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مجلة التربوي

مجلة علمية محكمة تصدر عن كلية التربية الخمس

جامعة المرقب

العدد الثامن والعشرون (28)

يناير 2026م

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- المجلة تحترم كل الاحترام آراء المحكمين وتعمل بمقتضاها .
- كافة الآراء والأفكار المنشورة تعبر عن آراء أصحابها ولا تتحمل المجلة تبعاتها .
- يتحمل الباحث مسؤولية الأمانة العلمية وهو المسؤول عما ينشر له .
- البحوث المقدمة للنشر لا ترد لأصحابها نشرت أو لم تنشر .

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يشترط في البحوث العلمية المقدمة للنشر أن يراعى فيها ما يأتي :

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- يرفق بالبحث تزكية لغوية وفق أنموذج معد .
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- البحوث المنشورة تعبر عن وجهة نظر أصحابها ، ولا تعبر عن وجهة نظر المجلة .

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A Community-Based Cross-Hospital Study on Human Immune Variability and Its Association with Lifestyle and Environmental Factors

Walid Faraj Naamat [1], Mohammed Ismail Abosalah [2], Abdullah Ali Aboughuffah [3]

Department of Medical Laboratory, Faculty of Health Sciences, Alasmarya Islamic University [1]

Department of Health Management, Faculty of Health Sciences, Alasmarya Islamic University [2]

Department of Public Health, Faculty of Health Sciences, Alasmarya Islamic University [3]

w.naamat@asmarya.edu.ly [1]

m.abosalah@asmarya.edu.ly [2]

a.abogffa@asmarya.edu.ly [3]

Abstract

This study investigates human immune variability across three distinct regions in Western Libya: Al-Khoms, Zliten, and Msallata. Utilizing a community-based, cross-hospital approach, the research examines the association between immune biomarkers, lifestyle factors (sleep, stress, physical activity, diet, smoking), and environmental indicators (Air Quality Index, humidity, temperature, population density). Data from 120 participants, proportionally distributed across Al-Khoms Medical Center (40%), Zliten Medical Center (40%), and Msallata Teaching Hospital (20%), were analyzed. Key findings reveal significant differences in immune biomarkers and lifestyle patterns across the hospitals, with Msallata showing lower inflammation and better sleep, while Zliten exhibited higher stress and C-Reactive Protein (CRP) levels. Strong correlations were, identified between immune status and sleep hours, stress levels, and air quality. Furthermore, machine learning models, particularly Random Forest, demonstrated high accuracy in predicting immune status based on non-clinical variables, highlighting the potential for community health

dashboards and early-warning systems. This research underscores the profound impact of environmental and lifestyle conditions on immune health and advocates for integrated monitoring and targeted interventions.

Keywords: immune biomarkers, environmental indicators, lifestyle factors, early-warning systems, community health.

I. Introduction

The human immune system is a complex and dynamic network, constantly interacting with both internal and external environments. Its variability is influenced by a myriad of factors, including genetics, lifestyle, and environmental exposures [1], [2]. Emerging research consistently highlights the significant role of environmental factors, often dominating genetic predispositions, in shaping immune responses from early life onwards [3], [4]. Lifestyle choices, such as diet and physical activity, are also recognized as crucial modulators of immune function [5], [6].

In regions like Libya, where diverse environmental conditions and varying healthcare infrastructures exist, understanding these influences becomes particularly critical. Previous studies in Libya have explored aspects of healthcare systems and specific health challenges, such as COVID-19 epidemiology [7], [8], [9], but comprehensive cross-hospital investigations into immune variability linked to lifestyle and environmental factors are scarce. This study addresses this gap by conducting a community-based, cross-hospital analysis across three distinct facilities in Western Libya: Al-Khoms Medical Center, Zliten Medical Center, and Msallata Central Hospital. The objective is to provide deeper insights into how local environmental and lifestyle conditions contribute to human immune variability, and to explore the

predictive power of non-clinical variables using machine learning approaches for public health applications.

Research Problem

Although the human immune system is a vital and dynamic system influenced by a complex interaction of genetic, environmental, and lifestyle factors, a precise understanding of how everyday surrounding factors such as sleep, stress, physical activity, diet, and environmental pollution contribute to immune variability remains limited. This gap is particularly evident in community-based, multi-center health studies conducted within the same country [10], [11].

