum of 3 months of experience in waste collection, sorting, or handling were eligible if they were working at selected study sites during data collection and were willing to provide verbal informed consent. The study exclusively focused on women, as this vulnerable population remains underrepresented in occupational health research, while male workers were excluded to address women-specific health knowledge gaps.

Recruitment was conducted in collaboration with owners and supervisors of solid waste management companies. All 90 waste workers approached across three sites met eligibility criteria and agreed to participate (100% response rate). Of these, 70 (77.8%) were informal workers (self-employed, daily-wage workers, or independent workers without formal contracts), and 20 (22.2%) were formal workers (employed by registered waste management companies or municipal facilities at the Teku Transfer Station). Data collection was completed within 15 days in March 2024. The participant number represents the workforce present during this period, though employment fluctuates due to informal and temporary work arrangements.

A structured questionnaire adapted from validated tools was used: demographic and disease-related sections from Salve and Bansod's municipal solid waste loader study, and PPE use and vaccination assessment from Marahatta et. al.'s occupational health hazards questionnaire. A pilot study was conducted among women waste workers in a similar setting outside the selected study areas to assess clarity and feasibility, and minor modifications were made based on the findings. Content validity was established through expert review by the research supervisor and faculty members from the School of Environmental Science and Management (SchEMS), Pokhara University. Internal consistency reliability of the scale items was measured using Cronbach's alpha, yielding 0.81. Face-to-face structured interviews lasting approximately 15 minutes were conducted in Nepali by a single trained researcher (the principal investigator) at workplaces, including dumping sites, transfer stations, and organization premises, during operational hours. Verbal informed consent was obtained, and confidentiality was maintained throughout.

Results

Table 1: Demographic characteristics

Variable	Category	Frequency (%), N=90
Demographic characteristics		
Age (in years)	(20-30) years	15(16.7)
	(30-40) years	43(47.8)
	40 years and above	32(35.6)
Educational level	Illiterate	50(55.6)
	Can read and write	25(27.8)
	Under SLC	8(8.9)
	Intermediate	7(7.8)
Marital status	Single	11(12.2)
	Married	79(87.8)
Caste	Brahmin	10(11.1)
	Chhetri	19(21.1)
	Janajati	47(52.2)
	Dalit	8(8.9)
	Madhesi	1(1.1)
	Other	5(5.6)
Monthly income	≤17 thousand	74(82.2)
	>17 thousand	16(17.8)

The socio-demographic analysis of the 90 surveyed WWWs in Kathmandu revealed that the majority (47.8%) were aged between 30 and 40 years, with a median age of 37 years. Over half (55.6%) of the respondents were illiterate, and only 8.9% had an education up to the Secondary Level Certificate (SLC). A large proportion (87.8%) was married. In terms of caste, more than half belonged to the Janajati group (52.2%), followed by Chhetri (21.1%) and Brahmin (11.1%). In terms of income, 82.2% of respondents reported earning at most 17,000 NPR per month, indicating low incomes among most workers.

Table 2: Work characteristics of WWWs

Work characteristics of WWWs		
Variable	**Category**	**Frequency (%), N=90**
Types of waste handled	Wet	6 (6.7)
	Dry	55 (61.1)
	Dry and wet both	29 (32.2)
Work shift	Morning	37 (41.1)
	Day	45 (50)
	Morning and day both	8(8.9)
Total working hours per day	≤ 8 hours	79 (87.8)
	> 8 hours	11 (12.2)
Received any specific training	Yes	11 (12.2)
	No	79 (87.8)

Among the 90 women waste workers (WWWs) surveyed, the majority (61.1%) handled dry waste, while 32.2% handled both dry and wet waste. Half of the workers (50%) reported working the day shift, with 41.1% working the morning shift and 8.9% working both the morning and day shifts. Most participants (87.8%) worked 8 hours or less per day, and only 12.2% reported working more than 8 hours. Notably, only 12.2% had received any specific training related to their work, while the vast majority (87.8%) had not received any training.

Table 3: Panel A: PPE use and vaccination Status, among WWWs

Variable	Category	Frequency (%), N=90
Use of personal protective equipment (PPE)	Yes	83 (92.2)
	No	7(7.8)
Types of PPE use	Mask and gloves	59(65.6)
	Gloves only	31(34.4)
Vaccinated against hepatitis	Yes	26(28.9)
	No	61(67.8)
Vaccination with tetanus toxoid (TT)	Yes	44(48.9)
	No	46(51.1)

Among the 90 WWWs, 92.2% reported using personal protective equipment (PPE), with 65.6% using both masks and gloves and 34.4% using only gloves. Despite high PPE usage, vaccination coverage was low; only 28.9% had received hepatitis vaccination, and 48.9% had received tetanus toxoid (TT) vaccination. A significant proportion remained unvaccinated: 67.8% for hepatitis and 51.1% for TT. A majority (92.2%) reported using at least one type of PPE, with 65.6% using both masks and gloves and 34.4% using only gloves. Regarding vaccinations, 28.9% had received the hepatitis vaccine, whereas 67.8% had not. Similarly, 48.9% were vaccinated with TT, while 51.1% had not received it.

Table 3: Panel B : Occupational health issues among WWWs

Disease type	Category	Frequency (%)	Overall Disease Prevalence
Cuts and injuries	Fracture	3 (15)	22.2%
	Glass object	14 (70)	
	Dog bite	2 (10)	
	Injuries	1 (5)	
	Total	20 (100)	
Chronic disease	Asthma	1 (5)	22.2%
	Cardiovascular Disease	2 (10)	
	Mental health disorder	17 (85)	
	Total	20 (100)	
Eye Disease	Yes	16 (17.8)	17.8%
	No	74 (82.2)	
	Total	90 (100)	
Skin Disease	Rashes	4 (10.5)	42.2%
	Fungal infection	7 (18.4)	
	Allergy	27 (71.1)	
	Total	38 (100)	
Gastrointestinal Disease	Loose motion	14 (48.3)	
	Worm infection	6 (20.7)	

	Ulcer	6 (20.7)	32.2%
	Foodborne Disease	2 (6.9)	
	Gastrointestinal cancer	1 (3.4)	
	Total	29 (100)	
Respiratory Disease	Dust allergy	20 (54.1)	41.1%
	Asthma	9 (24.3)	
	Running nose	8 (21.6)	
	Total	37 (100)	
Muscle related disease	Neck	18 (25.4)	78.9%
	Upper back	4 (5.6)	
	Lower back	9 (12.7)	
	Shoulder	14 (19.7)	
	Wrist and hand	19 (26.8)	
	Chest	7 (9.9)	
	Total	71 (100)	

The study found that women WWWs reported a range of occupational health problems. The most common issues were skin diseases (42.2%), with skin allergies accounting for 71.1% of these cases. Respiratory diseases were reported by 41.1% of respondents, primarily dust allergies (54.1%). Musculoskeletal disorders were also prevalent, with 25.4% reporting neck pain. Among chronic conditions, 85% of those affected reported mental health disorders. Gastrointestinal issues were noted in 32.2% of respondents, mainly diarrhea (48.3%), worm infections, and ulcers. Eye problems affected 17.8% of workers, and 20 workers (22.2%) reported injuries, mostly from glass objects.

Table 4: Panel A: Bivariate analysis

Bivariable analysis of types of disease and types of PPE used					
Types of disease		Types of PPE use			χ2-value (p-value)
Chronic Disease	Category	Mask and Gloves Count (%)	Gloves Only Count (%)	Total Count (%)	
	Yes	13 (22%)	7 (22.6%)	20(22.2%)	0.953 (0.576)
	No	46(78%)	24 (77.4%)	70 (77.8%)	
	Total	59 (100.0%)	31 (100.0%)	90 (100.0%)	
Eye diseases	Yes	11(18.60%)	5(16.10%)	16(17.80%)	0.089 (0.505)
	No	48(81.40)	26(83.90)	74(82.20)	
	Total	59 (100%)	31(100%)	90(100%)	
Skin diseases	Yes	30(50.80%)	8(25.80%)	38(42.20%)	**5.224 (0.019*)**
	No	29(49.20%)	23(74.20%)	52(57.80%)	
	Total	59 (100.0%)	31 (100.0%)	90 (100.0%)	
Respiratory disease	Yes	27(45.80%)	10(32.30%)	37(41.10%	1.513(0.156)
	No	32(54.20%)	21(67.70%)	53(58.90%)	
	Total	59(100.0%)	31 (100.0%)	90 (100.0%)	
Noise-related disease	Yes	25(42.40%)	16(51.60%)	41(45.60%)	0.735 (0.487)
	No	34(57.60%)	15(48.40%)	49(54.40%)	
	Total	59 (100.0%)	31 (100.0%)	90 (100.0%)	

Muscle-related disease	Yes	46(78%)	25(80.60%)	71(78.90%)	0.88 (0.497)
	No	13(22%)	6(19.40%)	19(21.10%)	
	Total	59(100.0%)	31 (100.0%)	90 (100.0%)	
Gastrointestinal disease	Yes	18(30.50%)	11(35.50%)	29(32.20%)	0.230 (0.401)
	No	41(69.50%)	20(64.50%)	61(67.80%)	
	Total	59(100.0%)	31 (100.0%)	90(100.0%)	
Bivariable analysis of different diseases with different variables					
Variables	Presence of chronic disease				χ2-value (p-value)
	Yes Count (%)		No Count (%)	Total Count (%)	
Presence of eye disease					
Clinic visit	Never	11(68.8)	18(24.3)	29(32.2)	12.55 (0.07*)
	Once in six months	1(6.3)	26(96.3)	27(30)	
	Once in a year	4(25)	30(88.2)	34(77.8)	
	Total	16(100)	74(100)	90	
Presence of skin disease					
Income	≤17000 rupee	26(68.4)	48(92.3)	74(82.2)	8.57 (0.005*)
	>17000 rupee	12(31.6)	4(7.7)	16(17.8)	
	Total	38(100)	52(100)	90	
Years of working	≤ 7 years	16(42.1)	43(82.7)	59(65.6)	16.01 (0.00*)
	>7 years	22(57.9)	9(17.3)	31(34.4)	
	Total	38(100)	52(100)	90	
Clinic visit	Never	17(45.9)	11(22)	28(32.2)	5.77 (0.053*)
	Once in six months	12(32.4)	21(42)	33(37.9)	
	Once in a year	8(21.6)	18(36)	26(29.6)	
	Total	16(100)	71(100)	87	
Presence of Gastrointestinal Disease					
Smoking habit	Yes	23 (79.3)	37 (60.7)	60 (66.7)	3.078 (0.0*)
	No	6 (20.7)	24 (39.3)	30 (33.3)	
	Total	29 (100.0)	51 (100.0)	90	
Presence of Respiratory Disease					
Income	≤17000 rupee	27 (73.0)	47 (88.7)	74 (82.2)	3.67 (0.091)
	>17000 rupee	10 (27.0)	6 (11.3)	16 (17.8)	
	Total	37 (100.0)	53 (100.0)	90	
Job type	Sorter	7 (18.9)	25 (47.2)	32 (35.6)	7.88 (0.036*)
	Sweeper	25 (67.6)	24 (45.3)	49 (54.4)	
	Waste picker	3 (8.1)	3 (5.7)	6 (6.7)	
	Both sweeper and Sorter	2 (5.4)	1 (1.9)	3 (3.3)	
	Total	37 (100.0)	53 (100.0)	90	
Type of waste handled	Wet	2(5.4)	2(3.8)	4(4.4)	5.68 (0.065)
	Dry	29(78.4)	30(56.6)	59(65.6)	
	Dry and wet both	6(16.2)	21(39.6)	27(30)	
	Total	37 (100.0)	53 (100.0)	90	
Years of working	≤ 7 years	19(51.4)	40(75.5)	59(65.6)	5.61 (0.024*)
	>7 years	18(48.6)	13(24.5)	31(34.4)	
	Total	37 (100.0)	53 (100.0)	90	

Presence of noise-related disease					
Training received	Yes	2 (4.9)	9 (18.4)	11 (12.2)	0.378 (0.061)
	No	39 (95.1)	40 (81.6)	79 (87.8)	
	Total	41 (100.0)	49 (100.0)	90	
Presence of muscle-related disease					
Years of working	<=7 years	43(60.6)	16(84.2)	59(65.6)	3.71 (0.062)
	>7 years	28(39.4)	3(15.8)	31(34.4)	
	Total	71(100)	19(100)	90	
Use of PPE	Yes	68(95.8)	15(78.9)	83(92.2)	5.91 (0.034*)
	No	3(4.2)	4(21.1)	7(7.8)	
	Total	71(100)	19(100)	90	
Training received	Yes	5(7)	6(31.6)	11(12.2)	8.41 (0.010*)
	No	66(93)	13(68.4)	79(87.8)	
	Total	71(100)	19(100)	90	

* Indicates the statistically significant at 5% level of significance

In bivariate analysis, a statistically significant association (χ^2=5.22; p=0.019) was found between the types of PPE used and the occurrence of skin diseases among women waste workers. The presence of eye disease was significantly associated with clinic visit frequency (χ^2 = 12.55, p = 0.007), with participants who visited clinics and used PPE more regularly reporting fewer eye problems. Skin disease was significantly associated with income level (χ^2 = 8.57, p = 0.003), with a higher prevalence among workers earning ⩽ 17,000 NPR. Respiratory disease showed a significant association with job type (χ^2 = 7.88, p = 0.036), with a higher prevalence among sorters. Similarly, years of work experience were significantly associated with respiratory disease (χ^2 = 5.61, p = 0.024), indicating an increased risk with longer work duration. The presence of muscle-related disease was significantly associated with the use of PPE (χ^2 = 5.91, p = 0.034), occurring more often among those not using proper PPE. It was also associated with training received (χ^2 = 8.41, p = 0.010), with a lower prevalence among trained workers.

The study examined the association between different disease types and PPE use in a sample population. Among the diseases studied, skin diseases showed a statistically significant association with PPE use (χ2 = 5.22, p = 0.019). For other types of diseases studied, such as chronic disease, eye disease, respiratory disease, noise-related disease, muscle-related disease, and gastrointestinal disease, no statistically significant associations with PPE use were found.

Multicollinearity was examined using tolerance and variance inflation factor (VIF). The tolerance values ranged from 0.701 to 0.874 (> 0.10), and VIF values ranged from 1.144 to 1.427 (< 10), indicating no evidence of problematic multicollinearity among the independent variables. Therefore, all predictors were retained in the multivariable logistic regression model. [11]

Multivariable analysis

Separate multivariable logistic regression models were fitted for each disease outcome to identify factors independently associated with that outcome. Independent variables that were statistically significant in the bivariate analysis (p < 0.05) were entered into the multivariable models. Specifically, income, years of work experience, and frequency of clinic visits were included as covariates. In the final analysis, skin disease was the only dependent variable that showed statistically significant associations with the explanatory variables.

Table 4: Panel B: Multivariable analysis of skin disease and independent variable

Variables	Category	B	S.E. (B)	Wald	df	Adjusted Odds Ratio	95% C.I. for odds ratio		p-value
							Lower	Upper	
Constant									
Income	≤17000 rupees	1.895	0.913	4.311	1	6.652	1.112	39.786	0.038*
	>17000	®							
Years of working	> 7 years	-1.91	0.605	10.01	1	0.148	0.045	0.483	0.002*
	≤ 7 years	®							
Clinic visit	Once a year	-2.29	0.785	8.566	1	0.1	0.022	0.468	0.003*
	Never	-0.71	0.808	0.789	1	0.488	0.1	2.376	0.374
	Once in six-months	®							
® Indicates the reference category									
* Indicates statistically significant at the 5% level of significance									

Multivariable logistic regression analysis (Table 4: Panel B) revealed that women waste workers earning ⩽ 17,000 NPR per month were significantly more likely to report skin diseases than those earning>17,000 NPR (AOR = 6.652, 95% CI: 1.112 – 39.786, p = 0.038). Similarly, workers with more than 7 years of experience were significantly less likely to report skin diseases than those with ⩽7 years of experience (AOR = 0.148, 95% CI: 0.045 – 0.483, p = 0.002). Furthermore, clinic visits once a year were associated with significantly lower odds of skin disease compared to those who visited once in six months (AOR = 0.1, 95% CI: 0.022–0.468, p = 0.003).

The overall logistic regression model was statistically significant, as indicated by the Omnibus Test of Model Coefficients (Chi-square = 28.493, df = 4, $p < 0.001$), suggesting that the set of predictors significantly improved model fit compared to a null model. The -2 Log Likelihood value was 94.087, indicating an acceptable fit of the model. The pseudo-R^2 values suggested moderate explanatory power, with Cox & Snell $R^2 = 0.271$ and Nagelkerke $R^2 = 0.365$. The Hosmer & Lemeshow goodness-of-fit test showed a non-significant result (Chi-square = 0.072, df = 5, p = 1.000), indicating that the model fits the data very well. Overall, the model meets the assumptions for a good fit and demonstrates adequate predictive capability for the outcome variable.[14]

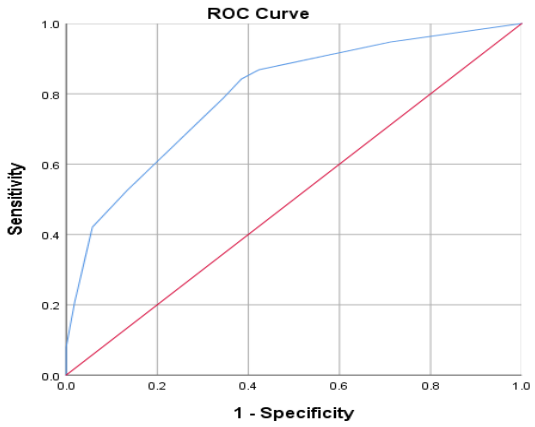

Figure 1. ROC Curve for the Logistic Regression Model of Skin Disease

The discriminative ability of the logistic regression model was assessed using the receiver operating characteristic (ROC) curve. The area under the curve (AUC) was 0.798, indicating good predictive accuracy and acceptable discrimination between individuals with and without skin disease.[14]

Discussion

This study revealed that a substantial proportion of women waste workers (WWWs) in Kathmandu experienced occupational health problems, particularly musculoskeletal disorders (71%), skin diseases (42.2%), and respiratory conditions (41.1%). The high prevalence of musculoskeletal and dermatological problems reflects the hazardous and physically demanding nature of informal waste work. Similar findings have been reported in studies from India and Bangladesh, where musculoskeletal disorders (65.2%), and skin allergies (32.9%) were among the most common occupational ailments among waste workers. The slightly lower prevalence of musculoskeletal disorders in the present study may be attributable to task variation, as women in Kathmandu are primarily involved in sorting rather than heavy lifting. Conversely, the higher rate of respiratory conditions may be attributed to Kathmandu's poor air quality and increased exposure to dust and bioaerosols during sorting activities.[15]

PPE use among participants was notably high (92.2%), similar to previous findings (87.2%) (13), suggesting increased awareness of occupational risks—possibly enhanced by the COVID-19 pandemic and institutional efforts to promote safety. However, only 65.6% reported consistent use of both masks and gloves, and 87.8% had never received formal training. Studies from other regions have emphasized that PPE use is influenced by workplace culture and supervision rather than individual motivation.[16] These results underscore that PPE distribution alone is insufficient without complementary training, vaccination programs, and ongoing health education.

Vaccination coverage among WWWs was critically low (28.9% for hepatitis and 48.9% for tetanus). Comparable studies from industrial waste sectors have also reported suboptimal coverage (7.5% for hepatitis and 46.8% for tetanus).[17] The slightly higher hepatitis vaccination rate in this study may reflect localized NGO health campaigns, but the persistent gender gap in access to preventive healthcare remains evident. Women's limited mobility, health literacy, and economic dependence likely constrain vaccine uptake.

Socioeconomic and educational factors were strongly linked to health outcomes. The majority of participants belonged to low-income groups (82.2%) and had low literacy levels (55.6%). Illiteracy was significantly associated with skin diseases ($p = 0.003$). These results align with findings from South Africa and India, where lower income and education levels limited workers' ability to recognize and manage occupational hazards.[18] Interestingly, longer work experience (>7 years) appeared protective against skin diseases (OR = 0.148, $p = 0.002$), suggesting that workers may develop adaptive behaviors such as improved waste handling or PPE practices over time.[19]

Job role-specific risks were also evident. Sorters had significantly higher rates of respiratory diseases ($p = 0.036$), consistent with literature showing that prolonged exposure to dust and chemical pollutants during sorting elevates respiratory vulnerability. Furthermore, PPE use ($p = 0.034$) and training ($p = 0.010$) were significantly associated with muscle-related disorders, reaffirming that preventive measures, when properly applied, mitigate occupational risks.[19] However, the persistence of musculoskeletal problems, even among PPE users, points to possible gaps in ergonomic practices or PPE quality.

Overall, this study reinforces that occupational health problems among WWWs are shaped by a complex interplay of task type, socioeconomic conditions, training, and preventive practices.

Limitations

This study has several limitations. The sample size was small (N = 90) and limited to three purposively selected wards, which may reduce the generalizability of the findings to other areas. The cross-sectional design prevents causal inferences between occupational exposures and health outcomes. A non-probability sampling approach may have introduced selection bias, and self-reported data could be affected by recall or social desirability bias.

In the analysis, a significance level of 0.05 was used for bivariate testing, and only statistically significant variables were included in the multivariable logistic regression. While this ensures robust associations, it may have excluded variables that are potentially relevant. The small sample size also affects the precision of multivariable estimates, resulting in wider confidence intervals for some predictors. Despite these limitations, the study provides important insights into the occupational health of women waste workers in the sampled wards.

Conclusion

This study provides evidence of the occupational health challenges faced by women waste workers (WWWs) in Kathmandu Valley and highlights the role of personal protective equipment (PPE) in mitigating health risks. The majority of participants reported exposure to occupational hazards, including skin diseases, musculoskeletal disorders, respiratory problems, gastrointestinal issues, eye disorders, and injuries. Skin diseases were the most prevalent, with allergies being the leading type, while musculoskeletal complaints, particularly in the neck and wrist/hand regions, were also highly common.

Bivariate analysis indicated that PPE use was significantly associated with a lower prevalence of skin and musculoskeletal diseases, whereas other diseases were influenced by factors such as income, job type, years of working experience, and clinic visit frequency. Multivariable logistic regression confirmed that low income, shorter work experience, and infrequent clinic visits were independently associated with skin disease. Workers who received occupational training and used PPE properly reported fewer musculoskeletal issues.

The overall logistic regression model demonstrated good a fit and moderate explanatory power, indicating that the included predictors are relevant for understanding skin disease risk among women waste workers.

In conclusion, women waste workers in Kathmandu are highly vulnerable to occupational health hazards. Promoting PPE utilization, health education, and workplace safety measures can significantly reduce disease burden and improve overall health and well-being.

Recommendations

Based on the findings of this study, improving occupational health among women waste workers in the sampled wards of Kathmandu Valley requires several targeted measures. Structured and practical training programs should be provided, focusing on proper waste handling and the correct use of PPE, with periodic refresher sessions to reinforce knowledge and ensure consistent application. Fit-tested and durable PPE, such as masks and gloves, should be supplied, along with guidance on proper use, maintenance, and safe disposal to maximize protection. Access to hepatitis and tetanus vaccinations should be strengthened through targeted outreach in collaboration with local health authorities, and vaccination records should be maintained to ensure ongoing coverage. Municipal authorities and waste management organizations should support safe working conditions by facilitating training, providing PPE, and ensuring access to occupational health services. These

recommendations are specific to Baneshwor, Koteshwor, and Teku wards, and caution is advised when applying them to other areas.

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Original Article

Physiological and environmental assessment of heat strain risk among welders using the predicted heat strain model

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ABSTRACT

Introduction: Welders are routinely exposed to high thermal loads, increasing the risk of heat stress. Environmental indices such as the Wet-Bulb Globe Temperature (WBGT) are commonly used for assessment but do not account for individual physiological responses. This study aimed to assess heat strain among welders using the Predicted Heat Strain (PHS) model defined by ISO 7933:2018 and to identify worker subgroups at higher risk.

Methods: An observational study was conducted in February 2025 among 41 male welders from the Kapal Niaga Division of PT PAL Indonesia, selected using total sampling. Environmental parameters were measured with a heat stress monitor, while metabolic rate was estimated through task observation and standardized values. Predicted water loss was calculated using the PHS model, and group differences were analyzed with independent samples t-tests.

Results: All participants experienced predicted water loss exceeding the 5% threshold recommended by ISO 7933:2018, ranging from 6.02% to 14.59%, indicating substantial heat strain risk. The average WBGT was 26.11 °C, surpassing the 25 °C limit for very high metabolic workloads. Welders with body weight below 65 kg had significantly higher proportional water loss (mean = 12.29%, SD = 1.62) compared to those with ≥65 kg (mean = 9.11%, SD = 1.51; $t = 6.50$, $p < 0.001$), suggesting that lower body mass may increase vulnerability to heat strain.

Conclusion: Welders face substantial heat strain risk, particularly those with lower body mass. Combining physiological modelling with environmental assessment offers a more complete evaluation of heat exposure risks. Preventive strategies should address both environmental and individual factors to enhance worker protection.

Keywords: Predicted heat strain, risk assessment, water loss, welders

Introduction

Welding is a fundamental process in the shipbuilding industry, widely used to fabricate and assemble metal structures.[1] However, welding exposes workers to various occupational hazards, with excessive heat being a primary concern.[2] During welding operations, workers

encounter extreme thermal conditions from open flames, infrared radiation, molten metal splashes, and contact with hot surfaces. To minimize the risks associated with heat exposure, welders are required to wear flame-resistant protective clothing made from high-density cotton fabrics.[3] While these garments provide necessary protection, they also reduce the body's ability to dissipate heat effectively, thereby increasing the risk of heat strain.

Heat stress has become an increasingly serious occupational health concern, especially for workers who must wear protective clothing in a high-temperature environment.[4] The inability to release body heat efficiently can lead to severe physiological consequences, including dehydration, cognitive impairment, and a higher likelihood of occupational injuries. Long-term exposure to excessive heat has also been associated with chronic health outcomes such as kidney disease and cardiovascular problems.[5] As climate change continues to raise global temperatures, the intensity and frequency of heat-related illnesses in the workplace are expected to rise.[6] In many tropical industrial settings, the actual heat burden remains poorly understood because indoor temperatures frequently exceed outdoor ambient conditions, leading to unmonitored physiological strain.[7] This situation becomes even more critical in tropical countries such as Indonesia, particularly in cities like Surabaya, which record some of the highest ambient temperatures and lowest humidity levels in the nation.[8] These climatic characteristics create an especially challenging environment for industrial workers exposed to heat.

In addition to environmental heat, working hours play a crucial role in determining the risk of heat stress. Most countries, including Indonesia, implement standard working hours from 8 am to 6 pm, a period that coincides with peak daytime heat.[9] For outdoor and industrial workers, such as welders in shipyards, this means prolonged exposure to thermal hazards during their shifts. When combined with protective clothing, environmental heat, and physical exertion, the risk of heat strain increases significantly.

Traditionally, occupational heat stress has been assessed using environmental indices such as the Wet-Bulb Globe Temperature (WBGT) index.[10,11] While useful, this approach has significant limitations because it does not account for individual physiological responses such as metabolic rate, core body temperature, and sweat rate, which are critical determinants of heat strain.[12] To address these limitations, ISO 7933:2018 introduces the Predicted Heat Strain (PHS) model, a more advanced framework that integrates environmental and physiological parameters to estimate the acceptability of exposure conditions.[13] This model enables more precise predictions and can inform preventive interventions in occupational settings.

Despite its advantages, the application of the PHS model in various industries remains limited. Several studies highlight barriers such as the complexity of data collection, the need for accurate physiological measurements, and challenges in adapting the model to local working conditions.[14,15] Computational tools such as the FAME Lab PHS Calculator have been developed to facilitate the implementation of the PHS model, enabling more accurate and accessible heat stress assessments.[13] However, research on the implementation of this model in Indonesia, particularly in industrial settings like shipyards, remains scarce. Existing studies have predominantly focused on environmental measurements without integrating workers' physiological responses, which limits the comprehensiveness of heat stress evaluation. To address this gap, the present study applies the ISO 7933:2018-based PHS model to welders at a shipbuilding company, integrating both environmental and physiological parameters to provide a more complete assessment of heat stress risk. By doing so, this study extends the context of previous research conducted in Indonesia by evaluating the PHS model in an industrial shipyard setting, providing insights that have not been previously addressed.

Given these considerations, this study aims to analyze occupational heat stress risks using the PHS model as defined in ISO 7933:2018 and to provide strategic recommendations for protecting workers from heat-related health issues. Specifically, the study will be conducted at PT PAL Indonesia, one of the country's largest and most prominent shipbuilding companies, located in Surabaya—a city with an especially high thermal burden.[16] By leveraging quantitative workplace data, this research will identify key risk factors, estimate acceptable exposure limits, and develop mitigation strategies that integrate both environmental and physiological dimensions of heat strain. Furthermore, the findings are expected to fill a critical knowledge gap in the practical application of the PHS model in Indonesia and contribute to the development of more robust occupational heat stress management frameworks tailored to tropical industrial environments.

Methods

This observational study was conducted among welders in the Kapal Niaga Division of PT PAL Indonesia on 20 February 2025. Ethical approval was obtained from Komisi Etik Penelitian Kesehatan STIKES Guna Bangsa Yogyakarta (approval number 022/KEPK/VI/2025), and written informed consent was secured from all participants prior to data collection. A total of 41 male welders participated in the study. Total sampling was employed, meaning all welders in the Kapal Niaga Division were included, and no specific inclusion or exclusion criteria were applied apart from being a welder. No experimental intervention was introduced to maintain the authenticity of the working environment and participants' responses.

Participant data were collected using a structured questionnaire that included questions on age, body weight, height, duration of employment, and working posture. All participants wore identical personal protective equipment (PPE), specifically coverall-type garments made of cotton with aluminum-painted reflective surfaces, ensuring consistency in clothing-related variables.

According to the National Institute for Occupational Safety and Health (NIOSH),[17] full heat acclimatization is assumed in workers who have been gradually exposed to hot environments for at least 7–14 consecutive days. In this study, acclimatization status was determined based on the duration of employment obtained from the structured questionnaire. All participants met this criterion, having worked in the hot welding environment for a period exceeding this threshold. Environmental parameters, namely dry-bulb, wet-bulb and globe temperature, relative humidity, and air velocity, were measured using the TSI QUESTemp° 44 Heat Stress Monitor. The instrument was calibrated prior to data collection according to the manufacturer's specifications to ensure measurement accuracy. Measurements were taken three times during an 8-hour work shift: at the beginning (07:00–08:00), middle (11:00–12:00), and end of the shift (15:00–16:00). The middle shift measurement was selected to capture the period of peak heat exposure. Measurement points were located directly at the workers' operating areas to ensure accurate representation of environmental conditions.[18]

The Wet-Bulb Globe Temperature (WBGT) Index was used to assess heat stress risk. The WBGT was calculated in accordance with ISO 7243:2017 using the following equation:[19]

$$WBGT = 0.7t_{nw} + 0.2t_g + 0.1t_a$$

where t_{nw} is natural wet-bulb temperature, t_g is black globe temperature and t_a is air temperature. The WBGT for each participant was calculated based on the average of the three measurements taken during the work shift.

Thermal stress among workers was assessed using the Predicted Heat Strain (PHS) model, as outlined in ISO 7933:2018. The PHS model estimates water loss due to heat exposure using computational analysis via the FAME Lab PHS Calculator. The input variables included worker characteristics, environmental parameters, metabolic rate, mechanical efficiency, movement

speed during work, and thermal and evaporative properties of clothing. Figure 1 illustrates the input variables and interface of the calculator. Movement speed during work was uniformly set at 4.99 km/h based on a meta-analysis by Bohannon & Williams Andrews (2011),[20] which represents the average walking speed during moderate-intensity manual labour.

Metabolic rate (M) was calculated using the following formula:

$$M\ (in\ W/m^2)\ =\ \frac{M\ (in\ Watt)}{ADu}$$

where $M\ (in\ Watt)$ is the maximum work capacity in watts and ADu is the individual body surface area, calculated using the DuBois and DuBois (1916) formula.

Maximum work capacity $M\ (in\ Watt)$ was estimated by the following equation:

$$M\ (in\ Watt)\ =\ (19.45\ -\ 0.133\ \times\ Age)\ Wbl$$

where Wbl represents lean body mass, which was calculated using the following formula:

$$Wbl\ =\ \frac{1.08\ -\ Wb}{(80\ \times\ Hb^2)}\ \times\ Wb$$

where Wb is body mass (kilograms) and Hb is body height (meters).

Mechanical efficiency (η) defined as the fraction of metabolic energy converted to external work, was estimated using the Fiala equation:

$$\eta\ =\ 0.2\ tanh\ \left(0.39\left(\frac{act}{58.15}\right)\ -\ 0.60\right)$$

where act represents the standardized level of physical activity in W/m^2.

Descriptive statistics were used to summarize the participants' characteristics, environmental parameters, and physiological responses, including predicted water loss. Differences in water loss percentage between body weight groups (<65 kg vs. ⩾65 kg) were analyzed using an independent sample t-test after confirming normality through the Shapiro-Wilk test. The cut-off value of 65 kg was selected based on the median body weight of the study population. All statistical analyses were conducted using Python programming language in the Google Colaboratory environment. A p-value of less than 0.05 was considered statistically significant.

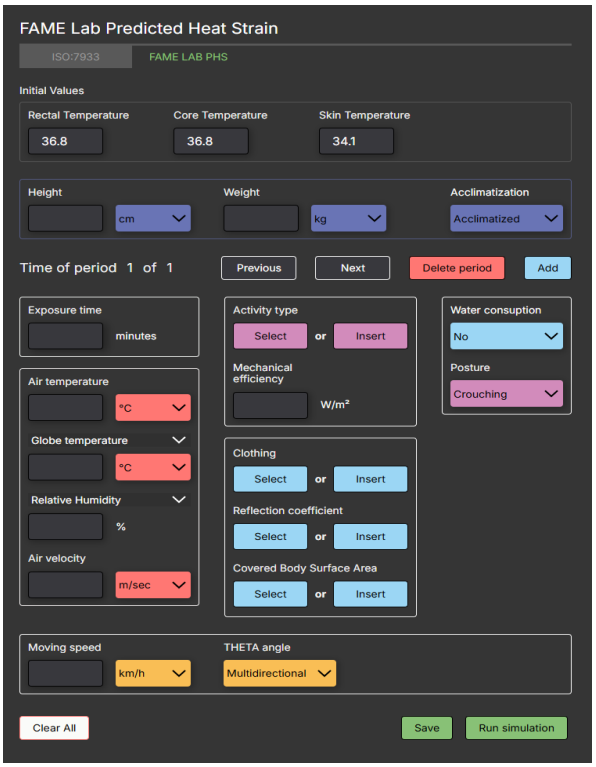

Figure 1. Snapshot of the FAME Lab PHS Calculator

Results

A total of 41 male welders participated in this study, aged 21-47 years (SD = 7.32). Their average work experience was 8.80 years (SD = 6.84), indicating that all participants were fully acclimatized to heat according to NIOSH criteria. Key demographic and environmental characteristics, including height, weight, work duration, and thermal exposure during welding tasks, are summarized in Table 1. Most workers (78%) performed tasks in a standing posture, while the remaining participants worked in sitting or crouching positions (Figure 2).

Environmental measurements, including dry-bulb temperature, wet-bulb temperature, globe temperature, relative humidity, and air velocity, were taken three times during each work shift—at

the beginning, middle, and end—at each measurement location. The reported values (Table 1) represent the averages of these three measurements to reflect the overall thermal exposure throughout the shift.

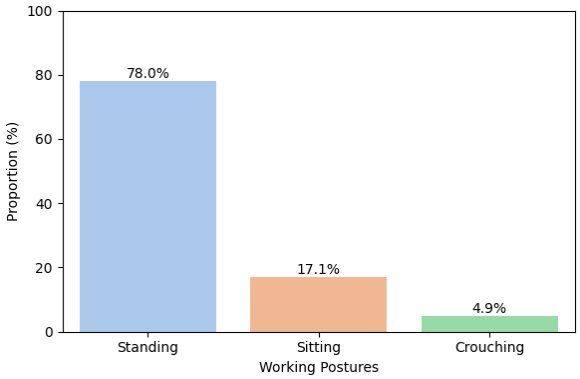

Figure 2. Distribution of work postures among participants during welding tasks.

Environmental conditions indicated relatively stable thermal patterns throughout the observation period, as demonstrated by the low standard deviations across all measured parameters. The average wet-bulb temperature was 23.45°C (SD = 0.17), the dry-bulb temperature was 32.25°C (SD = 0.17), and the globe temperature was 32.35°C (SD = 0.05). The mean relative humidity recorded was 44.87% (SD = 0.30), and the average air velocity was 0.66 m/s (SD = 0.06).

Table 1: Participants' demographic characteristics and environmental measurements during welding tasks (n = 41)

Variables	Min	Max	Mean	Standard Deviation
Age (year)	21	47	33.27	7.32
Height (cm)	157	177	165.95	4.88
Weight (kg)	48	96	64.95	11.55
Work duration (year)*	0.25	27	8.80	6.84
Metabolic rate (watt)	550.90	721.46	640.71	46.46
Wet-bulb temperature (℃)	23.2	s23.6	23.45	0.17
Dry-bulb temperature (℃)	32	32.4	32.25	0.17
Globe temperature (℃)	32.3	32.4	32.35	0.05
Relative humidity (%)	44.6	45.3	44.87	0.30
Air velocity (m/sec)	0.54	0.72	0.66	0.06
WGBT (℃)	25.9	26.24	26.11	0.14
Predicted Water loss (gram)	4944.8	7663.5	6700.15	625.22
Age (year)	21	47	33.27	7.32
Height (cm)	157	177	165.95	4.88
Weight (kg)	48	96	64.95	11.55
Work duration (year)*	0.25	27	8.80	6.84

Note. *Acclimatization status was inferred based on participants' work duration following NIOSH criteria.

The wet-bulb globe temperature (WBGT), a widely used index for assessing heat stress, reflects the thermal environment to which an individual is exposed. Accurate interpretation of WBGT values requires consideration of the individual's metabolic rate. The average metabolic rate among participants was 640.71 W (SD = 46.46), with values ranging from 550.90 W to 721.46 W. Based on ISO 7243:2017, this level of energy expenditure corresponds to Class 4, which is categorized as a very high metabolic rate. For workers in this category, the recommended

WBGT reference limit is 25°C. However, the measured average WBGT in this study was 26.11°C (SD = 0.14), exceeding the recommended threshold. This suggests that participants were working under environmental conditions that posed a significant risk of heat stress.

Thermal stress was evaluated using the Predicted Heat Strain (PHS) model, as defined in ISO 7933:2018, which determines physiological strain based on predicted water loss and rise in core temperature. The results showed notable variability in the predicted water loss, ranging from 4,944.8 g to 7,663.5 g. These values corresponded to between 6.02% and 14.59% of each participant's body weight. All 41 participants experienced water loss exceeding 5% of their body weight, which is the maximum allowable limit defined in ISO 7933:2018 for maintaining thermal balance and preventing excessive dehydration. To facilitate understanding of how each participant's predicted water loss compares to this limit, Figure 3 illustrates a comparison between actual water loss and the maximum allowable limit (5% of body weight). This visualization highlights the extent to which predicted values exceed the acceptable level across the group.

Notably, participants with body weight below 65 kg exhibited a higher average water loss of 12.29% (SD = 1.62), compared to 9.11% (SD = 1.51) among those weighing 65 kg or more. This difference was statistically significant ($t = 6.50$, $p < 0.001$), indicating a greater physiological burden in the lower-weight group. Exceeding this threshold may impair thermoregulation, reduce physical and cognitive performance, and increase the risk of heat-related illnesses. Detailed individual data are presented in the Appendix.

These findings underscore the need for further interpretation regarding their implications for worker safety, particularly in relation to hydration, body composition, and heat exposure. A detailed discussion of these aspects is presented in the following section.

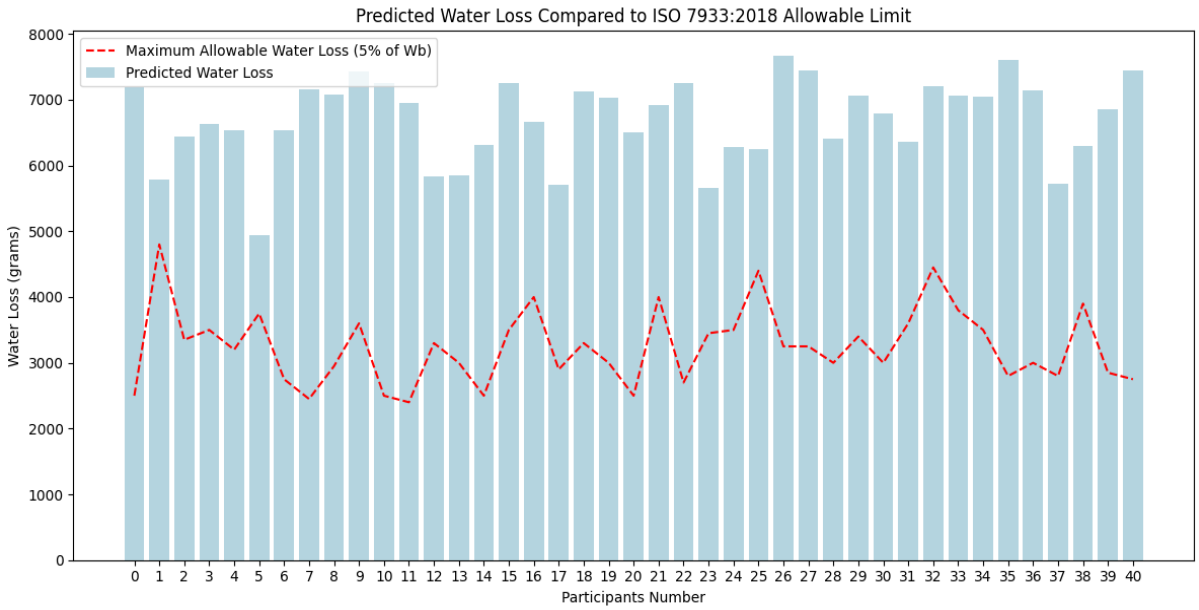

Figure 3. Comparison between predicted water loss and the maximum allowable limit (5% of body weight) for each participant.