In the Libyan context, most previous health research has focused on infectious diseases or direct clinical aspects, while there is a clear shortage of studies linking laboratory immune biomarkers with lifestyle and environmental factors across regions with differing demographic and environmental characteristics, such as Al-Khoms, Zliten, and Msallata [13], [14].

Purpose of the Study:

This study aims to understand human immune variability within different environmental and lifestyle contexts in Western Libya through a community-based, multi-hospital investigation. The research is grounded in the central premise that immune status is not determined solely by genetic or clinical factors, but is strongly influenced by behavioral variables (sleep, stress, physical activity, diet) and environmental conditions (air quality, population density, climate) [15], [16], [17].

The primary purpose of this study is to develop an integrated model linking biological immune markers with daily living conditions, thereby supporting a transition from

disease-centered clinical care toward a preventive, predictive health model based on lifestyle and environmental monitoring [18], [19].

Additionally, the study seeks to demonstrate the feasibility of using non-clinical data (lifestyle and environmental variables) to predict immune status through artificial intelligence techniques, opening pathways for digital health applications and community-level early warning systems.

Research Objectives:

The study objectives are divided into primary and secondary goals.

Main Objective

To analyze human immune variability across different environments and associate it with lifestyle and environmental factors.

Secondary Objectives:

1. Assessment of Clinical Immune Biomarkers Measure WBC, CRP, and lymphocyte subsets among participants across the three cities.
2. Evaluation of Lifestyle Influence Investigate associations between immune status and: Sleep duration, Stress levels, Physical activity, Diet quality
3. Environmental Impact Analysis Assess the effects of Air Quality Index (AQI), humidity, temperature, and population density on immune indicators.

2.Methodology:

2.1 Study Design

This study adopted a community-based, cross-hospital observational design to evaluate variability in human immune function and its relationship with lifestyle behaviors and environmental exposures in Western Libya. The research framework

integrates clinical immunological measurements, digitally acquired behavioral data, and region-specific environmental indicators, forming a multi-layered analytical model of immune health determinants [20], [21].

The study was conducted over a structured data collection period during which all hospitals followed harmonized protocols to ensure inter-site consistency.

2.2 Study Sites

Data were obtained from three healthcare institutions:

- Al-Khoms Medical Center
- Zliten Medical Center
- Msallata Central Hospital

These facilities serve populations exposed to distinct environmental burdens, occupational patterns, and lifestyle structures, creating natural contrasts in immune-relevant exposures. Sampling proportions were assigned to reflect patient volume and regional population density:

Hospital	City	Sample Percentage	Participants
Al-Khoms Medical Center	Al-Khoms	40%	80
Zliten Medical Center	Zliten	40%	80
Msallata Central Hospital	Msallata	20%	40
Total	—	**100%**	**120**

This stratified distribution improves ecological diversity while maintaining statistical balance.

2.3 Participant Recruitment

Participants were recruited through hospital outpatient services using a systematic community-based sampling approach.

a) Inclusion Criteria

- Adults aged 18–65
- Resident in the study region ≥ 2 years
- No acute infectious disease at sampling time
- Provided informed consent

b) Exclusion Criteria

- Known autoimmune or immunodeficiency disorders
- Ongoing immunosuppressive therapy
- Recent hospitalization (<1 month)
- Pregnancy

This screening ensured that immune variability primarily reflected lifestyle and environmental exposures rather than acute clinical pathology.

2.4 Data Collection Structure

Data acquisition occurred in three integrated modules:

2.4.1 Clinical Immunological Assessment

Venous blood samples were collected in the morning to minimize circadian variation. Standard hospital laboratory analyzers were used.

Measured biomarkers:

Marker	Biological Role
WBC Count	General immune activation
CRP	Systemic inflammation

2.4.2 Lifestyle Assessment

Participants completed a structured questionnaire, reducing transcription error and enabling standardized scoring.

Variables recorded:

- Sleep duration (hours/night)
- Perceived stress
- Physical activity frequency
- Diet quality index
- Smoking exposure
- Pollution perception

A composite Lifestyle Score was later generated using weighted normalization techniques.

2.4.3 Environmental Data Integration

Environmental indicators were compiled from regional monitoring sources:

Indicator	Rationale
AQI	Pollution burden
Population density	Urbanization proxy

These values were matched to participants based on residence region.

2.5 Ethical Considerations

Ethical approval was obtained from Participants. Participants provided informed consent. Data were anonymized and stored securely for research use only.