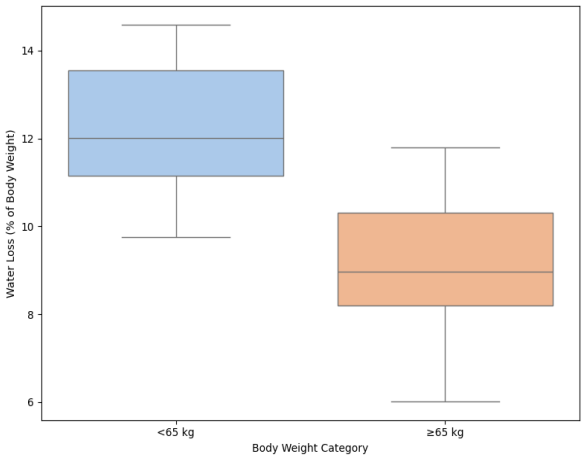

Figure 4. Comparison of water loss (% of body weight) between body weight category

Discussion

The present study aimed to evaluate heat stress among welders by considering both environmental conditions and individual physiological responses. To better understand the physiological demands experienced by the participants, we examined their estimated metabolic rate. The average metabolic rate was 640.71 W, which, according to ISO 7243:2017, falls under Class 4, or "very high metabolic rate." For this category, the recommended WBGT reference limit is 25 °C. However, the measured average WBGT in the work environment was 26.11 °C, thereby exceeding the threshold defined by the standard. This discrepancy indicates that workers were exposed to environmental conditions that surpassed acceptable limits for their level of physical exertion, highlighting a substantial risk of heat stress even before accounting for individual physiological responses. These findings are further supported by Kim & Lee (2020),[21] who identified welding as one of the occupation types associated with high metabolic workloads (400–500 W) and elevated risk of heat exposure, based on national work conditions and climate data in Korea. Furthermore, research in industrial settings indicates that such thermal exposure imposes a significant cardiac burden and can lead to inadequate heart rate recovery among workers.[22]

The physiological risk became more evident when analyzed using the PHS model. All participants were predicted to experience water loss exceeding 5% of their body weight, with values ranging from 6.02% to 14.59%. This surpasses the maximum allowable limit recommended by ISO 7933:2018 for maintaining thermal equilibrium and preventing dehydration-related complications. Research has shown that water loss above 2% of body mass is associated with measurable declines in both physical and cognitive performance. For example, Young et al. (2019) found that moderate dehydration (2–5% body mass loss) can impair memory, focused attention, and cardiovascular stability.[23] Similarly, Wittbrodt & Millard-Stafford (2018) reported in their meta-analysis that cognitive domains such as executive function, attention, and motor coordination are particularly vulnerable to degradation as dehydration severity increases.[24] These findings suggest that the level of water loss predicted in this study may have serious implications for workers' health, cognitive function, and overall safety on the job.

Further analysis revealed a significant difference in proportional water loss based on body weight. Participants with body weight below 65 kg experienced higher water loss as a percentage of their body mass compared to those weighing 65 kg or more. This difference was statistically significant ($t = 6.50$, p value = 0.00), indicating a greater physiological burden among lighter individuals under the same environmental and task conditions. Prior studies have shown that individuals with lower body mass are more vulnerable to heat stress due to their smaller heat

storage capacity and reduced ability to dissipate heat efficiently. Foster et al. (2020) identified low total body mass—particularly below 50 kg—as a major risk factor for thermal strain, noting a negative correlation between body mass and increases in core temperature during hot work.[25] Similarly, Ioannou et al. (2023) found that agricultural workers with smaller body sizes had higher heat-health risk profiles, emphasizing the role of body surface area in thermoregulation.[26] These findings support the current study's results and highlight the importance of considering body composition when evaluating individual susceptibility to occupational heat stress.

While these findings provide valuable insights into the role of body mass in heat stress susceptibility, several limitations should be considered when interpreting the results. First, movement speed during work was not measured directly but estimated based on a meta-analysis, which may not fully reflect actual work pace. Second, environmental parameters were recorded at specific time points rather than continuously, which may have missed short-term variations in heat exposure. Third, the sample consisted only of male welders from a single industrial site, limiting the generalizability of the findings.

Building upon these limitations, several avenues for future research can be identified. First, direct measurement of workers' movement speed using wearable sensors or video-based motion analysis would provide more precise data on physical workload compared to estimations from secondary sources. Second, continuous monitoring of environmental parameters with real-time logging devices is recommended to capture fluctuations in heat exposure that may occur throughout the work shift. Third, expanding the sample to include female workers, different job types, and multiple industrial settings would enhance the generalizability of the findings.

Conclusion

This study assessed occupational heat stress among welders by integrating environmental measurements with physiological modeling using the Predicted Heat Strain (PHS) framework. The results demonstrated that all participants experienced water loss exceeding the 5% safety threshold specified in ISO 7933:2018, indicating a considerable risk of thermal strain. Measured WBGT values also exceeded the recommended limit for workers with very high metabolic rates, further compounding the heat exposure burden. Notably, participants with lower body weight experienced significantly greater proportional water loss, suggesting increased physiological vulnerability. These findings highlight the need for heat stress prevention strategies that account not only for environmental conditions but also for individual characteristics such as body mass. Implementing targeted control measures and regular physiological monitoring may enhance worker protection in hot occupational environments.

Further analysis revealed a significant difference in proportional water loss based on body weight. Participants with body weight below 65 kg experienced higher water loss as a percentage of their body mass compared to those weighing 65 kg or more. This difference was statistically significant ($t = 6.50$, p-value = 0.00), indicating a greater physiological burden.

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Appendix

Participant-level data on WBGT, body mass, and water loss with reference to the 5% allowable limit.

No. Participants	WGBT (℃)	Body Mass (*Wb*) (kilogram)	Predicted Water Loss (gram)*	Maximum Allowable Water Loss (5% of *Wb*) (gram)	Water Loss (% of *Wb*) (%)**
0	26.24	50	7190.6	2500	14.38
1	26.24	96	5783.4	4800	6.02
2	26.24	67	6440.9	3350	9.61
3	26.24	70	6632	3500	9.47
4	26.24	64	6529.1	3200	10.20
5	26.24	75	4944.8	3750	6.59
6	26.24	55	6536.9	2750	11.89
7	26.24	49	7151	2450	14.59
8	26.24	59	7084.1	2950	12.01
9	26.24	72	7426.2	3600	10.31
10	26.24	50	7257.8	2500	14.52
11	25.92	48	6950.4	2400	14.48
12	25.92	66	5827.3	3300	8.83
13	26.04	60	5857.7	3000	9.76
14	26.04	50	6312.1	2500	12.62
15	26.04	70	7260.9	3500	10.37
16	26.04	80	6659.9	4000	8.32
17	26.04	58	5713.7	2900	9.85
18	26.04	66	7122.4	3300	10.79
19	26.04	60	7037.8	3000	11.73
20	26.04	50	6510.6	2500	13.02
21	26.04	80	6925.8	4000	8.66
22	26.04	54	7247.8	2700	13.42
23	25.92	69	5660.7	3450	8.20
24	25.92	70	6279	3500	8.97
25	25.92	88	6252.3	4400	7.10
26	25.92	65	7663.5	3250	11.79
27	25.92	65	7453.1	3250	11.47
28	25.92	60	6415.3	3000	10.69
29	25.92	68	7056.5	3400	10.38
30	26.24	60	6787.3	3000	11.31
31	26.24	72	6354.7	3600	8.83
32	26.24	89	7208.2	4450	8.10
33	26.24	76	7065.2	3800	9.30
34	26.24	70	7043.5	3500	10.06
35	26.24	56	7605.4	2800	13.58
36	26.24	60	7144.5	3000	11.91
37	25.92	56	5723.1	2800	10.22
38	26.24	78	6294.6	3900	8.07
39	26.24	57	6856.9	2850	12.03
40	26.24	55	7439.1	2750	13.53

Notes:

*Predicted Water Loss (gram) refers to the estimated amount of water loss for each participant, calculated using the Predicted Heat Strain (PHS) model.

** Water Loss (% of Wb) (%) represents the percentage of water loss based on each participant's body weight

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Original Article

Respiratory health of municipal solid waste workers in Greece: A Cross-Sectional Study

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ABSTRACT

Introduction: Municipal solid waste workers (MSWWs) are routinely exposed to airborne pollutants, including bioaerosols and combustion by-products, which may contribute to respiratory symptoms and reduced lung function. This study aimed to evaluate the respiratory health of MSWWs employed in local government cleaning services across six municipalities in Greece.

Methods: A cross-sectional study was conducted among 621 municipal employees, including 407 MSWWs and 214 office-based employees as controls. Participants underwent spirometry according to ERS/ATS 2019 guidelines and completed a structured questionnaire assessing respiratory symptoms, occupational history, and smoking status. Descriptive statistics were calculated. Between group comparisons were performed using unadjusted independent sample t-tests for continuous variables and chi-square tests for categorical variables. Pearson's correlation coefficient was used for correlation analyses.

Results: MSWWs demonstrated significantly lower mean FEV1 and FVC values compared to office employees ($p < 0.001$ and $p = 0.004$, respectively). Respiratory symptoms (cough, sputum production, wheezing, dyspnea) were more frequently reported among MSWWs. Descriptive stratified analyses indicated lower spirometric values among current smokers in both occupational groups; however, interaction effects were not formally tested. Spirometric indices showed modest inverse associations with years of employment; these associations were descriptive and may reflect confounding (e.g., age) rather than cumulative exposure effects.

Conclusion: These unadjusted findings are consistent with a potential occupational contribution to respiratory health differences. However, causal inference is limited. Further studies incorporating quantitative exposure assessment and multivariable modeling are recommended.

Keywords: Cross-Sectional Study; Greece; Municipal Solid Waste Workers; Occupational Exposure; Respiratory Symptoms; Smoking; Spirometry;

Introduction

Municipal solid waste management (MSWM) is a vital component of urban infrastructure and public health. Workers engaged in street cleaning and waste collection are routinely exposed to airborne pollutants, including particulate matter, bioaerosols, and combustion by-products, particularly in high-traffic urban environments. These occupational exposures, compounded by physically demanding outdoor work, have been associated with increased prevalence of respiratory symptoms and reductions in pulmonary function in several

occupational studies.[1,2]

While international data have reported respiratory effects among municipal solid waste workers (MSWWs), the magnitude and consistency of these associations vary considerably, influenced by factors such as waste composition, job tasks, environmental conditions, and the use of personal protective equipment (PPE).[3,4] In many settings, MSWWs have reported elevated rates of cough, sputum production, wheezing, and dyspnea, alongside modest but measurable decreases in spirometric indices such as FVC and FEV_1.[5]

In Greece, where waste recycling infrastructure remains limited and municipal waste generation is high, MSWWs often operate under occupational conditions that may lack consistent health and safety safeguards. However, context-specific data assessing respiratory outcomes in this workforce are limited. A cross-sectional study among municipal workers in the Attica region identified a higher prevalence of respiratory symptoms and decreased spirometric values among MSWWs compared with controls.[6]

Therefore, the present study aimed to compare respiratory symptoms and lung function indices between MSWWs and a control group of office-based municipal employees across six municipalities in Attica, Greece. The study also explored descriptive associations with smoking status and duration of employment.

Methods

This cross-sectional study was conducted from October 2023 to February 2024 in six municipalities in the Attica region, Greece. A total of 627 municipal employees initially responded to the study invitation (413 MSWWs and 214 office employees who served as the internal control group). Six MSWWs were excluded due to recent respiratory infection or spirometry contraindications; therefore, 621 participants (407 MSWWs and 214 office employees) were included in the final analysis

Participants were recruited following internal announcements within municipal services and informed invitations to staff. All employees who were present during the study period and consented to participate were included. The study therefore used a voluntary convenience sampling approach rather than probability-based sampling.

Inclusion criteria were active municipal employment in either sanitation services (MSWWs) or office-based positions during the study period and the ability to perform spirometry according to ATS/ERS guidelines. Exclusion criteria included recent respiratory infection within the preceding four weeks, contraindications to spirometry based on ATS/ERS safety screening, or unacceptable spirometric maneuvers. Among the MSWWs, 59.8% (n = 243) were garbage truck workers and 40.2% (n = 164) were street sweepers. All exposed participants were actively engaged in outdoor sanitation tasks. The overall response rate was 26.8% for MSWWs and 10.8% for office employees. Response rates varied across municipalities, ranging from 7.7% to 53.3% among MSWWs and from 5.9% to 22.9% among office employees, with the highest participation observed in Nikaia–Renti and Elefsina. Detailed participation rates by municipality are presented in Supplementary Table S1. Data collection was conducted through face-to-face interviews using a structured questionnaire and spirometry testing performed by trained personnel. The questionnaire collected information on demographic characteristics (age, sex, body mass index), occupational history (job title and years of employment), smoking status (categorized as current, former, or never smoker), respiratory symptoms (cough, sputum production, wheezing, dyspnea), and reported use of personal protective equipment (PPE). Participants were asked to report symptoms experienced during the preceding 12 months. The questionnaire was based on previously published occupational health surveys and adapted to the local municipal context. The full questionnaire is provided as Supplementary Table S2.

Use of PPE was assessed via the questionnaire item with three options “Always,” “Sometimes,”

and "Never."

Spirometry was performed in accordance with ERS/ATS 2019 guidelines using a portable, calibrated digital spirometer (MIR Spirobank II®, Medical International Research, Italy).[7] The measured parameters included forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), the FEV_1/FVC ratio, and forced expiratory flow at 25–75% of pulmonary volume (FEF25–75). Results were expressed as absolute values and as percentages of predicted values adjusted for age, sex, and height. Predicted values were calculated using the NHANES III reference equations as implemented in the spirometer software. Only spirometry tests meeting ERS/ATS acceptability and reproducibility criteria were included in the analysis.

Statistical analysis was performed using IBM SPSS Statistics version 26.0 (IBM Corp., USA). Continuous variables were summarized as means and standard deviations (SD), and categorical variables as frequencies and percentages. Between-group differences were assessed using independent-sample t-tests for continuous variables and chi-square tests for categorical variables. Correlation analyses between years of employment and spirometric indices were conducted using Pearson's correlation coefficient. A p-value <0.05 was considered statistically significant. There were no missing data for primary study variables.

The study was observational and non-interventional and was conducted in accordance with the principles of the Declaration of Helsinki (2013). According to applicable national regulations for non-interventional observational research involving no biological sampling or identifiable personal data, formal ethics committee approval was not required. All participants were informed about the procedures of the study, and verbal informed consent was obtained prior to participation. Participation was voluntary, and confidentiality and anonymity were maintained throughout data collection and analysis.

Results

A total of 621 employees participated: 407 MSWWs and 214 office employees. Among MSWWs, 243 (59.8%) were garbage truck workers and 164 (40.2%) were street sweepers. Response rates were 26.8% for MSWWs and 10.8% for office employees, varying by municipality (Supplementary Table S1). Demographic and baseline characteristics are summarized in Table 1.

Table 1. Demographic characteristics and baseline characteristics of MSWWs and office employees

Variable	MSWWs (n = 407)	Office employees (n = 214)	p-value
Age (years, mean ± SD)	46.3 ± 6.4	44.8 ± 7.1	0.11
Gender (male, %)	81.3%	68.7%	<0.01
BMI (kg/m²)	27.6 ± 3.4	26.8 ± 3.2	0.08
Current smoking (%)	39.5%	37.8%	0.64
Employment duration (years)	15.2 ± 7.5	10.6 ± 6.8	<0.01

Values are presented as mean ± standard deviation (SD) or percentage (%), for continuous variables and as percentages for categorical variables. p-values refer to between-group comparisons (t-test for continuous variables, chi-square test for categorical variables). Employment duration was used as a proxy for cumulative occupational exposure. Smoking refers to current smokers unless otherwise specified.

The mean age of the total population was 45.7 ± 6.8 years, and 77.2% were male. Given differences in sex distribution and employment duration between groups, spirometric comparisons are presented descriptively. Spirometric parameters among exposed and control groups, overall and stratified by smoking status, are presented in Table 2.

Table 2. Spirometric parameters among MSWWs and office employees, overall and stratified by smoking status.

Parameter	MSWWs (mean ± SD)	Office Employees (mean ± SD)	Mean Difference	95% CI	p-value
FEV_1 (% predicted)	91.5 ± 11.7	98.7 ± 10.9	–7.2	–9.05 to –5.35	< 0.001
FVC (% predicted)	94.1 ± 10.3	98.4 ± 9.8	–4.3	–5.95 to –2.65	0.004
FEV_1/FVC ratio	0.74 ± 0.06	0.76 ± 0.05	—	—	0.051
FEF25–75 (% predicted)	68.2 ± 22.1	74.5 ± 21.7	—	—	0.038
Stratified by smoking status					
FEV_1 – Current Smokers	89.4 ± 11.2	95.5 ± 10.1	—	—	0.015
FEV_1 – Former/Never Smokers	93.6 ± 10.9	100.2 ± 11.0	—	—	< 0.001
FVC – Current Smokers	91.5 ± 9.9	96.1 ± 8.5	—	—	0.033
FVC – Former/Never Smokers	96.7 ± 10.1	100.4 ± 10.3	—	—	0.007

Values are presented as mean ± standard deviation (SD). % predicted values are based on ERS/ATS reference equations adjusted for age, sex, and height. Mean differences and 95% confidence intervals (CI) were calculated for comparisons between groups using independent-sample t-tests.

MSWWs had lower mean FEV1 and FVC values compared with office employees (mean difference in FEV1: -7.2%, 95% CI: -9.05 to -5.35; mean difference in FVC: -4.3%, 95% CI: -5.95 to -2.65; p<0.001 and p = 0.004, respectively). Large standard deviations were observed in some strata (notably among smokers), indicating heterogeneity in spirometric values within groups. Self-reported respiratory symptoms (cough, sputum production, dyspnea, and wheezing) were more common among MSWWs than office employees (Table 3).

Table 3. Prevalence of respiratory symptoms among MSWWs and office employees

Symptom	MSWWs	Office employees	p-value
Cough	28.9%	15.4%	<0.001
Sputum production	24.1%	10.3%	<0.001
Dyspnea	19.2%	7.5%	<0.001
Wheezing	8.8%	4.2%	0.03

Values represent self-reported symptoms experienced within the past 12 months. p-values derived from Chi-square tests. Statistical significance set at p < 0.05.

These comparisons are unadjusted and should be interpreted considering baseline differences and potential reporting biases. Regarding respiratory PPE use, none of the MSWW participants reported consistent or occasional use; all selected the "Never" option. Spirometric results by years of employment are shown in Table 4.

Table 4. Spirometric parameters among MSWWs by years of employment

Years of employment	n	FVC (% predicted)	FEV_1 (% predicted)	FEV_1/FVC ratio	p-value
≤10 years	132	96.8 ± 9.7	94.3 ± 10.6	0.78 ± 0.05	Reference
11–20 years	178	93.5 ± 10.2	90.4 ± 11.8	0.76 ± 0.04	0.03
>20 years	97	90.2 ± 11.3	87.6 ± 12.5	0.75 ± 0.06	0.01

Values are presented as mean ± standard deviation (SD). Comparisons were conducted using independent sample t-tests relative to the reference group (≤10 years). $p < 0.05$ was considered statistically significant.

Years of employment showed modest inverse correlations with spirometric indices. Because years of employment is correlated with age and does not capture task variability or exposure intensity, these associations should not be interpreted as evidence of temporal decline or cumulative exposure effects. Correlation coefficients are presented in Supplementary Table S3.

Discussion

This study examined respiratory health among MSWWs in Greece and found that cough, sputum production, dyspnea, and wheezing were more frequently reported by MSWWs than office employees. In addition, MSWWs exhibited significantly lower FEV_1 and FVC values, though mean spirometric indices remained within normal limits. Despite these findings, spirometric reductions were not severe and may reflect the influence of the "healthy worker effect," whereby individuals with pre-existing respiratory disease may self-select out of physically demanding jobs.[8] These findings are consistent with prior studies suggesting occupational exposure in waste collection can negatively impact respiratory health.[9-12]

Similar trends have been documented in national studies. Athanasiou et al. reported decreased FVC and a higher prevalence of respiratory symptoms among MSWWs,[6] while Papageorgiou et al. observed reduced small airway flow (MMEF%pred) in this population.[13] Internationally, Vimercati et al. in Italy and Abou-ElWafa et al. in Egypt reinforce concerns regarding the respiratory risks associated with waste handling work, particularly in the absence of adequate protective measures.[10,11]

To the best of our knowledge, this is the largest study conducted in Greece to evaluate the respiratory health of municipal solid waste collection workers. The relatively large and diverse sample and inclusion of six municipalities across Attica broaden the geographic coverage of the study; however, voluntary participation and response rates may limit generalizability.

Smoking was strongly associated with reduced FEV1 values, as expected. Although stratified analyses showed lower spirometric indices among current smokers, no formal interaction testing was conducted; therefore, any synergistic effect between occupational exposure and smoking must be interpreted cautiously.

Importantly, none of the waste workers reported consistent use of PPE, despite reported availability. This reported lack of respiratory PPE use may indicate a potential occupational health gap. Previous studies suggest that consistent PPE use may mitigate exposure to airborne contaminants such as bioaerosols and particulate matter.[12,14,15] Furthermore, the importance of longitudinal studies in understanding the chronic respiratory effects of occupational bioaerosol exposure has been underscored by a

13-year follow-up among compost workers, which demonstrated persistent pulmonary function decline associated with prolonged exposure durations.[5]

This study has several limitations. The cross-sectional design precludes causal inference. Exposure was classified based on job title, which may introduce misclassification bias. Data on PPE use were self-reported, and no quantitative exposure measurements (e.g., dust or bioaerosol levels) were collected. No multivariable regression analysis was performed; therefore, potential confounding by age, sex, BMI, smoking status, or employment duration cannot be excluded. While years of employment were inversely correlated with lung function, this relationship may be confounded by age and unmeasured task-specific exposure. Additionally, the custom questionnaire used was not formally validated, although it was based on prior occupational health instruments.

Despite these limitations, this is the largest study to date in Greece examining the respiratory health of MSWWs, with over 600 participants across six municipalities. The limited number of Greek studies on this topic underscores the importance of the current findings. This study contributes context-specific data and highlights occupational health challenges in an under-monitored workforce.

Conclusion

This cross-sectional study found a higher prevalence of respiratory symptoms and modest reductions in lung function among MSWWs compared with office employees. Although causal relationships cannot be inferred, the findings are consistent with possible occupational influences on respiratory health. The findings emphasize the need for regular health surveillance and consistent use of respiratory protective equipment among sanitation workers. Future prospective studies with quantitative exposure assessment and adjusted analytical approaches are recommended to more accurately assess long-term respiratory risks in this population.

Acknowledgement

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Supplementary Table S1. Participant Distribution and Response Rates by Municipality

Municipality	MSWWs Invited	MSWWs Responded	ResponseRate (%)	Office Workers Invited	Office Workers Responded	Response Rate (%)
Agia Varvara	161	48	29.8	196	18	9.2
Elefsina	165	88	53.3	397	21	5.3
Nea Smyrni	271	35	12.9	331	15	4.5
Nea Ionia	299	23	7.7	238	14	5.9
Nikaia–Renti	463	190	41.0	528	121	22.9
Spata–Artemida	181	29	16.0	296	25	8.4
Total	1540	413	26.8	1986	214	10.8

MSWWs = Municipal Solid Waste Workers; R/R % = Response Rate Percentage

Supplementary Table S2. Structured Questionnaire Administered to Study Participants

UNIFIED FORM
PRE-EXAMINATION SCREENING & SPIROMETRY
(According to ATS/ERS Guidelines)

A. EMPLOYEE INFORMATION

Employee ID: ……
Gender: ☐ Male ☐ Female
Age: …… years
Height: …… cm
Weight: …… kg
Job Position:
☐ Street cleaner
☐ Waste collection worker
☐ Garbage truck driver
☐ Other: ……
Years of employment in sanitation services: ……

B. RESPIRATORY & MEDICAL HISTORY

Have you ever been diagnosed with:

Condition	YES	NO
Asthma	☐	☐
Chronic bronchitis	☐	☐
COPD	☐	☐
Other lung disease	☐	☐

Do you frequently experience:

Symptom	YES	NO
Cough	☐	☐
Sputum production	☐	☐
Wheezing	☐	☐
Exertional dyspnea	☐	☐

Respiratory infection within the last 4 weeks: ☐ YES ☐ NO

C. CONTRAINDICATION SCREENING (ATS/ERS SAFETY CHECK)

Do you currently have or have you recently had (within the last 12 months):

Condition	YES	NO
Hemoptysis	☐	☐
Syncope during forced expiration	☐	☐
Myocardial infarction / severe cardiac event (last 3 months)	☐	☐
Thoracic or abdominal surgery (last 3 months)	☐	☐

➞ Any "YES" answer requires medical judgment or test postponement.

D. SMOKING HISTORY

☐ Never smoker
☐ Former smoker
☐ Current smoker
If current/former smoker:
Years of smoking: ……
Cigarettes per day: ……

E. OCCUPATIONAL EXPOSURE

During your work, are you exposed to:

Factor	YES	NO
Dust / airborne particles	☐	☐
Exhaust fumes	☐	☐

Use of respiratory personal protective equipment (PPE):
☐ Always
☐ Sometimes
☐ Never

F. MEDICATIONS (ATS/ERS PRE-TEST)

Do you take respiratory medications? ☐ YES ☐ NO
If yes: ……
Have you used inhaled medications today? ☐ YES ☐ NO

G. FINAL MEDICAL ASSESSMENT

☐ Fit for spirometry
☐ Postponement – reason: ……
Comments / Interpretation:
……

H. COMPLIANCE STATEMENT

Spirometry was performed in accordance with ATS/ERS guidelines, following structured pre-test screening, with acceptable and reproducible maneuvers.
Occupational Physician: ……

This questionnaire was developed based on relevant occupational health and spirometry guidelines (ATS/ERS 2019).

Supplementary Table S3. Correlation of spirometric parameters with years of employment

Parameter	Pearson's r	p-value
FVC (% predicted)	–0.27	0.01
FEV_1 (% predicted)	–0.33	0.001
FEV_1/FVC ratio	–0.21	0.02

Values represent Pearson's correlation coefficients (r). $p < 0.05$ was considered statistically significant.

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Original Article

Risk of work-related musculoskeletal disorders and occupational health hazards among the footwear making workers in West Bengal, India

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ABSTRACT

Introduction: Shoe making industry is one of the largest industries of the country which employs more than 1.10 million workers coming from the rural areas. They are exposed to different types of occupational hazards at the workplace. Musculoskeletal disorder (MSD) is one of the major burdens among the workers.

Methods: In this comparative study, physiological and demographic characteristics of the randomly selected shoe making workers (150) and non-teaching staff of schools (150) were measured by standard physiological methods and surveys. The study was conducted in the month of February to April 2025 in Nadia district, West Bengal. Modified Nordic questionnaires and body part discomfort (BPD) scale was used to record the musculoskeletal disorders and degree of pain felt. Rapid Entire Body Assessment (REBA) was used to evaluate the working postures.

Results: In this study, it was found that shoe making workers were suffering from excess fatigue (88.66%), accidents (92.00%), addiction (78.66%), and MSDs (96.66%). It was observed that wrist (OR-21.98, 95% CI- 10.06-48.04, p - <0.0001) was the most affected body parts followed by neck, hip, lower back *etc.* due to pulling, bending and twisting postures as well as repetitive actions. Strong significant correlation had been found between MSD with age less than 30 years (OR-11.70, p - <0.0001) and experience up to 5 years (OR-3.73, p - 0.0001).

Conclusion: Shoe making workers were suffering from different types of occupational stress and adverse working conditions. Proper working postures, work-rest cycle, training, and frequent medical check-up can reduce the occupational stress among them.

Keywords: Body parts discomfort (BPD) scale, Rapid Entire Body Assessment (REBA), Shoe making workers, Work- related musculoskeletal disorder (WMSD)

Introduction

The Indian footwear industry is one of the leading industries in the country's employment status and economic development. India poses second position after China in footwear production with an annual production rate of 2.58 billion pairs (2018).[1] The market size of the Indian footwear industry is USD 17.89 Billion (2024).[2] Major footwear production cities of India are Chennai, Mumbai, Kanpur, Jalandhar, Agra, Kolkata, Pune, Delhi, Ludhiana and Faridabad where more than 1.10 million workers are engaged in this footwear manufacturing and production industry.[3] Most of the workers engage in this occupation through unorganized small factories. The footwear manufacturing process is mainly done through manual process.

Till today, shoes are getting more priority than the shoe makers.

In the shoe making process, different hazardous chemical substances such as benzene, toluene, xylene, n-hexane etc. are present in the adhesive which has several toxic effects such as cancer, respiratory disease, neurotoxicity etc.[4,5] Aplastic anaemia, leukaemia and other serious health problems were also reported among the child labour of this industry due to exposure in high toxic solvents.[6] In this footwear manufacturing industry, dust particles and adhesive affected the workers lung capacity and also peak expiratory flow rate (PEFR) reported by Gangopadhyay et al.[7]

Musculoskeletal disorder (MSD) is known as the pain, numbness or discomfort in the joints, ligaments, muscles as well as in the tendons and it is one of the most common occupational disorders among the workers. Leite et al. reported that shoe manufacturing workers suffered from multisite work-related musculoskeletal disorder (WMSD) especially in shoulder and wrist regions with special relation to the biochemical, mechanical and psychosocial factors.[8,9] Excessive physical work load, restlessness, obesity and smoking were also causing multisite WMSD among the workers.[10] Work ability reduction, request for disability retirement and absenteeism due to WMSD was significantly reported among the workers in this footwear industry.[11,12] WMSDs arise by different factors such as physical, physiological, environmental as well as psychosocial.[13] According to Almeida et al., significant correlation had been observed between MSD and perceived stress among the footwear manufacturing workers.[14] Judyangel et al. showed significant risk of respiratory disorders, skin alignment and musculoskeletal problems among the leather footwear manufacturing workers.[15] Jadhav et al. found that the most affected area of MSDs is lower back followed by neck, thigh, shoulder, wrist, knee among the hand-sewn crafted footwear workers in Kolhapur, India.[16] As reported by Riaz et al., the cobblers of Faisalabad, Pakistan suffered from neck and shoulder pain.[17] According to Sarkar et. al., these shoe manufacturing workers suffered from pain in their limb joints, lower back and neck region.[18]

These footwear manufacturing workers are exposed to different types of occupational health hazards regularly. They are also suffering from different types of occupational diseases and disorders. Several hazardous working environments are also accelerating these occupational diseases and disorders among them.

So, the main aim of this present study is to find out the factors which cause the musculoskeletal disorders and different occupational health hazards among these shoe making workers of West Bengal, India.

Methods

Most of the footwear making small scale factories in West Bengal, India are maintained by private parties. Due to lack of direct government observations in these private factories, workers who are involved in this field are often suffered from different types of occupational health hazards. In Nadia district, West Bengal, nearly 400 workers are engaged in the shoe making process through different unorganized (private) small footwear making factories. So a comparative study had been design to evaluate different occupational problems among these shoe making workers. For this present study, the data was collected through the survey which includes age, sex, educational details, demographic characteristics, job details of the subjects. The survey sheet contained objective types MCQ questionnaire which was communicated through local language to the workers.

Physical and physiological parameters of the subjects were measured according to standard methods. Modified Nordic questionnaire was used to study the MSDs and psychological stress of the workers.[19] In MSDs, pain or discomfort in nine different regions of the body such as neck,

shoulders, elbows, wrists/hands, upper back, lower back, hips, knees, and ankles/feet during last 7 days were recorded for this survey. Body Parts Discomfort (BPD) scale was used to measure the intensity of pain feeling of the subjects. BPD scale uses 1-10 scores of discomfortibility/pain where 1= identifiable pain, 5= moderate pain and 10= intolerable pain.[20] Rapid Entire Body Assessment (REBA) method was used to evaluate the working postures of the subjects.[21] Videography of the each working cycle was done by IPhone 13 Pro max (USA), and each videography freeze-framed at 20 seconds interval for getting the frequently maintained postures. Most frequently maintained posture of each part of the shoe making process and working activities of non-teaching staff had been selected and stick diagrams were made from freeze framed videography for the posture analysis by REBA method. Inside the shoe making factories, different environmental parameters such as dry bulb temperature (DBT), Wet bulb temperature (WBT), Relative Humidity (RH) were also recorded by SILVA ADC Pro (Sweden) whereas illumination level, noise level and UV radiation was measured by lux meter (Mastech MS6610, India), digital sound meter (Metravi SL4005, India) and UV meter (Lutron UV-340A, USA) respectively. Heat stress inside the factories was calculated by Wet bulb globe temperature (WBGT) index.[22]

This survey was conducted in the month of February to April, 2025 at different shoe making factories and high schools of Nadia District, West Bengal, India.

The present study had been approved by the Departmental Research Committee, Department of Physiology, Murshidabad University (Memo No. – MU/Physiol/01-02/25). This study was conducted according to the Helsinki Declaration (2013) where written consents had been taken from all the participants. The objectives of this study were also clearly explained (Layman terms) to all the subjects.

In this study, the inclusion criteria for shoe making workers (SW) were age (16 to 65 years) and experience (minimum 1 year) and for the control group (CG) were subjects having a minimum of one year full working experience and age between 22 to 60 years. In this study, the subjects who had any past history of orthopedic disorders and had an earlier history of accidents outside the working place were excluded from the survey.

For the present study, 150 male shoe making workers (SW) out of 188 workers were randomly selected from 12 small factories (unorganized sector) of Nadia district, West Bengal, India. For the control/referent group (CG), 150 male non-teaching employees (group-c and group-d staff) out of 182 employees from 12 high schools (organized sector) of the same district were randomly selected for this comparative study.

All the survey data were entered into the MICROSOFT EXCEL sheet to calculate the average (mean) value, standard deviation (SD) value, frequency and percentage. MATLAB 7.0.4.365(R144) service pack 2 software tool was used to calculate the t-test, Odd Ratio (OR), 95% Confidence Interval (CI) and p-value.[23]

Results

In this present study, different physical, physiological, demographical, psychosocial parameters and job details had been collected from the shoe making workers as well as non-teaching staff of different high schools of Nadia district, West Bengal, India. Physiological parameters with job details of the study are shown in Table 1. The mean age of the shoe making worker was found 30.28 ±13.42 years ranging from 16 to 65 years whereas in the control group, the mean age was found 40.72±10.05 years ranging from 22 to 60 years. From the BMI calculation it was found that 89(59.33%) workers were under normal range

but 52(34.66%) workers were found BMI less than 18.5. Mean systolic and diastolic blood pressure (BP) was 130.6±22.59 mmHg and 79.77±12.87 mmHg in case of workers whereas 133.89±14.22 mmHg and 81.02±10.91 mmHg in case of control group. Haemoglobin value (Hb) and random blood sugar (RBS) were also measured where it was observed that both the parameters found high among the non-teaching staff of the schools compared to the shoe making workers (13.31±0.99 gm/dL and 112.81±22.62 mg/dL). These shoe making workers had an average working experience of 11.94±10.77 years whereas 68(45.33%) of them were working in this field for more than 10 years. Average daily working hours of these shoe making workers was 10.91 hours whereas 81(54%) workers were engaged more than 12 hours per day. They were taking tiffin breaks ranging between 30 to 180 minutes per day with an average of 67.9 minutes per day. The BPD score was found higher in case of SW than CG. The student's t-test had been done between the experimental and control group where significant differences were found in case of age, BMI, Hb value, working hours per day, tiffin hours and BPD score.

Table 1: Physiological parameters with working details

Parameters	SW (n=150)/CG (n=150)	*t - Value*	*p - value*
Age (year)	30.28±13.42 / 40.72±10.05	7.5908	<0.0001
BMI (kg/m^2)	19.92 ±3.10 / 24.57±3.25	12.6451	<0.0001
< 18.5	52(34.66%) / 03(2.00%)		
18.5 - 25	89(59.33%) / 84(56.00%)		
> 25	09(6.00%) / 63(42.00%)		
BP Systolic (mmHg)	130.60±22.59 / 133.89±14.22	1.5143	0.1310
BP Diastolic (mmHg)	79.77±12.87 / 81.02±10.91	2.3222	0.0209
Heart Rate/min	77.89±11.70 / 79.28±13.05	0.9031	0.3672
Hb (g/dL)	13.31±0.99 / 14.62±01.11	10.7101	<0.0001
RBS (mg/dL)	112.81±22.62/126.21±47.35	3.1307	0.0019
Working Experience (year)	11.94±10.77/13.54±09.55	1.3002	0.1945
Working hours (per day)	10.96±1.31/6.67±01.33	28.6455	<0.0001
Tiffin Hours (min/per day)	65.73±44.66/30.00±05.00	10.9744	<0.0001
BPD Score	5.31±1.44/4.50±01.89	4.3600	<0.0001

In this present study, odd ratio of different occupational problems was calculated and presented in Table 2. It was noted that significant risk of tiredness (OR-4.40; 95% CI- 2.40-8.05), MSDs (OR-20.43; 95% CI- 7.91-52.77) and addiction (OR-14.15; 95% CI- 8.12-24.67) were also present among these shoe making workers (Table 2). Both the groups i.e. SW and CG were equally suffering from headache as shown from the Table 2.

Table 2: Analysis of odd ratio of occupational problems

Occupational problems	SW [n=150 (%)] / CG [n=150 (%)]	OR[23]	95% CI	*p – value*
Accidents (Yes)	138(92.00%) / 41(27.33%)	30.57	15.32-60.99	<0.0001
Headache	91(60.66%) / 90(60.00%)	1.02	0.64-1.63	0.9061
Feeling tired after work	133(88.66%) / 96(64.00%)	4.40	2.40-8.05	<0.0001
Eyesight Problem	65(43.33%) / 78(52.00%)	0.70	0.44-1.11	0.1334
Hearing Problem	16(10.66%) / 27(18.00%)	0.54	0.27-1.05	0.0727
MSDs	145(96.66%) / 88(58.66%)	20.43	7.91-52.77	<0.0001
Addiction	118(78.66%) / 31(20.66%)	14.15	8.12-24.67	<0.0001

Wrist was found as the most significantly affected body parts of the workers (OR-21.98; 95% CI- 10.06-48.04) followed by neck (OR-11.20; 95% CI- 6.50-19.29), hip (OR-9.11; 95% CI- 5.32-15.59), lower back (OR-5.37; 95% CI- 3.21-8.99), upper back (OR-5.09; 95% CI- 2.43-10.63), whereas high risk of elbow and knee pain were also observed among these workers as shown in Figure 1.

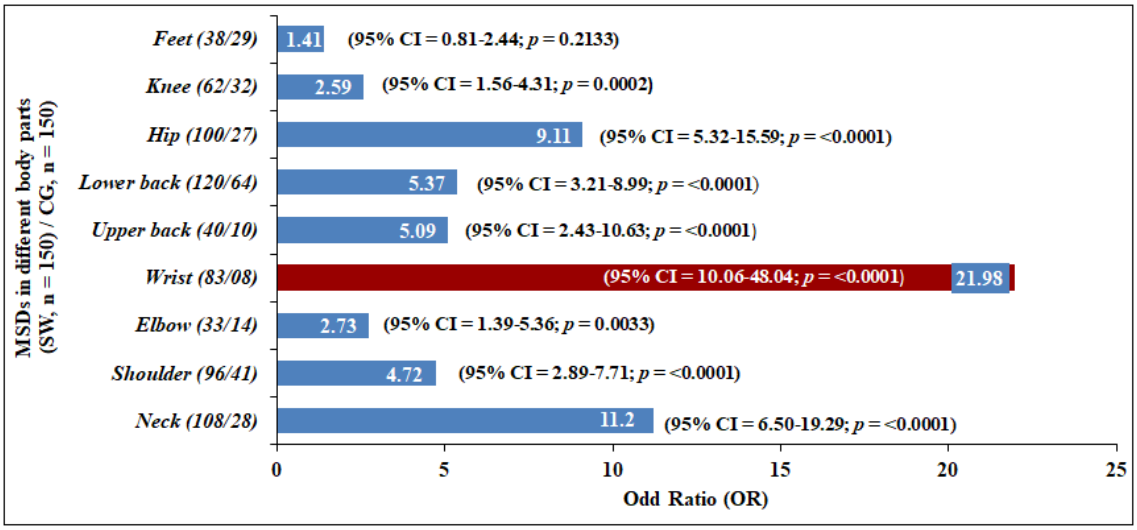
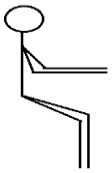
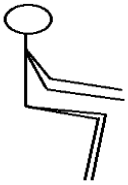
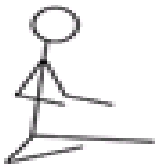


Figure 1: Musculoskeletal disorders in different body parts with Odd Ratio[23]

Table 3: Analysis of Odd Ratio between MSDs with age and work experience

	SW [n = 145 (%)] / CG [n = 88 (%)]	OR[23]	95% CI	*p - value*
MSDs with Age				
< 30 years	87 (60.00%) / 10 (11.36%)	11.70	5.59-24.45	<0.0001
≥ 30 years	58 (40.00%) / 78 (88.63%)	0.08	0.04-0.17	<0.0001
MSDs with work experience				
Up to 5 years	63 (43.44%) / 15 (17.04%)	3.73	1.96-7.12	0.0001
5 - 10 years	24 (16.55%) / 25 (28.40%)	0.49	0.26-0.94	0.0330
> 10 years	58 (40.00%) / 48 (54.54%)	0.55	0.32-0.94	0.0314

Table 4: Posture analysis of shoe workers and non-teaching staff by REBA method

Shoe making workers			Non-teaching staff		
Stick diagram & process	**REBA score with comment**		**Stick diagram & process**	**REBA score with comment**	
	Right	**Left**		**Right**	**Left**
 Hammering	8	8	 Office table task 1	7	6
	High risk			Medium risk	
 Pasting	6	6	 Office computer task	3	3
	Medium risk			Low risk	
 Upper making	9	10	 Office table task 2	3	3
	High risk			Low risk	
 Cutting	7	6	 Office task (standing)	3	3
	Medium risk			Low risk	
 Fitting	6	6	 Laboratory task	6	7
	Medium risk			Medium risk	
 Stitching	11	11	 Laboratory task (standing)	5	6
	Very high risk			Medium risk	

In this study, it was observed that 145 shoe making workers and 88 non-teaching employees of schools were suffering from MSDs. Odd ratio calculation of MSDs with age and working experience was also done where it was observed that shoe making workers less than 30 years of age (60.00%) were more prone to MSDs. It was also found that workers up to 5 years of working experience (43.44%) showed significantly higher risk of MSDs compare to non-teaching employees (17.04%) as shown from Table 3.

In this study, most frequently maintained working postures of shoe making workers and non-teaching staffs were analyzed by REBA method (Table 4). In the small scale shoe making factory, every worker who engaged in this shoe making process followed different steps such as hammering, pasting, upper making, cutting, fitting and stitching. It is found that hammering and upper making postures fall in the high risk category whereas stitching posture is categorized in the very high risk level as shown in Table 4. Every non-teaching employee of schools is involved in different office works as well as laboratory activities. Frequently maintain working posture analysis of these staff by REBA method revealed that office table task 1 and laboratory tasks fall in the medium risk category as shown in Table 4.

BPD score was measured and plotted with age, experience, education, working hours and tiffin break (Figure 2). From this figure it is found that BPD scores rise with increasing age and experience whereas it is inversely proportional with educational level and tiffin break. It is also noted that the highest BPD score (5.40) recorded among the workers with daily working time up to 8 hours followed by working time ≥ 10 hours.