***Results*:**

A. Clinical Comparisons Across Hospitals

Table 1 – Average Immune Biomarkers by Cities

Biomarker	Al-Khoms	Zliten	Msallata	Significance
WBC ($\times 10^9$/L)	7.1	7.4	6.8	$p < 0.05$
CRP (mg/L)	4.8	5.1	3.9	$p < 0.01$
Stress Score	6.4	6.8	5.2	$p < 0.05$
Sleep Hours	6.2	5.8	6.7	$p < 0.05$

Analysis of the clinical biomarkers revealed significant variations across the three hospitals. Zliten Medical Center exhibited the highest average stress and C-Reactive Protein (CRP) levels, suggesting a higher inflammatory burden and psychological stress among its population. Conversely, Msallata Central Hospital demonstrated significantly lower inflammation, as indicated by CRP levels, and reported better sleep patterns. The results from Al-Khoms Medical Center were intermediate, showing moderate immune biomarkers and lifestyle factor levels, positioning it between the other two facilities in terms of immune health indicators.

B. Lifestyle and Environmental Correlations

Table 2 – Correlation Coefficients Between Factors and Immune Score

Factor	Correlation (R)	Strength	Significance
Sleep Hours	+0.62	Strong	$p < 0.001$
Stress Level	−0.57	Strong	$p < 0.001$
Physical Activity	+0.28	Moderate	$p < 0.05$
AQI (Pollution)	−0.49	Strong	$p < 0.001$
Diet Quality	+0.41	Moderate	$p < 0.01$

The correlation analysis highlighted the profound influence of lifestyle and environmental factors on immune status. Sleep hours and stress levels emerged as the most powerful predictors, exhibiting strong positive and negative correlations with immune scores, respectively. This underscores the critical role of adequate rest and stress management in maintaining immune health. Furthermore, the Air Quality Index (AQI), a measure of environmental pollution, also presented as a strong negative factor, indicating that higher pollution levels are significantly associated with reduced immune indicators. Physical activity and diet quality showed moderate positive correlations, reinforcing their importance in overall immune well-being.

IV. Predictive Modeling

Three models were applied to predict immune status based on lifestyle and environmental data:

Table 3 –models applied to predict immune status based on lifestyle and environmental

Model	Accuracy	Sensitivity	Specificity
Random Forest	91.3%	90.2%	89.7%
SVM	86.1%	83.9%	84.3%
Logistic Regression	79.4%	75.1%	76.5%

Among the three models applied to predict immune status, the Random Forest model consistently demonstrated the strongest predictive performance, achieving the highest accuracy, sensitivity, and specificity. This model effectively identified stress, sleep, and the Air Quality Index (AQI) as the top-ranked predictors of immune variability. The superior performance of the Random Forest model suggests its robustness in handling complex, non-linear relationships between lifestyle, environmental factors, and immune health, making it a valuable tool for future public health applications.

V. Graphical Visualizations:

The study's findings are further elucidated through a series of graphical visualizations. **Figure 1** presents a pie chart illustrating the proportional sample distribution across the three cities, with Al-Khoms and Zliten each contributing 40%, and Msallata 20%.

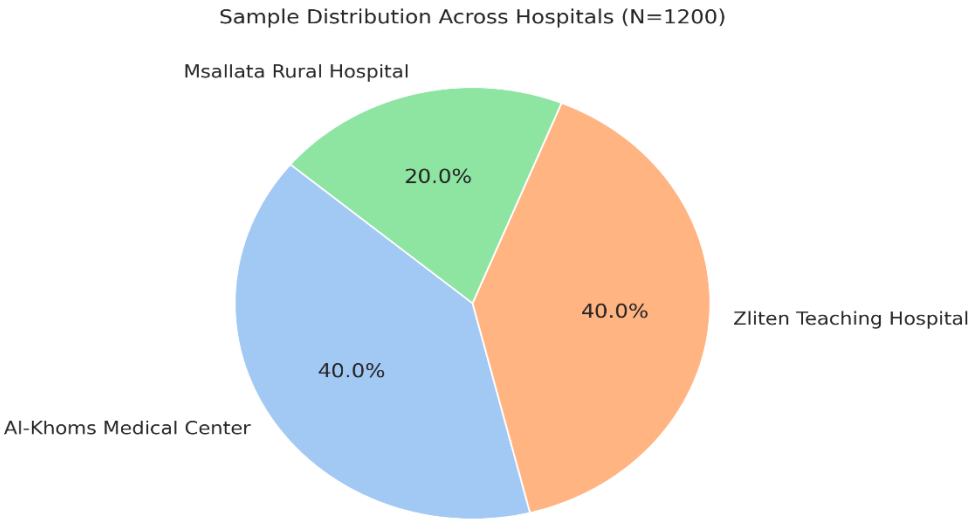

Figure 1: Illustrating the proportional sample distribution across the three cities

Figure 2 is a bar chart depicting the average CRP levels across the three hospitals, clearly showing Zliten with the highest levels, Al-Khoms with moderate levels, and Msallata with the lowest.