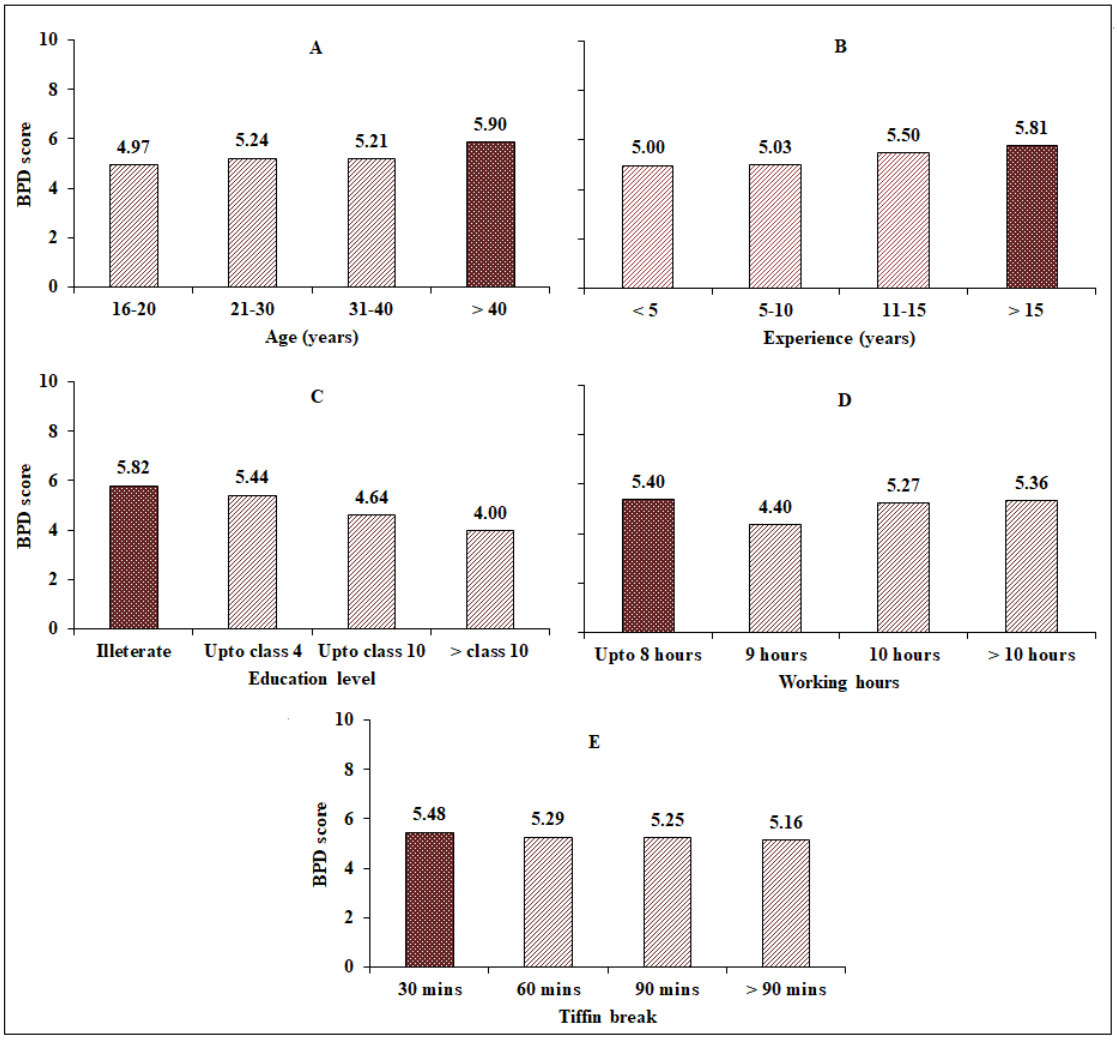


Figure 2: Analysis of BPD score with age (A), experience (B), education (C), working hours (D) and tiffin time (E)

Table 5: Environmental parameters inside the shoe making factories

Parameter	Average ± SD	Maximum	Minimum
DBT (°C)	33.1 ± 0.8	33.9	30.7
WBT (°C)	28.1 ± 1.1	29.3	26.3
WBGT (°C)	29.6 ± 0.8	30.5	27.6
RH (%)	78.9 ± 5.2	84.8	67.4
LUMI (lux)	44.0 ± 19.1	88	14
NOISE (dBA)	69.8 ± 8.4	91.4	60.4
UV (nm)	16.2 ± 5.1	30.0	10.0

Mean dry bulb temperature (DBT), wet bulb temperature (WBT) and wet bulb globe temperature (WBGT) of the workplaces were found as 31.4°C, 28.1°C and 29.1°C respectively with an average relative humidity of 78.9%. Illumination, noise and UV radiation was also measured which was found 44.0±19.1 Lux, 69.8±8.4 dBA and 16.2±5.1 nm respectively (Table 5).

Discussion

The shoe making process is dominated by male workers in India. In Nadia district, West Bengal, mostly local village people are engaged through very small-scale industries which are run mainly by private parties. Earning of these workers depends on their working hours and production rate per day, hence they have an average 11 hours of daily strenuous working hours which is more than the recommended working time.[24] In this study, significant difference had been observed in case of BMI, Hb value, working hours per day, tiffin hours and BPD score. It was found that more than 1/3rd of our study population had lower BMI but the majority of the workers had normal BMI. The study of Leite et. al. showed that nearly 50% Brazilian footwear manufacturing workers had normal BMI whereas only 5% had lower BMI.[8] Prolonged working hours (more than 11 hours), repetitive work style and adverse working environmental conditions (high temperature and humidity, low light) might be the reason behind the significantly higher rates of accidents, fatigueness and MSDs. The long working hours, stressful working environment with low pay lead them towards the poor living conditions which may get them addicted to smoking and alcoholism which was found in this study. They maintain different types of poor body postures during prolonged working hours which cause MSDs in different body parts of them. In this comparative study, it was observed that the highest risk of MSD found in hand/wrist (OR = 21.98, 95% CI = 10.06-48.04, p = <0.0001) part of the body among the workers followed by neck, hip, lower back, upper back, shoulder, knee and elbow. According to frequency analysis of MSDs among the workers, it was found that 80% workers were suffering from lower back pain followed by neck, hip, shoulder, wrist, knee, upper back, feet and elbow pain. These shoe making workers used different types of hand tools, performed repetitive and forceful hand intensive tasks as well as bullying in this shoe making process which might be the reason behind the highest risk of hand/wrist MSDs and this study is also supported by Barr et. al.[25] This pain or discomfort in hand/wrist region was worsened when workers performed such tasks in awkward or extreme wrist forearm postures.[26,27] In these shoe making process, workers maintained a prolonged forward bending neck posture which might be the cause of high neck pain or discomfort. This result corroborated by

the observations of Cagnie et. al.[28] Significant risks of hip and lower back pain were also observed among the workers in our study. Five out of six different steps of shoe making processes were found in the risk category where workers were in sitting or squatting on the floor with their legs and knee bending position as well as maintaining forward bending and twisting posture. This result is also supported by the observation of Fransen et al. and Quynh et al.[29,30] Forward bending and twisting back postures affects the vertebral disc and surrounding spine muscles which can cause lower back pain or discomfortability.[31] Several studies have shown that shoe making workers were suffering from different WMSDs due to prolonged maintained of awkward postures, perceive stress, bullying, biomechanical and psychological factors.[8,9,14,15,18,32] This fully handmade shoe making process have different steps such as hammering, pasting, upper making, cutting, fitting and stitching. Every worker followed these steps for making shoes and most of the steps are manually handled. In this shoe making process, workers maintain different types of working postures for a prolonged period of time. In this study frequently maintained working postures were analysed by REBA method which showed that pasting, cutting and fitting postures have fallen in the medium risk category due to forward bending (20°), twisting of neck, trunk and wrist positions. Hammering and upper making postures had fallen under the high risk category due to forward bending (>20°), twisting of neck, trunk, lower arm and wrist position with high REBA activity score. Stitching posture had been categorized as very high risk (highest REBA activity scores) due to forward bending and twisting of neck and trunk; abducted upper arm and lower arm position; bend and twisted wrist position as well as bending leg action (>50°). Several studies had shown that shoe making workers were suffering from MSDs due to maintaining prolonged awkward working postures.[8,21,27,33] In this present observation it was also noted that shoe making workers less than 30 years of age and up to 5 years of work experience had significantly high risk of developing MSDs when compared with referent group.

In this study, more than 96% shoe making workers were suffering from different types of MSDs. This MSDs or discomfortability was measured by BPD scale and plotted with age, experience, education, working hours and tiffin break. It was noted that discomfortability or pain feeling increased with age (might be due to decreased mobility, increased fatigueness and stiffness in muscular system), experience (might be due to overconfidence, carelessness, impatient about the work) and working hours (might be due to fatigueness, over time, increased psychosocial stress and reduce work-rest cycle). Similar observations were also found by Letie et al. and Haukka et al.[8,10] It was interesting to observe that BPD score inversely proportional with education level which might be due to proper knowledge and education among the literate/educated workers. This BPD score was also inversely proportional with increased tiffin break which might be due to increased work-rest cycle leading to decrease the muscular tension, reduce continuous work load and recovery from fatigue. Our present finding is also supported by the observations of Palsson et al. and Martinez et al. regarding the effects of educational status and work-rest cycles on MSDs respectively.[34,35]

It was observed in this study that workplace temperature reaches 33.9^{O}C with an average 33.1^{O}C which is beyond the recommended level.[36] Relative humidity inside the shoe factories was also found very high. High WBGT at workplace was also noted in our study which indicate the heat discomfortability among the workers according to USARIEM.[37] High air temperature with humid working condition might lead the workers to severe discomfort and psychological stresses which could increase the work place accident rates.[38,39] High risk of MSDs, very high workplace accident rates (92%) and heavy tiredness (88%) after the daylong hard work among the shoe making workers were also found in this study which might be due to high

workplace temperature with humidity, prolonged duration of work, poor working conditions, lack of personal protective equipment and mental stress. Our present observations are also supported by the research work of Leite et. al. and Vieira et al.[8,40] Workplace illumination level was found very low than the factories' recommended level (750 Lux).[41] A large number of these shoe making workers were suffering from frequent headache problems and accidents which might be due to very low illumination level and adverse working environmental conditions and these results have also been supported by the observations of Katabaro et. al. and Li et al.[42,43]

Suboptimal sample size, short term observations, lack of seasonal variations of working environmental parameters etc. were the limitations of the present study.

Conclusion

These shoe making workers mainly comes from socio-economically lower sections of the rural areas. In this present study it is observed that these shoe making workers were suffering from different types of occupational hazards and health related problems along with WMSDs. To prevent the occupational hazards and musculoskeletal problems among the workers, few measures can be taken such as maintain proper sitting support, incorporation of semi-automated or automated process as much as possible, proper work-rest cycle, comfortable working environment, awareness campaign, proper education and training, as well as periodic medical health check-up. To promote the health status as well as to prevent the occupational stress of these workers, government and non-government initiatives should be encouraged.

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Systematic Review

Health and safety in digestive endoscopy personnel: a systematic review

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ABSTRACT

Introduction: Health professionals face various workplace risks, including infections, improper patient handling, toxic chemicals including high level disinfectants and detergents, radiation, excessive heat and noise, psychosocial hazards, violence and harassment, injuries and inadequate access to safe water and sanitation. The aim of this systematic review was to investigate the occupational health and safety risks for health professionals working in digestive endoscopy departments.

Methods: A Systematic Literature Review was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses review method in the PubMed and Scopus databases. The inclusion criteria were used: cross-sectional studies, longitudinal studies, studies published in English, studies published in the last decade (2014-2024), and studies exclusively on endoscopic digestive tract workers.

Results: The majority of the review results showed the high prevalence (up to 70%) of musculoskeletal injuries of healthcare professionals associated by the majority of health professionals to their work. The consequences of these injuries are absences from work, needing medical treatment, undergoing physical therapy or surgery. Other occupational hazards included infections and exposure to radiation during procedures with fluoroscopy.

Conclusion: Undoubtedly, healthcare professionals working in endoscopic digestive departments are at high risk for occupational injuries and infections. Education of health professionals, at undergraduate level and throughout their professional life, the adoption and implementation of international guidelines and recommendations, while providing appropriate protective equipment, will improve the safety of health professionals and significantly reduce the impact on their health and the functioning of health services.

Keywords: Endoscopy, health, risk, safety, worker

Introduction

Enhancing health care coverage and ensuring that residents, especially patients, can achieve the highest possible levels of health depends on the availability, accessibility, acceptability, and quality of these services. The World Health Organization (WHO) predicts a shortage of 10 million health professionals by 2030, mainly in low- and lower-middle-income countries. Nevertheless, nations at all levels of socioeconomic progress face challenges, to varying degrees, in training, employing, developing, retaining, and optimizing their workforce.

Healthcare workers include people engaged in activities aimed at improving health, such as doctors, nurses, midwives, public health experts, laboratory technicians, both medical and non-medical technicians, personal care assistants, community health workers, therapists, and traditional medicine practitioners. The term includes health management and support staff, including cleaners, drivers, hospital administrators, regional health directors, social workers, and other occupational categories engaged in health-related activities, as described by the International Standard Classification of Occupations (ISCO-08). Health professionals are the foundation of any functioning health system. While facilitating the enjoyment of the right to health for all, health professionals must also have the right to healthy and safe working conditions to maintain their own well-being.[1]

Occupational health is a field of public health that aims to promote and maintain the optimal physical, mental, and social well-being of workers in all occupations.[2] Its objectives are:

- Maintaining and enhancing the health and capacity of workers to perform their occupational tasks.
- Improving working conditions and the environment to promote safety and health.
- To foster an organizational and work culture that embodies the core values of the enterprise, incorporating effective management systems, personnel policies, participatory principles, and voluntary quality management practices to promote occupational safety and health.

Occupational health encompasses various disciplines, such as occupational medicine, nursing, ergonomics, psychology, hygiene, safety, and others. The World Health Assembly urges countries to develop national policies and action plans and build institutional capacity in occupational health, expand coverage with key interventions for the prevention and control of occupational diseases and work-related injuries and occupational health services, ensure collaboration with other relevant national health programs, such as those related to communicable and noncommunicable diseases, injury prevention, health promotion, mental health, environmental health, and health systems development.[2]

Healthcare professionals face a variety of risks in the workplace, including infections, improper handling of patients, toxic chemicals, radiation, excessive heat and noise, psychosocial risks, violence and harassment, injuries, and inadequate access to safe water and sanitation.[3-8] WHO estimates indicate that over 54% of health workers in low- and middle-income countries have latent tuberculosis, a prevalence 25 times higher than that of the general population.

In clinical settings in Africa, between 44% and 83% of nurses experience chronic back pain, compared to 18% of office workers. Globally, 63% of healthcare professionals report having experienced some form of violence in the workplace. Throughout the COVID-19 pandemic, 23% of frontline healthcare workers worldwide have experienced despair and anxiety, while 39% have experienced insomnia. In addition, healthcare workers face an increased risk of suicide worldwide. Hazardous working conditions leading to occupational diseases, injuries, and absenteeism impose a significant economic burden on the healthcare sector, estimated at up to 2% of health expenditure. To date, only 26 of the 195 WHO member states have implemented policy tools and national programs to monitor the occupational health and safety of healthcare professionals in the healthcare sector.[1]

The work at an endoscopy department reflects all these realities and presents a variety of hazards to the staff. Indeed, there is a constant flow of patients, including patients with obesity and/or trauma that need to be moved and possibly retained in various positions resulting in potential musculoskeletal strains and injuries. Endoscopes to ensure patient safety have to be reprocessed using detergents and high-level disinfectants

(HLD) that constitute a chemical hazard. Both in- and outpatients are potentially infectious as carriers or microbial, fungal or viral diseases. The nature of endoscopic procedures exposes workers through direct contact, splashes, droplets or percutaneous injuries from sharps to biologic material that may include blood, mucous, feces and provides a source of potential exposure to a variety of infective agents including viruses of hepatitis B and C, HIV and SARS-CoV-2. Exposure to radiation used during procedures with fluoroscopy such as ERCP (Endoscopic Retrograde Cholangiopancreatography) is another concern as well as the repetitive nature of endoscopic procedures, usually under a heavy workload and expectations of high productivity. The latter in combination with the potential complications of endoscopy define a high stakes clinical environment that may act as psychosocial stressors that could impact workers accordingly. Overall, work in the endoscopy department is a complex environment that entails exposure to multiple hazards. We herein aim to systematically review current research regarding occupational health and safety risks for health professionals working in digestive endoscopy departments.

Methods

The purpose of this systematic review was to investigate occupational health and safety risks for healthcare professionals working in gastrointestinal endoscopy departments. The research questions answered in this study were:

- What occupational health and safety risks do healthcare professionals working in gastrointestinal endoscopy departments experience?

A systematic literature review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) review method[9,10] was conducted in the databases of the US National Library of Medicine of the National Institutes of Health and Scopus. The following inclusion criteria were used:

- Cross-sectional studies, longitudinal studies
- Studies published in English
- Studies published in the last decade (2014-2024)
- Studies exclusively on employees in endoscopic departments for the digestive system and not on healthcare professionals outside these departments.

The following keywords were used to conduct the systematic review: care, chemical, digestive, endoscopy, handling, hazard, health, infection, occupational, patient, psychological, professional, radiation, risk, safety, violence, and worker. For a more effective search and retrieval of all relevant articles, all possible combinations of keywords were entered into the Pubmed database using the advanced search service.

Results

A total of 15 studies were identified from the systematic literature review.[11-25] Figure 1 shows the phases of the systematic review process, and Table 1 (supplementary material) summarizes the data and findings of the articles included in the systematic review.

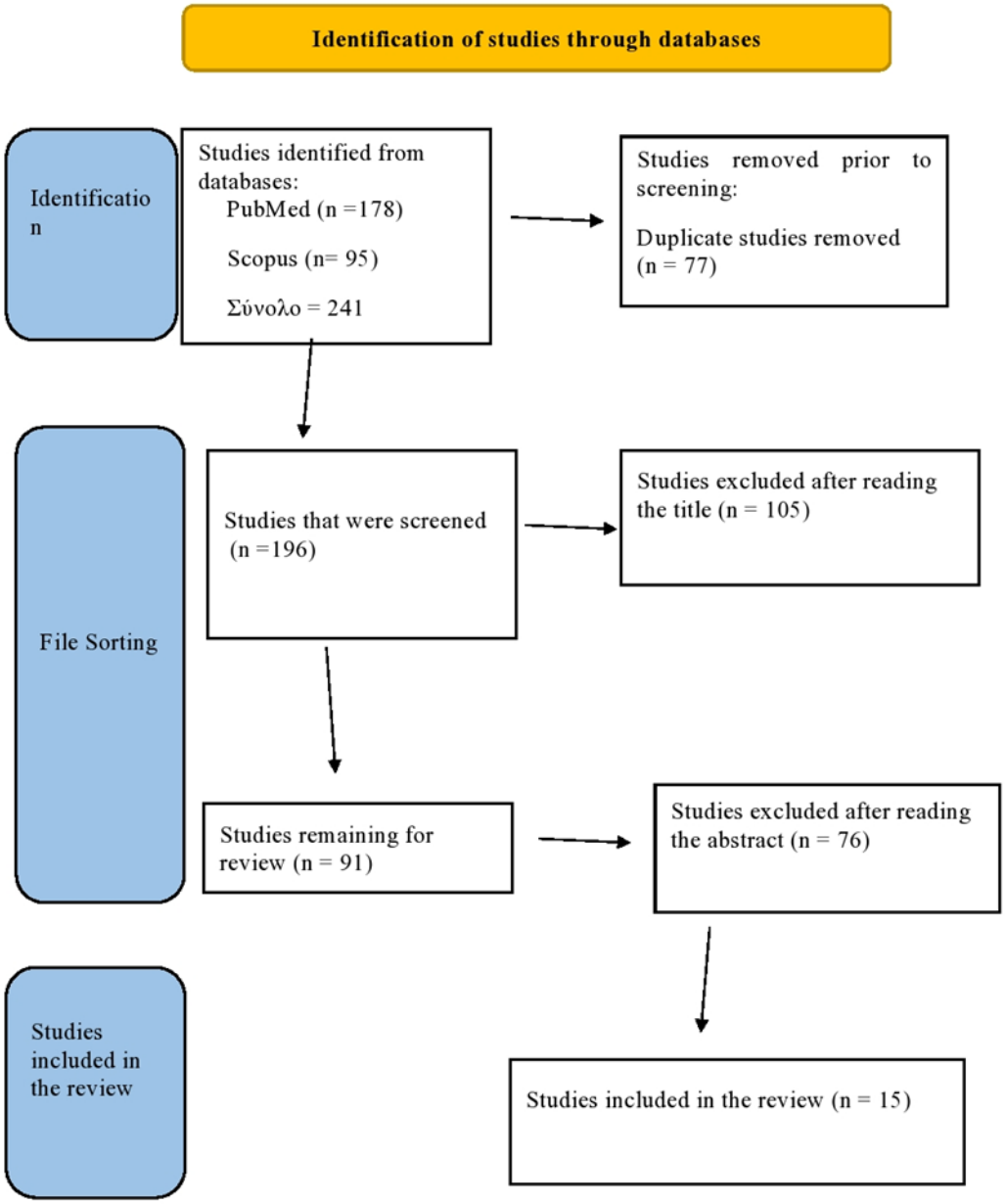

Figure 1: Flow diagram showing phases of the systematic review process

Discussion

This systematic review highlighted the significant occupational risks faced by healthcare professionals working in endoscopic digestive departments. The majority of studies highlighted musculoskeletal injuries as the main risk factors for the health of healthcare professionals. The prevalence of musculoskeletal injuries reached up to 75% of healthcare professionals. The main musculoskeletal injuries included pain in the neck, shoulders, back, and fingers. As a result of these musculoskeletal injuries and disorders, healthcare professionals were forced to take time off work and limit their social activities. Treatment required medication and physical therapy, while some required surgery. Musculoskeletal injuries are a highly prevalent phenomenon among healthcare workers in general. In 2013, the Occupational Safety and Health Administration (OSHA) of the United States Department of Labor published a report on the safety of hospital staff.

The data show that, while injury and absence rates among hospital workers have been steadily declining since 1993, the period from 2000 to 2011 reveals that these rates in the hospital sector are

the highest among all occupational sectors.[26] According to the same report, healthcare workers have more days of absence from work due to injuries than workers in other sectors. These absences have consequences for the provision of health services and also reduce employee productivity.

Work-related musculoskeletal injuries represent a heterogeneous group of clinical conditions affecting the musculoskeletal system, which occur due to exposure to various risk factors in the workplace, and are the predominant injury among healthcare workers due to the physical demands of their work, such as patient handling or pushing and pulling tasks. The most commonly affected areas of the body are the lower back, neck and shoulders, and hands/wrists. When managing these disorders, not only the direct costs (insurance, compensation, medical and administrative expenses) but also the indirect costs, such as periods of sick leave, the recruitment and training of new employees during periods of absence, reduced productivity levels and the impact on production and quality of work, while some authors argue that direct costs represent a small proportion of the global economic burden of musculoskeletal injuries in the workplace. A recent national report from Portugal stated that in 2013, 5,161,343 working days were lost due to occupational accidents and that 21.2% of these incidents resulted in a period of absence exceeding 30 days. The prevalence of musculoskeletal injuries reported in a systematic review ranged from 28% to 96% over a one-year period. The lower back was the most commonly affected part of the body.[27]

Similar findings were reported in an analysis of data on injuries to healthcare professionals in the US for the period 2012-2014.[28] Overall, for the 112 healthcare facilities that participated in the data analysis, rates of patient handling injuries and workplace violence were highest among nursing assistants and nurses. In contrast, physicians, dentists, residents, and fellows have low injury rates. Other studies have found that musculoskeletal disorders are increasing among healthcare personnel. Healthcare professionals are exposed to various risk factors for musculoskeletal disorders: 1) caring for overweight/obese and acute patients, 2) high patient-to-nurse ratios, 3) long shifts, 4) current efforts to mobilize patients almost immediately after medical interventions, and 5) high workload.[29-32]

An important finding of this review is the low percentage (only 20%) of employees in endoscopy departments who have received training in ergonomics. A study has shown that in the US, medical students receive very limited training in ergonomics.[33,34] A significant number of studies have shown the positive effect of ergonomic training programs on the prevention of musculoskeletal injuries in all healthcare professionals.[35-40] These programs could be incorporated either into the undergraduate curriculum of healthcare professionals or into continuing professional development through educational activities that can be organized by the healthcare services where healthcare professionals work.

With regard to the exposure of healthcare professionals to infections, this systematic review showed that all indoor aerosols during medical procedures in an endoscopy unit are significant sources of aerosol production. In the context of SARS-Cov-2, the results of this study clearly show that there is a possibility of virus transmission in an endoscopy unit during medical procedures. This can occur through direct contact due to close interaction with patients or through respiratory aerosols and through contact with contaminated surfaces, equipment, accessories, and body fluids with the virus, which can remain viable for a longer period of time, thus putting uninfected patients and endoscopy staff at risk. Healthcare professionals during the COVID-19 pandemic have emerged as a vulnerable group with an increased risk of exposure, infection, severe illness, and mortality. A significant number of healthcare professionals lost their lives after

becoming seriously ill with COVID-19. The World Health Organization estimated that between 80,000 and 180,000 health and care workers may have died from COVID-19 between January 2020 and May 2021, converging on a median scenario of 115,500 deaths.[41] The International Council of Nurses estimates the number of health professionals who lost their lives to COVID-19 at 115,000.[42] Another study in this review found that face masks (FFP2 or FFP3) and negative pressure rooms were not available in 10.9% and 75.1% of health services.

Training courses on the use of PPE were provided in only 57.2% of centers. Doctors (2.9%), nurses (3.5%), and other healthcare professionals (3.5%) were diagnosed with COVID-19. Participation in a COVID-19 care team (OR: 4.96) and lack of training courses on PPE (OR: 2.65) were associated with an increased risk of COVID-19 infection.[16] Guidelines and recommendations have been issued for the protection of healthcare professionals in endoscopy departments in order to prevent infection among healthcare professionals.[43,44]

Conclusion

Undoubtedly, healthcare professionals working in endoscopic digestive departments are at high risk of occupational injuries and infections. The training of healthcare professionals, at undergraduate level and throughout their professional life, the adoption and implementation of international guidelines and recommendations, and the provision of appropriate protective equipment will improve the safety of healthcare professionals and significantly reduce the impact on their health and the functioning of healthcare services.

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Supplementary material

Table 1: data and findings of the articles included in the systematic review.

Country/ Researchers/ Year	Population	Results	Conclusions
Southern Europe T du Toit, O C Buchel, S J A Smit 2015	92 endoscopy health professionals	Thirty-two (55%) in the control group tested H. pylori(+). Twenty participants (59%) in the combined endoscopy groups (34 in total) tested H. pylori (+). The seropositive rate was higher in those who underwent endoscopy more frequently in the endoscopy groups. No findings were statistically significant.	Not confirmed that endoscopy was a risk factor for H. pylori infection in the endoscopy groups.
USA Ridtitid et al., 2015	684 endoscopists	362 (53%) experienced musculoskeletal injury that was considered definitely (n=204) or probably (n=158) related to endoscopy. Factors associated with a higher rate of endoscopy-related injuries included a higher volume of procedures (>20 cases/week, p< 0.001), greater number of hours of weekly endoscopy (>16 hours/week, p< 0.001), and total number of years of endoscopy experience (p = 0.004). Most common sites of injury were the neck and/or upper back (29%) and the thumb (28%). Only 55% of injured endoscopists used practice modifications in response to their injuries. Specific treatments for injuries included medication (57%), steroid injection (27%), physical therapy (45%), rest (34%), splints (23%), and surgery (13%).	High prevalence of injuries among endoscopists. Higher procedure volume, more endoscopy time per week, and cumulative years of endoscopy experience are associated with more work-related injuries.
Korea Seo et al., 2016	126 ERCP	Studied endoscopic staff who had assisted in 80 consecutive therapeutic endoscopic retrograde cholangiopancreatography (ERCP) procedures. The use of radiation protective curtains placed in the radiology room was randomly determined for each procedure, and radiation doses were measured with electronic pocket dosimeters placed outside the protective apron. When protective curtains were not used, the average radiation doses to endoscopists, first assistants, second assistants, and nurses were 340.9, 27.5, 45.3, and 33.1 µSv, respectively, and the doses were reduced to 42.6, 4.2, 13.1, and 10.6 µSv, respectively, when protective curtains were used (p < 0.01). When the patient had to be restrained during ERCP (n = 8), the radiation dose to second assistants without protective curtains increased by 9.95 times (p < 0.01) compared to cases where restraint was not required.	During ERCP, not only endoscopists but also assistants and nurses were exposed to high doses of radiation. Radiation exposure of staff members during ERCP was reduced by the use of protective curtains.

Great Britain, Al-Rifaie et al., 2017	368 colonoscopy endoscopists	The most common areas of musculoskeletal injury were the lower back (n = 85, 36.5%), the neck (n = 82, 35.2%), and the left thumb (n = 79, 33.9%). Of the endoscopists who experienced musculoskeletal injury, 98 (30.7%) made some modification to their practice, such as stretching exercises and ergonomic changes. Of the endoscopists, 134 (42.0%) considered repetitive strain on the extremities to be a possible causative mechanism. Approximately 40% believed that twisting and awkward body positions were predisposing factors for musculoskeletal injury. Participants used various treatment methods for musculoskeletal injuries, including: physiotherapy (n = 109), medication (n = 70), rest (n = 43), splints (n = 31), steroid injections (n = 26), and surgery (n = 11).	In conclusion, we would say that a significant percentage of colonoscopists experience musculoskeletal injuries. The majority of the proposed modifications to practice can be adopted by any endoscopist. The findings of this study underscore the need to recognize musculoskeletal injuries as a significant occupational health risk for endoscopists.
USA Austin et al., 2019	165 gastroenterologists	Twenty percent reported having suffered a musculoskeletal injury. Female gender was the only factor associated with a higher rate of reported injury ($p < 0.01$). The most common injuries reported were thumb and other hand-related pain (n = 28 [64%]).	Musculoskeletal injuries can affect up to 20% of gastroenterologists. Female colleagues report injuries more frequently and may be at particularly high risk, which has not been found in previous research reports on gastroenterologists.
Portugal Morais et al., 2020	171 endoscopists	The prevalence of at least one musculoskeletal injury related to endoscopy was 69.6% (n=119), with neck pain (30.4%) and thumb pain (29.2%) being the most common. The median time to develop a musculoskeletal injury was 6 years (range 2 months-30 years). Severe pain was reported by 19.3%. A change in endoscopic technique was made by 61.3% and a reduction in endoscopic workload was made by 22.7%. Work loss was reported by 10.1%, with a median time away from work of 30 days (range 1-90). Female gender and ≥ 15 years in practice were independently associated with musculoskeletal and severe pain. Years in practice, weekly endoscopy time, and gender were significant predictors of the number of musculoskeletal injuries.	The prevalence of musculoskeletal injuries was significant among Portuguese endoscopists and had a significant impact on their regular endoscopy and professional activities.

USA Samuel Han, Hazem T. Hammad, Mihir S. Wagh 2020	45 endoscopists	Thirty-one (69%) endoscopists reported current musculoskeletal injuries, with 71% (n = 22/31) believing that these began after starting third-space endoscopy, and 48.9% (22/45) reported more symptoms after third-space endoscopy compared to endoscopic ultrasound/endoscopic retrograde cholangiopancreatography. Common musculoskeletal injuries included the shoulders (42.2%), back (37.8%), neck (33.3%), and wrist (24.4%). With regard to the lower extremities and injuries, these were reported to be most common in the feet (11.1%). A minority experienced disability (2.2%), a change in endoscopy scheduling (6.7%), or surgery (2.2%). Only 15.6% of endoscopists had previously received ergonomic training. Logistic regression did not reveal any significant predictors of musculoskeletal injuries.	More than two-thirds of endoscopists performing third-space endoscopy suffer from musculoskeletal injuries, with many reporting the onset of symptoms after beginning third-space endoscopy.
Italy Mariani et al., 2021	314 health professionals at endoscopy centers	The results of the study showed that personal protective equipment (PPE) was available in most centers, but face masks (FFP2 or FFP3) and negative pressure rooms were not available in 10.9% and 75.1% of centers, respectively. Training courses on the use of PPE were provided in only 57.2% of centers. Doctors (2.9%), nurses (3.5%), and other healthcare professionals (3.5%) were diagnosed with COVID-19. Participation in a COVID-19 care team (OR: 4.96) and lack of training courses on PPE (OR: 2.65) were associated with an increased risk of COVID-19 infection.	The risk of COVID-19 infection among endoscopy department workers was not negligible and was associated with working in a COVID-19 care team and a lack of training on the proper use of PPE.
Japan Matsuzaki et al., 2021	110 endoscopists	The most common sites of musculoskeletal injuries were the neck, waist, and shoulders. Logistic regression analyses showed that greater endoscopic submucosal clearance (odds ratio: 5.7; 95% CI: 1.3-25.0), the lowest endoscopic submucosal clearance (odds ratio 4.9; 95% CI: 1.1-22.0), and the lowest gastrointestinal treatment (odds ratio: 5.6; 95% CI: 2.3-13.3) were significantly associated with the development of musculoskeletal injuries in the lumbar region. In addition, longer duration of endoscopic submucosal dissection (odds ratio: 5.0; 95% CI: 1.2-20.2) was a risk factor for left shoulder symptoms.	This study suggests a correlation between the volume of therapeutic endoscopic procedures, including endoscopic submucosal dissections, and the risk of musculoskeletal injuries, mainly in the lumbar region and left shoulder.

Brazil Luiz Pereira et al., 2022		During these procedures, increases in the mean aerosol concentration (< 5 µm) relative to the reference concentration for colonoscopy, upper endoscopy, bronchoscopy, and bidirectional endoscopy procedures were 12, 72, and 39%, respectively. These results showed that, depending on the type of activity performed within the room, the aerosol concentration differed significantly from the reference concentration. The results also showed that aerosol-generating events during medical procedures in an endoscopy unit fall into two categories: events that generate and disperse aerosols mechanically, and events that cause the patient to produce aerosols. In the context of SARS-CoV-2, the stability characteristics of the virus and its modes of transmission make all sources analyzed high risk for COVID-19 transmission.	This study reveals that all indoor aerosols during medical procedures in an endoscopy unit are significant sources of aerosol production. Aerosol generation significantly alters the concentration and distribution of indoor aerosols, with a potential risk of infection for healthcare professionals. In the context of SARS-Cov-2, the results of this study clearly show that there is a possibility of virus transmission in an endoscopy unit during medical procedures. This can occur through direct contact due to close interaction with patients or through respiratory aerosols and through contact with contaminated surfaces, equipment, accessories, and body fluids with the virus, which may remain viable for a longer period of time, thus putting uninfected patients and endoscopy staff at risk.
Germany Sturm et al., 2022	151 endoscopists	The survey showed that most participants suffered from general musculoskeletal disorders (82.8%) and work-related musculoskeletal disorders (76.8%). The most affected parts of the body were the neck, lower back, thumb, and shoulder. Temporary absence from work due to symptoms was reported by 9.9% of respondents. Over 30% of endoscope participants reported the need for analgesics or physiotherapy due to musculoskeletal disorders. Age, professional experience, and working hours were identified as relevant risk factors for musculoskeletal health problems.	A large number of German endoscopists suffer from musculoskeletal disorders due to specific working postures and repetitive movements, which have a significant impact on their personal health.
Pakistan Zainab Shah et al., 2022	56 endoscopists and support staff	Pain and numbness were reported by 75% of participants, with pain in the neck (41.1%), lower back pain (32.1%), shoulder pain (21.4%), thumb pain (12.5%), hand pain (23.2%), elbow pain (8.9%), and carpal tunnel syndrome (7.1%). Of these, 33.3% attributed their symptoms to endoscopy, 14.2% stated that the symptoms were not caused by endoscopy, and 52.4% were unsure whether endoscopy caused their symptoms. 21.4% of endoscopists needed to take time off work, while 33.9% took medication for pain. Ergonomic modifications to prevent musculoskeletal injuries, including placing the endoscopic monitor at eye level and the monitor in front, interrupting the procedure to move patients, the seat during colonoscopy, and the use of a height-adjustable bed were used by 21.4%.	Three-quarters of endoscopists reported musculoskeletal injuries, of which more than half were unsure or attributed the problem to endoscopy.

USA Ruan et al., 2023	146 pediatric gastroenterologists and trainees	Overall, 55.6% (n = 80/144) reported experiencing a musculoskeletal injury, with 34.7% (n = 50/144) reporting an injury attributable to endoscopy. Among those with musculoskeletal injuries, the most common sites were the neck/upper back (44.0%), thumb (42.0%), hand/finger (38.0%), and lower back (36.0%). Women were more likely to experience musculoskeletal injury than men (43.4% vs. 23.4%, p=0.013). Only 20.9% of participants had formal training in ergonomics.	In conclusion, pediatric endoscopists, especially women, experience significant musculoskeletal injuries, while training in ergonomics in endoscopy is rare. Improved ergonomics training is needed for both practicing pediatric gastroenterologists and trainees.
Japan Ikezawa et al., 2023	Data from 631 ERCPs in healthcare professionals	A strong correlation was found between the eye dosimeter measurements and the radiation exposure of patients. The shielding percentages of lead glasses were 44.6%, 66.3%, and 51.7% for operators, assistants, and nurses, respectively.	This prospective study revealed the actual radiation exposure to the lens of the eye of staff during ERCP, the positive and strong correlations between occupational radiation exposure of the eye lens and patient radiation exposure values, and the effectiveness of lead glasses in reducing radiation exposure to the eye lens. Although the systematic use of eye dosimeters for accurate measurement is recommended, patient radiation exposure values can help estimate staff eye lens radiation exposure due to their strong correlation.
India Musunuri et al., 2024	148 gastroenterologists endoscopists	The annual prevalence and point prevalence of work-related musculoskeletal injuries were 85.1% (n = 126) and 60.1% (n = 89), respectively, and nearly 45.3% (n = 67) of respondents were forced to limit their professional or personal work, such as endoscopy, housework, or hobbies, due to the occurrence of musculoskeletal injuries in the previous year. The most frequently involved sites of musculoskeletal injuries were the shoulder (27.7%), neck (25.6%), and lower back (22.9%), followed by those of the hands. The thumbs (23.6%) are the most common site involved in the hands, followed by the wrists (20.9%), fingers (17.5%), and elbows (16.2%). Among individuals who experienced musculoskeletal injuries, nearly 31.4% (n=28) had symptoms for more than a year and 40.4% (n = 36) had symptoms lasting from one month to one year, while the rest had symptoms lasting less than a month. Almost 25.8% (n = 23) had continuous bothersome symptoms, while the rest (74.2%, n = 66) had intermittent symptoms. In 28% (n = 25) of cases, the symptoms were mainly during work, while 42.7% (n = 38) had symptoms after working hours.	A high prevalence of musculoskeletal injuries was recorded, with significant impacts on the professional and social lives of participants.

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Review Article

Integrating spiritual wisdom into occupational health practice: Insights from the Bhagavad Gita

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ABSTRACT

This paper explores how the teachings of Bhagavad Gita contribute to enhance occupational health and safety of the employees in the workplace. Modern occupational health and safety (OHS) practices have become effective in addressing physical and psychosocial risks. However, they fail to deal with emotional challenges faced by employees Hence, the spiritual approaches have drawn the attention of both employer and employees to enrich workplace resilience and integrity. This study answers how the spiritual teachings of the Bhagavad Gita contribute to promoting holistic approaches for the safety of employees and their ethical culture. The research seeks to integrate core Gita's teachings into modern OHS frameworks with a view to enhancing emotional resilience and ethical behavior of employees. The teachings such dharma (righteous duty), vairāgya (detachment), abhyāsa (practice), ātma-jñāna (self-knowledge), and sthita-prajña (emotional stability) offer deep insights in order to foster mental health, ethical conduct and purposeful action in high-pressure occupational settings. The study develops a psychospiritual model for occupational health and safety. The study draws its reference from Eknath Easwaran's translation of the Gita. It also focuses recent research in positive organizational psychology, mindfulness-based stress reduction and psychosocial risk frameworks. This interdisciplinary study illustrates how ancient wisdom can complement modern practices. The proposed model emphasizes inner transformation as a foundation for external well-being. It offers a holistic approach to OHS that includes ethical clarity, emotional regulation, resilience and self-transcendence. Ultimately, this article argues that the Bhagavad Gita, acting as a practical manual for cultivating occupational health in the modern era, makes a paradigm shift toward psychospiritual integration in workplace policies, training and leadership development.

Keywords: Occupational Health and Safety (OHS), Psychospiritual Well-being, Workplace Mental Health, Ethical Leadership, Mindfulness and Resilience

Introduction

Occupational health and safety (OHS) focuses on a one-dimensional approach to addressing workers' physical stresses. However, it has failed to address their emotional disorder. It is believed that the Gita presents only myth and historical details of the ancient society. However, the Gita's teachings offer frameworks for resolving employees' inner conflicts through the dialogues between Arjuna, a warrior prince, and Lord Krishna on the battlefield of Kurukshetra. Its teachings highlight universal moral dilemmas, stress and loss of mental equilibrium. Arjuna's inter- and intrapersonal conflict is the byproduct of his contradiction between emotion and duty.

Krishna employs a counsel model that serves as therapy for resolving contradiction. Gita's teachings offer a spiritually robust framework for addressing employees' health and ethical safety issues. In contemporary settings, employees face stress and ethical dilemmas and thus suffer from mental and emotional disorders. Modern science has focused solely on physical safety, sidelining psychological and ethical guidelines. We can apply these Gita guidelines to resolve inner conflict under pressure. This study, therefore, aims to explore how the teachings of the Bhagavad Gita can contribute to nurture holistic framework for occupational health and safety. Early scholarly interpretations of the Bhagavad Gita emphasize its religious-philosophical doctrines of dharma (duty), vairāgya (detachment), and ātma-jñāna (self-knowledge). Edgerton's critical edition has been framed the text as a synthesis of Indian religious philosophy, while Radhakrishnan underscores its ethical and metaphysical dimensions.[1,2] These foundational works set the stage for later explorations of the Gita's psychological and practical applications. By the late 20th century, Eknath Easwaran began presenting the Gita's teachings as practical tools for modern life, interpreting Karma Yoga as a discipline for equanimity, stress reduction and purposeful action.[3] In parallel, Western occupational health research—such as Cooper and Marshall's early stress models and Karasek's demand-control framework—focuses on workplace strain and psychosocial risks but largely excludes spiritual perspectives.[4,5] In the 2000s, Indian management scholars initiated explicit linkages between the Gita and organizational well-being. Nur Khalisah emphasized rational discernment as a foundation for emotional intelligence and effective decision-making.[6] Concurrently, global organizational psychology emphasizes mindfulness and emotional regulation. Goleman integrates contemplative traditions into the construct of emotional intelligence and Hülsheger et al. demonstrate the positive effects of daily mindfulness on job performance, emotional exhaustion, and work–family conflict. [7,8] These approaches resonate with the Gita's focus on abhyāsa (consistent practice) and self-mastery. Post-2020, the COVID-19 pandemic prompted renewed interest in spiritual approaches to resilience. Rarick suggests that the Bhagavad Gita provides guidance for coping with stress and ethical dilemmas, while Dhiman highlights its role in fostering resilience and ethical clarity in contemporary workplaces.[9,10] Integration with global psychosocial risk models such as the World Health Organization's guidelines on mental health at work,[11] and frameworks like positive organizational psychology,[12] signals a growing synthesis of Eastern and Western paradigms. Despite this momentum, scholarship still lacks a comprehensive interdisciplinary framework that fully integrates Gita-based psychospiritual principles into occupational health and safety (OHS) standards. This study seeks to bridge that gap by proposing a holistic approach to workplace well-being that systematically combines the Gita's teachings with contemporary OHS models.