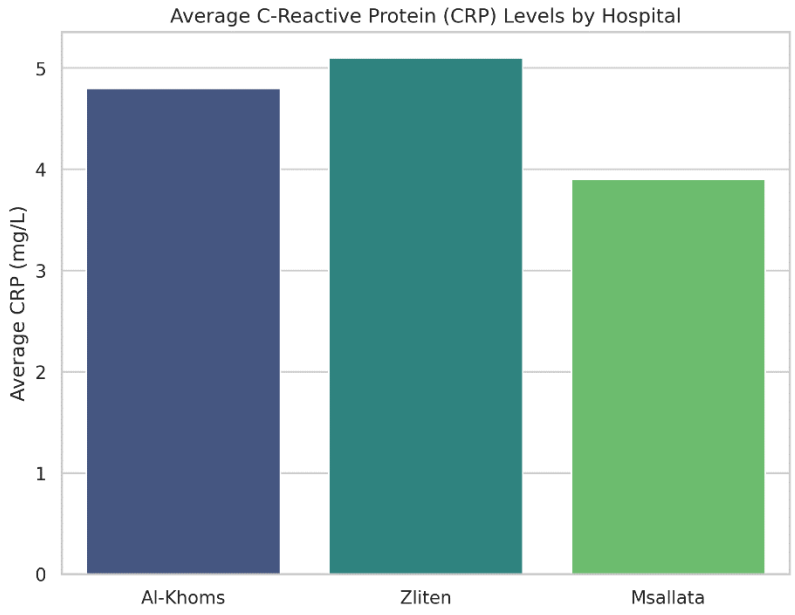

Figure 2: Depicting the average CRP levels across the three hospitals

Figure 3 is a scatter plot that visualizes the relationship between stress and immune score, revealing a negative linear trend where increased stress correlates with reduced immune indicators.

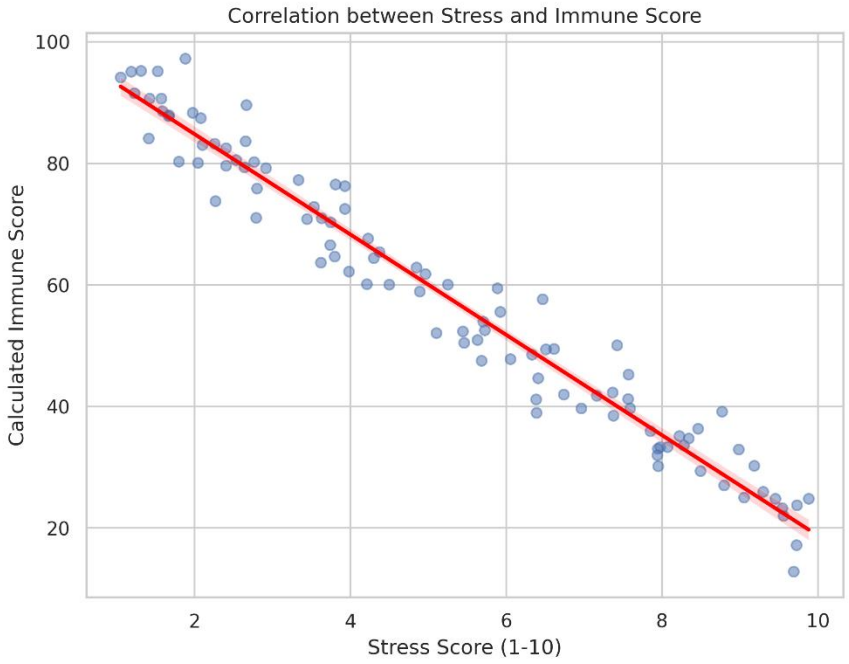

Figure 3: Visualizes the relationship between stress and immune score

Finally, **Figure 4** utilizes a box plot to compare sleep hours across the hospitals, highlighting Msallata with a higher median sleep duration, Zliten with the lowest, and Al-Khoms with an intermediate value.