Methods

This study employs a qualitative approach to explore mechanisms that address workers' emotional disorders. The primary analysis is based on selected verses from the translated version of the Bhagavad Gita by Eknath Easwaran. The study will interpret Gita's teachings such as *dharma*, *vairāgya*, *abhyāsa* and *ātma-jñāna*. These findings from the teachings will be integrated into contemporary occupational health scenarios in order to discover new frameworks that can address employees' emotional problems resulting from burnout. The study further draws on information from various research articles to substantiate the research claim. It aims to formulate a hybrid framework for holistic occupational health and safety.

Results

Bhagavad Gita introduces different ideas such as *dharma* (righteousness), *vairāgya* (detachment), *abhyāsa* (practice) and *triguṇa* (sattva, rajas, tamas). The principle of *dharma* (duty) encompasses moral obligation, ethical responsibilities and virtue. *Vairāgya* (detachment) focuses on maintaining inner balance, self-control and devotion to duty without being attached to the results. The concept of *abhyāsa* (regular discipline) emphasizes deep

concentration, restraint and decreasing exhaustion. The *triguṇa* framework (sattva, rajas, tamas) explains human behavior and nature. *Sattva* refers to harmony, purity and balance in human life. *Rajas* denotes restlessness driven by desire, and Tamas denotes darkness and ignorance. The following discussion analyses these findings in relation to contemporary Occupational Health and Safety (OHS) principles, focusing on their relevance in the contemporary working environment.

Discussion

The Bhagavad Gita presents the concept of *dharma*, which encompasses moral obligation, righteousness, and ethical integrity. Krishna advises Arjuna to fulfill his *svadharma* (personal duty) and not to withdraw from action even in moments of difficulty. This teaching underscores the importance of adhering to one's own ethical responsibilities regardless of challenging circumstances. They enhance workers' and leaders' capacity to perform their job responsibilities and-* adhere to ethical codes and safety rules, even under pressure. Krishna, through Arjuna, instructs individuals to perform their own duty, even imperfectly, rather than do another's duty. Following another person's path can lead to confusion and harm.[3] Krishna's concept aligns with Gunningham and Sinclair's ethical system theory. Their idea underscores responsibility, accountability and proactive moral engagement.[13] If the individuals emphasize results not embracing moral regulations, ethical failures occur. *Svadharma*, a dynamic ethical phenomenon, aligns with one's role and societal impact. This empowers workers to make their tasks meaningful, encouraging ethical diligence even in mundane roles. Fernández-Muñiz et al. emphasize that organizational safety cultures thrive when individuals feel morally invested in their roles.[14] Krishna's worldview emboldens this internalization in order to uphold righteousness and moral obligation.

Arjuna becomes physically and mentally distressed after witnessing his relatives gathered on the battlefield. His limbs weaken, his mouth dries and his clarity begins to fade. His condition reflects mental stress, emotional paralysis and burnout. He confesses, "O Krishna, I see my own relations here anxious to fight, and my limbs grow weak; my mouth is dry, my body shakes, and my hair is standing on end".[3] This closely parallels the symptoms of work-related stress and anxiety disorders in contemporary settings. Krishna guides Arjuna compassionately towards resilience, self-awareness and inner strength. Krishna consoles, "You speak words of wisdom, but you grieve for those beyond grief. The wise grieve neither for the living nor for the dead."[3] This response reflects an approach similar to cognitive restructuring and meaning-making strategies used in preventive stress management programs.[15] Krishna further encourages Arjuna to transcend identification with transient emotional states and to act with greater awareness. Krishna teaches Arjuna the notion of detachment to be liberated from anxiety resulting from the quest of outcomes. Krishna stresses that one should perform one's duties without expecting results.[3] This corresponds with the principle of control in occupational psychology that emphasizes attention towards controllable factors such as effort and behaviors, rather than uncontrollable outcomes like promotion, recognition and job security. Ganster and Rosen argue that work stress can be reduced when employees experience greater autonomy and control over their work.[16] Krishna also emphasizes the principle of equanimity in both successful and failed* outcomes. He encourages individuals to maintain mental equilibrium regardless of success or failur. This approach reduces psychological distress by shifting focus from external results to internal regulation and purposeful action. It is consistent with resilience models in positive psychology.

Burnout results from over-identification with the results, over-ambition, and relentless striving. The Bhagavad Gita offers a preventive remedy for* burnout through the principle of *nishkama karma*. *Nishkama Karma* refers to a selfless act, giving up attachment to results. Krishna urges Arjuna to perform his duty without being motivated by expectations. Krishna preaches that individuals should perform their duties without being driven by results and not withdraw from action.[3] His notion captures the essence of *vairāgya*,

detachment. Detachment keeps an individual from becoming obsessively engag* with results and promotes equanimity of mind. However, in modern workplace psychology, burnout has been linked to excessive workload, lack of control and over-involvement in work roles.[17] Externally controlled outcomes fuel chronic stress and eventual disengagement. Schaufeli et al. emphasize the cultivation of intrinsic motivation against the clinging to results, acting for the value of the work itself.[18] The Gita precisely highlights service-oriented action instead of reward. Krishna's teachings provide a spiritual framework that makes even mundane work significant and psychologically sustainable. Incorporating *vairāgya* into occupational health frameworks fosters resilience by emphasizing effort over outcomes, limiting identity attachment to result-oriented phenomena, and preventing emotional exhaustion.

The Gita presents the concept of leadership that encapsulates empathy, morality and strategic thinking. The text advocates the democratic exercise of power against authoritarianism. Krishna employs counsel and empowerment techniques to enhance the leadership quality of human beings. Krishna states that the behavior of leaders establishes standards that are internalized and replicated by others.[3] His concept emphasizes that leader should play a role to set workplace culture and norms. One should demonstrate ethical behavior through example. This reflects the concept of psychologically safe leadership in occupational health literature, where leaders foster trust, open communication and ethical responsibility.[19] Brown and Treviño highlight that ethical leadership embodies fairness, integrity and people-centered values. It reduces workplace abnormality and increases employee morale.[20] Krishna's leadership approach focuses on wisdom (*buddhi*), compassion and long-term vision. Arjuna learns wisdom from Krishna's teachings that remove Arjuna's confusion. Then Arjuna becomes ready to move for action. Organizations can adhere to Krishna's concept to foster cultures based on trust, emotional intelligence and clear purpose.

The Gita offers *abhyāsa* (repeated practice) and *yoga* (mental unification) as powerful tools to soothe mental stress of the workers. Krishna instructs Arjuna that mental balance comes from sustained effort and detachment. Krishna suggests that the restless mind can be cultivated through practice (*abhyāsa*) and detachment (*vairāgya*).[3] This resonates with Kabat-Zinn's Mindfulness-Based Stress Reduction technique, which emphasizes regular attention training to develop awareness, reduce reactivity and improve task engagement.[21] Workplace studies indicate that mindfulness enhances concentration, emotional regulation and decision-making, all of which are essential for occupational safety.[8] The Bhagavad Gita's notion of equanimity as a yogic practice resonates with contemporary interpretations of mindfulness. Through the integration of structured practice and internal tranquility, individuals can foster mental resilience and mitigate cognitive fatigue. Gita's yoga serves as a mechanism for both meditative engagement and interaction with the external environment. It harmonizes awareness, equilibrium and concentrated action, representing an optimal approach for demanding professional contexts. The Bhagavad Gita offers composure, empathy and understanding as powerful internal and external conflict resolution tools. Arjuna's crisis in the battlefield represents both intrapersonal and interpersonal conflict. Intrapersonal conflict arises from moral confusion marked by fear and grief. His interpersonal conflict results from his duty towards his relatives. This dual struggle resonates with the emotional and relational tensions often experienced in contemporary workplace environments. Krishna encourages Arjuna to transcend reactionary behavior and cultivate equanimity. Krishna asserts that a person demonstrates true strength when they remain balanced in both praise and criticism, as well as in honor and dishonor.[3] Krishna's idea helps to deescalate conflict in the present scenario. Lipsky et al. argue that effective conflict management systems require both formal resolution mechanisms and the development of interpersonal skills, including empathy, composure and clarity.[22] Krishna's counsel offers a blueprint for the resolution of conflict in the

modern-day workplace environment. Furthermore, the Gita's idea of non-attachment and self-control (*ātma-vashyā*) helps to reduce emotional disorder that creates disputes in workplace. De Dreu and Weingart show that relationship conflict, rather than task conflict, undermines team performance and mental health.[23] The Gita transforms such conflicts by shifting emphasis from ego-driven competition to collaboration rooted in awareness. Incorporating Gita's values such as *titikṣā* (forbearance) and *karuṇā* (compassion) into workplace training strengthens psychological safety and fosters relational harmony.

The Gita, advocating for spiritual humanism, challenges discrimination based on caste, creed and social identity. It stands against external status by showing value towards the intrinsic quality of all beings. Krishna stands against social inequality based on background and position. Krishna teaches that a wise person behaves all beings with equal regard, irrespective of their status, background and form.[3] This concept creates a spiritual foundation for introducing diversity and inclusiveness into the workplace. In the context of occupational health, it parallels inclusivity that nurtures equal treatment, going beyond gender, caste, race, age and ability. Contemporary OHS frameworks emphasize the role of equitable treatment in enhancing psychological safety. Cox and Blake suggest that cultural diversity enhances problem-solving and innovation, particularly when organizations foster genuinely inclusive environments.[24] Similarly, Shore et al. demonstrate that inclusive climates correlate with higher job satisfaction, engagement and retention.[25] Krishna claims that all beings are manifestations of the same universal consciousness (Brahman). He sets a spiritual logic to dispel bias and embrace compassion-led leadership. Organizational and mental health flourish only when employees feel inherently respected and valued.

The Bhagavad Gita introduces three *gunas* (modes of nature) such as *sattva* (harmony), *rajas* (restlessness) and *tamas* (confusion). These *gunas* determine human behavior, emotion and mental health. Krishna describes that *sattva* gives rise to knowledge, *rajas* to desire and greed and *tamas* to confusion and delusion.[3] The *triguṇa* framework can be understood as an early psychological model that helps individuals recognize and regulate their mental states in the workplace. In modern terms, these *guṇas* can be loosely compared to balanced, overactive and depressive states of mind. Linley et al. suggest that fostering positive affect and meaning at work, analogous to *sattvic* qualities, enhances both mental health and productivity.[12] In contrast, excessive *rajas* beget burnout. *Tamas* contributes to disengagement and safety risks. Organizations can learn negative impacts of these forces. They can develop stress management techniques by adopting the Gita's notion of *satva*.

Prompt decision-making capacities are the fundamental aspects of occupational health and safety, even under pressure. Krishna guides Arjuna about the precise decision-making process amid emotional and ethical conflict. Workers face such challenges when they are in dilemmas during unsafe practices. Krishna addresses this moral paralysis by encouraging *gyana-yoga*—the yoga of discernment. Krishna suggests that one has to transcend duality of mind to be free from conflicting knowledge and external influences.[3] This parallels James Reason's concept of situational awareness in high-reliability organizations, where clarity of judgment and moral responsibility are prioritized over rigid adherence to protocol.[26] Krishna warns against decisions driven by uncontrolled emotions. He explains that anger disrupts clarity, leading to confusion, loss of judgment and ultimately harmful outcomes.[3] This chain illustrates the psychological degradation that poor emotional regulation can cause, leading to unsafe or unethical choices. If Krishna's advice were applied to Modern OHS training programs, modern workers would benefit from learning how to develop emotional intelligence, stress inoculation, and moral clarity. Integrating ethical norms, self-awareness and clear judgment into decision-making models, organizations will be thrived to ensure safety, dignity and long-term sustainability.

The Gita introduces ātma-*jñāna*, the knowledge of the true self, a permanent and unchanging entity.

It is neither unaffected by success, nor by failure. It does not succumb to birth and death, rather it continues to exist beyond the body.[3] This realization creates the spiritual bedrock of equanimity, resilience and purpose. These qualities are essential for mental health in occupational settings. Self-awareness is the foundation of effective interpersonal skills, conflict management and leadership.[7] The Gita claims that self-knowledge liberates people from fear, anxiety and ego-attachment. Ashkanasy and Daus indicate that individuals with higher emotional awareness are better able to regulate their behavior and maintain composure in stressful work environments.[27] Krishna's teachings closely align with contemporary mindfulness and self-reflection practices used to improve well-being at work. If a person gets absorbed in his/her job, they face a mental disorder. To be free from this case, the Gita offers a path to return to inner calm and self-awareness. When individuals are enlightened through ātma-jñāna, they can handle stressful situations with complete calm and integrity.

Conclusion

This article has explored the convergence between the Bhagavad Gita's spiritual teachings and the evolving field of occupational health and safety. The Gita provides practically applicable insights to address mental stress and ethical dilemmas. It also offers prompt decision-making approaches and teaches us how to develop serenity of mind and handle emotional disorders at work. It presents a vision of *dharma* that promotes integrity and ethical responsibility of the workers. It highlights the key role of *nishkama karma as a remedy for employee and employer burnout*. Moreover, the Gita emphasizes *samatvam*, which helps to maintain emotional balance among workers. It highlights the significance of *ātma-jñāna*, self-awareness, which helps nurture the highest occupational integrity. It provides a psychospiritual framework that enhances both individual and organizational health. Its teachings do not replace scientific notions; rather, they complement science by integrating ancient wisdom into the contemporary working environment. This integration helps to create humane, ethical, and spiritually conscious workplaces in addition to productivity.

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Review Article

Water education: A valuable tool for water sustainability

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ABSTRACT

Introduction: Water is a fundamental natural resource for health, social well-being and sustainable development. Despite the implementation of technical and institutional measures, water challenges persist, highlighting the need for interventions that also focus on human behavior. In this context, education is recognized as a critical factor in shaping sustainability-oriented approaches to water management. The aim of this study is to review and synthesize the literature on water education, with emphasis on educational levels, thematic units, pedagogical approaches and reported learning outcomes.

Methods: A narrative literature review was conducted in international scientific databases. Studies were selected that concerned educational initiatives and interventions on water within the context of Environmental Education and Education for Sustainable Development.

Results: The findings show that most interventions are implemented in primary and secondary education and utilize experiential and participatory pedagogical approaches. Most studies document positive effects on knowledge and attitudes, while data on long-term behavioral change remain limited.

Conclusion: Water education contributes substantially to strengthening water culture and environmental awareness, while highlighting the need for more systematic evaluation and further research on long-term educational outcomes.

Keywords: Environmental education, Education for Sustainable Development, water education, water literacy, water sustainability.

Introduction

The environmental problems facing humanity are numerous, critical, interrelated and directly linked to human activities and pressures on ecosystems. These specific actions create problems such as climate instability, depletion of natural resources, energy insecurity and air pollution,[1] which require immediate international action. Water is a natural resource vital for the survival of living organisms and ecosystems. It is also essential for social and economic development,[2] as many activities are inextricably linked to it. Nevertheless, only a limited share of the Earth's water resources is readily accessible and exploitable, with pollution posing an additional threat.[3] Approximately 2.5 billion people remain without access to basic sanitation services, while over 1 billion face inadequate access to safe drinking water. At the same time, water scarcity is increasing worldwide, with developing countries being hit hardest.[4]

The growing world population, the rapid development of industry and agriculture, and the improvement of the quality of life are factors that

lead to an ever-increasing demand for water, at a time when its supply is decreasing due to pollution and unsustainable groundwater extraction.[1] According to United Nations estimates,[5] global water use has increased at a rate approximately twice that of population growth over the last century, leading to situations in which water availability is insufficient to meet demand. In 2021, it was estimated that approximately 800 million people lived in areas experiencing high or extreme levels of water stress.[6] In addition, nearly 4 billion people face periods of severe water scarcity lasting at least a month each year, according to data that takes into account seasonal changes in water supply and use. Nearly half of this population lives in China and India.[5]

Water scarcity is expected to increase, particularly in sub-Saharan Africa, unless water production increases significantly in the coming decades. Annual water withdrawals are projected to be 20-50% higher in 2050 compared to 2020, based on current trends.[6] Even if global warming is limited to 1.3-2.4 °C by 2050, an additional 1 billion people will experience severe water scarcity. Extreme climate events (heat waves, severe and frequent droughts, etc.) are projected to further exacerbate water scarcity in many nations and regions.[7] Economic scarcity is another important factor contributing to water insecurity, in addition to natural shortages. Many populations lack access to adequate water due to economic constraints that make it difficult to access available water resources.[4] Of the natural hazards that threaten the global community, water-related hazards account for close to 90%.[8]

The lack of safe and adequate water in many regions of the world, together with inefficient water management, has contributed to the global water crisis, which has led, among other consequences, to high mortality rates.[9] According to the first United Nations World Water Development Report, the global water crisis stands out as the challenge with the greatest impact on human survival and the long-term sustainability of the planet.[10] Many countries have tried and are still trying to mitigate the water crisis. However, the legislative or technical measures they have taken have not been able to end or even mitigate this issue,[11] leaving billions of people struggling to survive. According to the World Water Assessment Program (WWAP) report, the lack of public recognition of the severity of the water crisis, combined with the lack of appropriate and sufficient skills for a consistent response, creates obstacles to timely interventions.[12]

To address the water crisis, it is imperative that water policy and management are implemented effectively and in a way that allows human activities to develop sustainably.[13] Given the nature of environmental problems, including the water crisis, is considered deeply social, their management requires a redefinition of the relationship between humans and the environment, in order to achieve their harmonious coexistence. This change requires a lifestyle shift and a reshaping of human behavior regarding water, with an emphasis on establishing an ethical code.[1] Changing these human values and attitudes is possible through promoting awareness of international and complex environmental issues, for which social, economic and ecological goals must be combined and reconciled.[14]

In promoting social awareness focused on water conservation and sustainable management, education plays a fundamental role. This orientation of education is linked to a comprehensive and far-reaching change in society and in the approach to the human-environment relationship, which also requires a fundamental change in our perceptions of the role attributed to individuals.[15] Through appropriate knowledge and skills, education can shape individuals with readiness and insight, capable of understanding the complex and multi-layered nature of environmental problems, such as the water crisis, so that they can explore in depth both the value system behind their root causes and the choices made at the individual, social and political levels, as well as be able to formulate strategies and take actions to address them.[16] After all, as Hoy & Stelli

report, people respond more favorably to education and awareness-raising, as opposed to the imposition of legislative restrictions.[15]

It is no coincidence that the need for active citizen participation, as a necessary condition for achieving the goals of sustainable planning, has been included in the key points of the latest World Conferences. In this direction, education acts as a catalyst, as it prepares the individual for action by providing not only scientific knowledge, but also a moral dimension.

Throughout its long history, Environmental Education (EE) or Education for Sustainable Development (ESD), as it has come to be known, has gone through various stages of development in response to the escalating environmental issues facing societies around the world. Its evolution reflects our growing understanding of the complex interactions between nature and humanity, with the aim of preserving the environment, a common good, essential for sustainability.[17] The ESD supports the transformation of knowledge into responsible attitude and practice, promoting sustainability as an element of everyday life and social participation. Undoubtedly, when citizens are informed, they can protect and sustainably use water resources, and not only that, but also improve the prevailing situation on the planet.[18]

The value of environmental education has been recognized by the International Community at international and regional conferences and meetings and is supported by international and regional organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO), the European Union (EU), the Organization for Economic Co-operation and Development (OECD) and the Council of Europe (CE). The urgent need to integrate the key points of environmental sustainability into all levels of education is evident in the 2030 Agenda for Sustainable Development. This recognition has strengthened international efforts to introduce environmental education into curricula at all levels of formal education, as well as in training programs. It is also promoted by environmental, state and non-state organizations, associations and companies mobilized in the environmental sector.[1,19,20]

The Nordic countries, and especially Sweden, through a multitude of initiatives, policies, research and actions, are considered pioneers in integrating sustainability into their educational systems. The national curriculum in Sweden includes environmental education, which places a strong emphasis on critical thinking and interdisciplinary learning. Swedish schools prioritize supporting students in understanding complex environmental concepts and encouraging them to actively engage in sustainable behaviors, as part of achieving one of the sixteen national educational goals related to Sustainable Development.[21] To achieve these goals, sustainable development is taught and promoted in nine-year compulsory education (7-16 years old), either individually in all subjects by teachers or through cross-curricular teaching. This approach has been applied since 1980, usually in secondary education, through thematic units where various teaching approaches of the respective fields coincide.[21]

Environmental Education and Sustainable Development are also highly valued in Denmark. Danish educators, aware of pollution issues and concerned about the availability of water resources in light of ever-increasing pollution, had been trying since the 1960s and 1970s to raise awareness among parents and students about these issues. As a result, environmental education should have a prominent place in high school and, together with other policies and actions, strengthen the sense of responsibility and active participation in caring for the environment.[22] These methods used in Nordic countries demonstrate a commitment to developing the skills and mindsets needed for students to actively support sustainable development, in addition to teaching environmental issues.[23]

For the most effective implementation of ESD, all stakeholders (policymakers, educators, students,

parents, community) are required to act in synergy to promote environmental sustainability. This implies (Fig. 1):[24]

• Policy and vision for sustainability and their subsequent integration into educational strategies that shape the education system: clearly defined national guidelines with specific goals and actions in which students play an active role, participation of all stakeholders in strategic planning, positive school culture, training and capacity building among teachers and principals, opportunities for continuous professional development, collaboration platforms, etc.