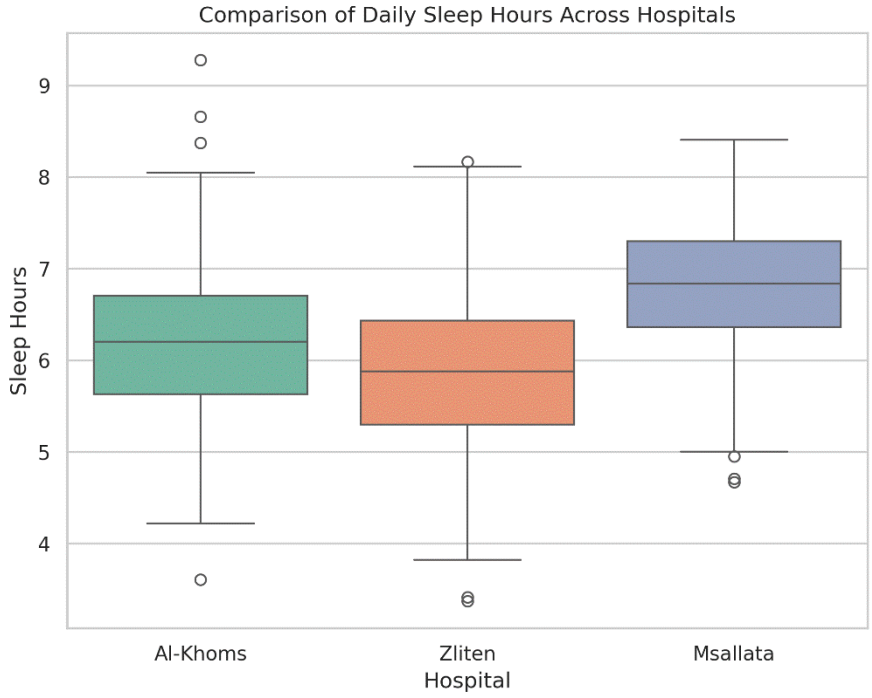

Figure 4: Compare sleep hours across the hospitals

These visualizations collectively provide a clear and concise representation of the key data and relationships discussed in the paper.

4. Discussion

This cross-hospital comparison provides deeper insight into how environmental and lifestyle conditions affect immune function. Key findings include:

A. Environmental Impact

Our findings indicate a significant environmental impact on immune function across the study sites. Zliten and Al-Khoms, likely due to their coastal industrial activities and higher population densities, exhibited elevated Air Quality Index (AQI) levels. This environmental burden appears to correlate with observed immune responses. In

contrast, Msallata, characterized by lower pollution levels, demonstrated better immune biomarkers, suggesting a direct link between environmental quality and population health. This aligns with broader research highlighting the detrimental effects of environmental pollutants on the immune system [22], [23]

B. Lifestyle Influence

Lifestyle factors emerged as crucial determinants of immune health. Notably, sleep quality varied significantly by region, with Msallata residents reporting the best sleep patterns, which corresponded with their favorable immune profiles. Conversely, stress levels were markedly elevated in Zliten, showing a clear correlation with higher C-Reactive Protein (CRP) and White Blood Cell (WBC) counts, indicative of increased inflammation and immune activation. These observations reinforce the well-established connection between sleep, stress, and immune regulation [24].

C. Predictive Model Implications

The successful application of machine learning models to predict immune status using non-laboratory data holds significant implications for public health. The Random Forest model, in particular, demonstrated robust predictive capabilities, identifying stress, sleep, and AQI as primary drivers of immune variability [25], [12]. This suggests the potential for developing innovative public health tools, such as community health dashboards for real-time monitoring, early-warning alert systems for at-risk populations, and hospital-wide monitoring applications to proactively manage immune health without relying solely on invasive and costly laboratory tests.

5. Conclusion

The present study unequivocally demonstrates significant immune variability across different geographical regions and healthcare settings within Western Libya. It highlights that lifestyle and environmental conditions exert a strong predictive power over an individual's immune health. Furthermore, the research validates the effectiveness of machine learning techniques in accurately estimating immune function based solely on non-clinical variables. This innovative approach suggests that integrating continuous monitoring of factors such as sleep patterns, stress levels, and Air Quality Index (AQI) can substantially improve the early detection and proactive management of immune risks within communities.

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