• Integrating critical environmental issues into the curriculum (e.g. climate change, water crisis, etc.) and promoting key competencies, skills and attitudes such as critical and systemic thinking, a culture of responsibility, collective decision-making, future orientation, etc.

• A learning environment with appropriate infrastructure, innovative practices, teaching facilities and educational materials are part of sustainability education. Student-centered and action-oriented pedagogical methods that support inquiry and interdisciplinary learning, collaboration, problem-focus, and linking formal and informal learning to develop key sustainability competencies.

It also requires adequate resources (funding, time, materials), adequate educational evaluation tools and monitoring procedures to document the impact of new policies and programs related to ESD, as well as reviewing learning environments that can motivate students to act for environmental sustainability.[24]

Figure 1 outlines the main policy, curricular, pedagogical and institutional elements that need to work together for the successful integration of ESD into education systems and for supporting learners in developing the skills and attitudes required for sustainability.

Figure 1: Key factors involved in the effective implementation of Education for Sustainable Development

Strengthening institutional leadership is crucial for wider acceptance of the principles of ESD. However, the implementation of environmental education programs around the world is influenced by cultural, political and educational factors. For example, in the United States, ESD has been widely integrated into school curricula. However, states and school districts may vary significantly in their scope of application.[25]

Environmental education programs are a global need and can be a powerful tool for building sustainability.[26] Of primary importance in the ESD is the development of skills and this should be done after careful selection of the topic, which should include elements of topicality and criticality for mechanisms of sustainable future development.[27]

Water availability and quality are undoubtedly key challenges. The importance of water as a

fundamental condition of life, the complex global interactions and the potential for action make it a valuable thematic area for the ESD.[27] In order to achieve sustainable development, it is essential to combat the pressures on water resources and ensure their security. Progress in their management can be achieved when technical and legislative measures are combined with changes in human behavior,[19] and the adoption of sustainable values, and this can be achieved through education.[28] Education can enhance the formation of active citizens who participate responsibly in water management. This active participation is based on understanding the natural environment and human impacts, as well as on developing skills that allow for the recognition of complex interdependencies and the implementation of appropriate management practices.[29,30]

This literature review captures the role of water education as a mechanism for shaping knowledge, attitudes, and practices that support sustainable water management, and examines the context of relevant educational programs in terms of educational levels, thematic units, pedagogical approaches, and reported learning outcomes.

Methods

Focusing on water education initiatives, this literature review used a structured approach to explore how education could change attitudes as well as behaviors regarding water resources management. This study focuses on examining the development processes of various educational initiatives, the program content and existing case studies.

A comprehensive search was conducted in four major academic databases: Scopus, Springer, Web of Science and ScienceDirect. The search strategy was designed to identify a wide range of studies related to water education within the context of Environmental Education and Education for Sustainable Development. Indicative search terms and combinations included: "Water Education, Water Education for Sustainability, Water Education Programs, Environmental Education, Education for Sustainable Development", combined with logical operators (AND, OR), to ensure coverage of both the educational and broader framework of sustainable water management.

The search yielded a significant number of relevant publications. After removing duplicate records, the results were subjected to a two-stage screening process. Initially, titles and abstracts were screened to assess relevance to the review topic. Potentially eligible studies were then reviewed in full text to determine whether they met the inclusion criteria.

The review included studies that addressed the organization, content, or evaluation of water education initiatives and interventions, as well as studies that examined the impact of education on knowledge, attitudes, or perceptions regarding water resources management. Empirical and case studies were preferred, while only peer-reviewed academic articles, conference proceedings, and scientific book chapters were considered. The review included recent publications in the English language.

Studies were excluded when they did not focus on water education, did not adequately describe educational interventions, or lacked a clear educational dimension. From the selected studies, data were extracted on the educational context, level of education, thematic units, pedagogical approaches and reported results. The synthesis was carried out through thematic analysis to identify key patterns, best practices and research gaps. The quality of the studies was assessed based on the clarity of methodology, educational design and adequacy of outcomes, and only studies with sufficient data were included.

The interpretation of the findings should consider the methodological constraints associated with this review. Its narrative rather than systematic approach does not allow for quantitative comparisons or estimation of effect sizes, but focuses on identifying key thematic trends. At the same time, the heterogeneity of

studies in terms of educational contexts, target groups and pedagogical approaches limits the comparability and generalizability of results, especially in relation to long-term behavioral change. Finally, there may be language and publication limitations, as the review is based primarily on peer-reviewed English-language studies. Nevertheless, it offers a coherent picture of the main trends and challenges in water education in the context of sustainability.

Results

The synthesis of the reviewed literature suggests that by supporting individuals and communities in addressing water challenges, future generations can be empowered and bring about change. However, although social awareness of environmental protection and knowledge have increased in recent years, the problems have not been resolved or mitigated.[20] This finding shows the gap between knowledge and the adoption of pro-environmental behaviors.

The reviewed literature shows that the transmission of knowledge and skills related to water can be implemented either within the framework of formal education or informally by Non-Profit Organizations or other entities (e.g. museums, water treatment plants, etc). Water education processes are addressed to both children and adults,[19] however the findings show a clear emphasis on formal education, particularly primary and secondary education.

Many countries include water education in their curricula. Table 1 presents indicative examples of countries with different strategies and levels of integration of water education into the curricula.[3,19,26,31,32,33] These programs are essential tools for educators and include water resource sustainability issues. Different levels of education should be taken into account in the design of programs, so as to leverage existing knowledge, reinforce concepts and skills, and develop new ones.[19] Therefore, there should be continuity in curricula and sustainability education activities in primary and secondary education. It has also been argued that academic programs should allow students to focus on specific sustainability issues and that such programs should include clearly defined learning objectives along with clear methods for achieving and assessing them.[24,34]

The prerequisites for the successful implementation of water education programs include adapting them to the cognitive level of students and adopting interdisciplinary approaches,[19] as water education is part of the ESD. In all the studies reviewed, water education programs cover a wide range of thematic areas. The main topics covered in the existing literature are "water as an environment and source of life, water needs and resources, water uses, water treatment, conservation methods, water saving, water quality and the effects of pollution, the water cycle, the spatial and temporal dynamics of water, the geological action of the sea, watershed management, chemical composition and properties of water, water as a source of energy, water as a dynamic element of the landscape, water and climate, water and hygiene."[19]

Examining these thematic areas can lead to the development of fundamental competencies for sustainability (e.g. interdisciplinary knowledge acquisition, critical thinking and proactive action). For example, examining the ecological, economic and health dimensions of water, as well as the ways in which they interact, can enhance interdisciplinary teaching approaches, as these issues are directly linked to students' consumer behaviors.[27] Discussions initially take place on a local scale, but activities are not neglected on a global scale, in order to understand the unequal availability of water.[35]

Table 1: Information from countries implementing water education programs

Country	National strategy	Education Level	Bibliography
Pennsylvania	• Watershed and Wetland Education • Teacher training and support • Supporting material for participants	Preschool to higher education	Gruver et al., 2009
Singapore	• Water - central role in the education of future generations • Innovative approach to sustainable water management and climate change issues • Exploratory learning • Revision 2006, 2010, 2014	Preschool to higher education	Irnine et al., 2015
Guangzhou, China's 3rd largest city	• Water education has not kept pace with economic growth • Limited reference (0.2–1.4%) to water conservation in 4 compulsory courses • A need for a systematic curriculum is highlighted	Primary Secondary	Xiong et al., 2015
Morocco	• Interdisciplinary approach to develop skills and values • Broad subject matter • Limited presence of field-based and extracurricular activities	Primary Secondary	Amahmid et al., 2018
Spain	• In-depth treatment of the concept of water • Optional courses • Training that requires further strengthening • A need for institutional adjustments is noted	Secondary	Martínez-Borreguero et al., 2020

A successful water education program effectively combines various learning objectives and offers a "*balance between knowledge, attitudes and behaviors*."[19] Learning processes should support understanding of the different aspects of water-related issues (environmental, economic, social and cultural),[36] as students combine them with sustainability.[3] Curricula should be developed in a way that connects different aspects of sustainable development. They should also use innovative pedagogical methodologies to encourage students to act on challenges by finding solutions[19] for the sustainability of this precious natural resource. Experiential, participatory and learner-centered methods are often mentioned in the literature.

Experiential pedagogical methods that promote a better understanding of aspects of sustainability, such as water management, are cornerstones.[11] Water-themed activities can be organized that incorporate practical real-life situations and are based on environmental concern.[37] These activities may include problem-based learning, case studies, poster design, workshops, practical assignments and experiments, inter-school competitions, conferences and debates, theatre and the arts, and even interactive learning technologies and digital tools.[19] For example, involving students as water conservation supervisors in their schools or homes allows them to monitor water use, identify potential waste points, and develop strategies to enhance water efficiency. This role

not only enhances problem-solving and leadership skills, but also fosters a sense of responsibility and accountability towards local water resources. One such project is "The BLUTUBE - Chi porta l' acqua a casa? (Who brings the water home?)", which adapted game activities for primary school students in Lucca, Italy, and showed that games can promote sustainable water use among students and parents.[38]

In other studies, the use of spreadsheets (Excel),[39] smart teaching systems,[40] the application of virtual reality,[41] have been shown to enhance the curriculum, making water sustainability education more effective, as it increases student participation and motivation.[42] Additionally, experiential projects such as creating school gardens, orchards, or similar agricultural initiatives provide a practical learning environment where students can apply the principles of water efficiency in agriculture. By participating in activities such as these, students learn practical aspects of irrigation techniques, soil moisture management, and the challenges associated with water scarcity.[43] Such experiences have the ability to bridge the gap between classroom theory and real-world applications, thereby deepening students' understanding of sustainable practices. As students observe the direct impacts of their actions, are more likely to develop a long-term commitment to environmental sustainability, which can inspire further community involvement and support for water-saving policies.[44]

An example of an experiential method is the study by Valenzuela-Morales et al.,[26] which aimed to determine the effectiveness of an educational intervention on the knowledge and perceptions of 5th-grade elementary school students (10 years old) in Mexico regarding water conservation. Specifically, students from Ahuacacatitlán and San Miguel Laderas (rural areas within the Nenetzingo River watershed with different water availability challenges) were selected for the study and students from the first area were trained for 630 minutes (7 sessions of 90 minutes each) with activities related to a broader water-related topic. Table 2 summarizes the structure and content of the educational intervention, presenting the thematic units, the intended learning dimensions and the pedagogical strategies applied in each session. The results of the educational intervention showed an increase in knowledge and improvement in attitudes and perceptions regarding water use, which were maintained after a period of 3 months compared to the control group (San Miguel Laderas students), who reported similar levels of knowledge.[26]

Table 2: Overview of the water education intervention sessions conducted in elementary schools within the Nenetzingo River Catchment, Mexico[26]

Session 1
Students explore the presence of water on Earth, the water cycle, and its primary physical and chemical characteristics through videos, diagrams, and guided explanations.
Session 2
This session focuses on understanding water availability and the concept of watersheds. Learners engage in storytelling and model-making activities to visualize how water moves and is distributed locally.
Session 3
Students discuss the essential role of water for humans, animals, and plants and experiment with the unique properties of water, such as surface tension and solvent ability.
Session 4
The session examines water use and pollution, wastewater paths, and alternative treatment methods like natural wetlands. Learning takes place through educational games, stories, and songs.

Session 5 Learners explore ways to conserve water, identify different types of water, and discuss the reuse of gray water. The activities include watching videos, analyzing diagrams, and building a small model wetland.
Session 6 This session connects healthy habits and community well-being to responsible water management, encouraging reflection through storytelling and class discussion.
Session 7 The final session introduces rainwater harvesting systems, safe rainwater use, and purification methods at home. Students design posters and infographics to communicate what they have learned.

These approaches lead to greater awareness and a stronger sense of responsibility regarding water management.[45] Thus, students adopt positive attitudes and behaviors regarding water resources.[19] Experiential, integrated learning experiences are best suited to promoting lifelong learning.[46] Extracurricular activities can also increase the interest of students or the public, enhance their awareness, appreciation of the natural environment and develop appropriate skills, attitudes and values.[47] These educational actions are often interdisciplinary and incorporate holistic approaches,[29] elements of particular importance for environmental education in general.

In extracurricular activities, actions can be carried out that contribute to the investigation of questions such as the origin of water, the actions that affect this natural resource, and also allow students to develop skills that are necessary to identify solutions to sustainability issues.[48] Such activities include tours of water treatment plants, rivers, water museums, and interactive exhibitions. With these activities, students will better understand the underlying mechanisms, participate in measurements, and learn about the history of water. In addition, there is an emphasis on participatory educational activities that could include a competitive format, leveraging collaborative learning.[19]

On the other hand, participation in field research helps students better understand environmental concepts and strengthens responsibility and positive attitudes towards natural resource management.[19] It also promotes students' observational and perceptual skills,[49] enhances motivation and curiosity, and enhances retention of the concepts being taught,[50] which is why field research is a teaching strategy in the curriculum in many countries.[19,32] Furthermore, experiences taking place in familiar environments, including homes and schools, are well suited to highlighting the effects of everyday behavior.[29] They can promote water literacy and culture, helping students understand water issues in their area, their rights and their responsibilities.[43]

Studies show that educational interventions related to water sustainability have also been implemented in the community context and even include collaboration between volunteers, educators, water professionals and students, highlighting the role of education in supporting local actions in water management. Such a program was implemented between 2017 and 2020 with four community projects of students, researchers, professionals, and the rural community of Manglaralto in Ecuador, which involved the construction of wells for pumping water and other structures (e.g., embankments, green filters), which help in the use and replenishment of aquifers.[41,51]

Overall, the reviewed literature reports positive outcomes of water education initiatives in terms of knowledge acquisition and attitude change. However, evidence on long-term change remains limited and varies across studies and educational contexts.

Discussion

The findings of this review show that water-related environmental problems are increasingly understood as deeply social. Their effective

management, therefore, requires not only interventions in infrastructure and regulatory measures but also a review of human values and practices. Education emerges as a key mechanism for enhancing ethical awareness, social responsibility and evidence-based decision-making regarding water sustainability.

In this context, education on water-related issues should be a lifelong process and should also include all stakeholders and users. This entails promoting interdisciplinary approaches to provide the necessary knowledge, skills and values to achieve water sustainability.[19] Substantial and lasting change in water management depends on the ability of individuals and communities to understand complexity and act accordingly. These approaches should include all water uses (e.g. urban, agricultural, industrial, energy, domestic) by providing education in schools, vocational and technical education, as well as to policymakers, local communities and the media.[19]

The review highlights that water education initiatives are mainly implemented within the formal education context, particularly in primary and secondary education. Attitude change should be a concern of the education system and implemented systematically.[3,27] Compulsory education (primary and secondary) is a very important level of water education, as these developmental stages are crucial for cultivating critical thinking, while teachers greatly influence children.[19] Between the ages of 6 and 16, children develop the ability to understand other points of view, but they also develop social and analytical skills, which help them discern logical relationships.[52] These elements lead to the understanding and explanation of interdependencies between various concepts, the critical analysis of water-related behaviors, and the identification of solutions.[19]

Equipped with these skills, school-age children who are educated to be environmentally friendly with regard to water gain the motivation to change their behavior and take action to address the water crisis, both at the local and national levels, while at the same time interacting positively with the social environment, promoting sustainable development.[43]

The school is an environment in which educational processes can be implemented with the aim of forming active citizens, ready to act responsibly in water management. This space provides unique training opportunities, as it brings together many students and there is usually appropriate educational material to achieve the learning objectives.[19]

Teachers, whose role is important in water education, implement curricula with appropriate methodologies to achieve educational objectives. It is not enough to design comprehensive curricula if teachers do not have the capacity to implement them and vice versa. Teachers' capacity can be improved through training courses, workshops, exchange of ideas with other professionals, etc.[3] However, the effective integration of ESD in schools, of which water education is a critical element, requires support and targeted funding in curriculum design. This would ensure that sustainability education becomes a systematic process and not simply a matter of teacher choice.[3,34]

Pedagogical approaches appear to play a crucial role in shaping educational outcomes. These lead to in-depth awareness and an increased sense of responsibility regarding water management.[45] Thus, students adopt positive attitudes and behaviors regarding water resources.[19] Learning experiences that combine practice and integration effectively promote lifelong learning.[45] Extracurricular activities can also increase the interest of students or the public, enhance their awareness, appreciation of the natural environment and develop appropriate skills, attitudes and values.[47] These educational actions are often interdisciplinary and incorporate holistic approaches,[29] elements of particular importance for environmental education in general. However, the extent to

which these pedagogical benefits translate into long-term behavioral change remains poorly documented, highlighting the need for more systematic and longitudinal evaluation of educational outcomes.

The thematic scope of the studies examined in the review reflects the multifaceted nature of water sustainability, covering issues such as availability, quality, pollution, conservation, watershed management and climate-related challenges. However, studies show that presenting topics such as the water cycle, watershed systems and climate change in school curricula does not automatically encourage students to adopt proactive behaviors regarding water conservation or resource management.[53] For example, only a small number of students understand that runoff from rainfall contributes significantly to river pollution or can infer how land use and diffuse pollution affect the water cycle. These gaps make the development of aquatic literacy one of the central educational challenges today.[54]

To maintain behavior change, repetition and continuous practical experience are essential for those participating in training programs. Most importantly, children need role models (e.g., parents, teachers, others) to share and support their behavior, which will aim to conserve water resources.[19] Capacity building is crucial to ensuring water security. This process is essentially supported by policy makers, water sector experts and technicians, local populations, relevant parties and information professionals are an integral part of it. They are the main actors communicating on water issues, influencing the public and shaping opinions. Therefore, they must develop and disseminate sustainable values and practices.[55] It is important to spread understanding of water issues, as well as to develop the skills of decision-makers and professionals. Developing platforms to exchange knowledge, information, good practices and facilitate collaborations can be profitable in this direction. Choosing appropriate communication methods with an emphasis on new technologies and experiential activities is also essential to encourage the participation of community members.[55]

Case studies discussed in the literature further demonstrate the potential of experiential educational interventions to improve knowledge and attitudes toward water conservation in diverse geographical and social contexts. Community-based initiatives show that education can contribute to local water management practices by enhancing collaboration between students, educators, professionals, and community members.[41,51]

These programs should be tailored to the specific needs of the local community. However, to be successful, it is essential to take into account prior knowledge and adapt the topic and activities to the different age context of the audience. Community education can also be implemented by establishing community learning centers and pursuing valuable partnerships with various stakeholders. Communities should also be able to formally participate in the decision-making process.[55]

In the case of community education, schools can also play an essential role, along with higher education institutions, which can be transformed into real, successful examples of water management. By becoming more involved in the issues facing the community, these institutions will share their expertise with the general public, educators, and other water and media professionals in order to enhance the impact of their work on society.[55]

Despite these positive indications and the contribution of water education to promoting informed, responsible water users, the diversity of educational programs limits the comparability of findings and the generalizability of results. Beyond specific educational settings, the effectiveness of water education is influenced by institutional support, sociocultural contexts, and the continuity of educational efforts at different levels and sectors.

These observations also highlight the need for further research that systematically examines the long-term impacts of water education in diverse educational and sociocultural contexts.

Conclusion

Overall, the findings of this review allow for a synthetic approach to the role of water education in addressing contemporary water challenges. Water adequacy and quality are emerging as critical and interrelated issues for modern societies, with direct impacts on the environment, public health and sustainable development. The increasing pressure on water resources makes it clear that water management cannot be based solely on technical and institutional measures, but also requires changes in behavior and social practices.

The results show that water education plays an essential role in enhancing knowledge, awareness and attitudes towards water resources. The relevant educational interventions are implemented in formal and informal contexts, utilizing a variety of pedagogical approaches, with the literature recording overall positive results in the acquisition of knowledge and skills.

However, the available evidence on the maintenance of pro-environmental behaviors over time remains limited, which highlights the need to shift the educational emphasis from the transmission of information to the development of critical thinking, ethical reflection and active participation. In this context, experiential, participatory and interdisciplinary approaches contribute to a more substantial understanding of complex water systems and to the active participation of learners.

The effectiveness of water education is also influenced by factors related to the context of implementation, such as institutional support, coherence between educational levels and the broader socio-cultural environment. The fragmentation of educational interventions and the lack of systematic long-term evaluation limit the ability of education to consistently contribute to shaping sustainable water-related behaviors.

From a research perspective, the findings highlight the need for longitudinal studies that examine the long-term effects of water education on behavior and decision-making. At the same time, the importance of further exploring the role of emerging technologies, innovative pedagogical tools and the adaptation of educational initiatives to different social and cultural contexts is highlighted.

In conclusion, water education should be prioritized within public policy agendas, social strategies, and democratic and participatory governance frameworks. When supported by collective efforts of all stakeholders, it can contribute to the formation of informed, responsible and active citizens who will defend environmental sustainability and contribute to effective and sustainable water management practices.

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