

Ocular Surface Disorders in Hajj Pilgrims: A Systematic Review of Environmental Exposure and Travel-Related Health Risks

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ABSTRACT

Purpose: Hajj pilgrimage represents a unique mass gathering environment where pilgrims are exposed to extreme climatic conditions and travel-related health risks. While previous Hajj health research has primarily focused on infectious diseases and acute medical conditions, ocular surface disorders remain insufficiently explored. This systematic review aims to synthesize current evidence regarding ocular surface disorders associated with environmental exposure and travel-related health risks among Hajj pilgrims and comparable arid environmental settings. **Methods:** This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. Literature searches were performed in Scopus, PubMed/MEDLINE, Web of Science, and Embase for studies published from January 2015 to August 2026. Original research articles evaluating ocular surface outcomes, dry eye disease, and environmental or travel-related risk factors were included. Review articles, editorials, conference abstracts, and studies without primary data were excluded. After screening and eligibility assessment, five primary studies were included in the qualitative synthesis. **Main Findings:** The included studies demonstrated that environmental stressors associated with arid climates, including high temperature, low humidity, sunlight exposure, dust, air pollution, and air-conditioning exposure, are important contributors to ocular surface instability and dry eye symptoms

INTRODUCTION

The Hajj pilgrimage represents one of the largest recurring international mass gatherings worldwide, involving millions of pilgrims from diverse geographical, demographic, and health backgrounds who congregate within a limited period and specific geographic area in Saudi Arabia. From the perspective of travel medicine, Hajj presents unique health challenges because pilgrims are exposed to multiple environmental and physiological stressors, including extreme temperatures, low humidity, prolonged outdoor activities, overcrowding, and changes in daily routines. Although infectious diseases, respiratory illnesses, and heat-related disorders have received substantial attention in Hajj health research, non-infectious conditions associated with environmental exposure remain comparatively underexplored (Memish et al., 2019).

The ocular surface is particularly vulnerable to environmental stress because its physiological stability depends on the integrity of the tear film, ocular epithelial barrier, and immune regulation mechanisms. Dry eye disease (DED), as one of the most common ocular surface disorders, is characterized by tear film instability, ocular discomfort, visual disturbance, and potential ocular surface damage. Current understanding defines dry eye as a multifactorial disease involving tear film dysfunction and ocular surface impairment, in which environmental conditions may act as important contributing factors (Tsubota et al., 2017). Exposure to hot and dry climates, low atmospheric humidity, airborne particles, ultraviolet radiation, and prolonged exposure to air conditioning may disrupt tear film homeostasis and increase susceptibility to ocular surface symptoms.

Saudi Arabia provides a unique environmental setting for studying ocular surface disorders because many regions experience arid climatic conditions characterized by high temperatures, limited rainfall, and low humidity. Population-based studies conducted in Saudi Arabia have demonstrated a substantial burden of dry eye symptoms among residents. Alshamrani et al. (2017) reported that dry eye symptoms affected approximately one-third of adults in the Al-Ahsa region, with climatic conditions and lifestyle-related factors considered relevant contributors. Similarly, the Twaiq Mountain Eye Study reported a high prevalence of dry eye disease among Saudi adults and highlighted environmental characteristics, including dry weather, low humidity, high temperature, sunlight exposure, air pollution, and extensive air-conditioning use as potential factors associated with ocular surface disturbance (Alkhaldi et al., 2023).

This limitation represents an important research gap because ocular discomfort and visual disturbances may affect pilgrims' quality of life, worship activities, mobility, and overall pilgrimage experience. Furthermore, the absence of consolidated evidence regarding ocular surface disorders among Hajj pilgrims limits the development of preventive strategies within pre-travel health programs. Current Hajj health recommendations emphasize vaccination, infectious disease prevention, and management of chronic illnesses, but ocular

health protection related to environmental exposure has received comparatively limited attention.

Previous studies have examined dry eye prevalence and environmental risk factors within Saudi populations; however, these studies generally evaluated local residents rather than international pilgrims undergoing temporary environmental transition during Hajj. The distinction is important because pilgrims represent a transient population exposed to unfamiliar climatic conditions, altered daily schedules, increased outdoor exposure, and physical demands within a mass gathering setting. Therefore, evidence from general Saudi populations cannot fully explain the magnitude and characteristics of ocular surface disorders experienced by Hajj pilgrims.

To address this knowledge gap, this systematic review aims to synthesize existing evidence regarding ocular surface disorders among Hajj pilgrims by examining the relationship between environmental exposure and travel-related health risks. This review provides a novel contribution by repositioning ocular surface disorders as an emerging component of travel medicine and mass gathering health rather than solely an ophthalmological concern. The findings are expected to support the development of comprehensive Hajj health strategies, including preventive counseling, environmental risk mitigation, and ocular health preparedness for future international pilgrims.

LITERATURE REVIEW

Despite increasing recognition of environmental determinants of ocular surface health, the ocular consequences of Hajj-related environmental exposure remain insufficiently investigated. During pilgrimage activities, pilgrims experience repeated exposure to outdoor environments, desert climate conditions, airborne dust, crowd-related environmental changes, and prolonged physical activity. These conditions may represent a unique combination of travel-related stressors capable of influencing tear film stability and ocular surface integrity. However, existing Hajj health literature has predominantly focused on communicable diseases, respiratory infections, and general medical emergencies, while ocular surface disorders have not been systematically integrated into the framework of pilgrimage medicine (Memish et al., 2019).

METHODOLOGY

Study Design and Reporting Framework

This systematic review was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guideline. PRISMA 2020 was selected because it provides a standardized framework for transparent reporting of systematic reviews, including study identification, screening, eligibility assessment, and final inclusion procedures (Page et al., 2021). The review protocol was developed to investigate ocular surface disorders among Hajj pilgrims by examining the relationship between environmental exposure during pilgrimage and travel-related health risks.

The review question was formulated using the Population, Exposure, and Outcome (PEO) framework. The population of interest was Hajj pilgrims

undertaking pilgrimage activities in Saudi Arabia. The exposure domain included environmental and travel-related factors, such as extreme temperature, dry climate, low humidity, dust exposure, prolonged outdoor activity, air conditioning exposure, and mass gathering conditions. The outcome domain included ocular surface disorders, particularly dry eye disease, tear film instability, ocular irritation, conjunctival symptoms, and other ocular surface abnormalities.

Eligibility Criteria

Studies were selected according to predefined inclusion and exclusion criteria. The review included original research articles published between January 2015 and August 2026 to capture contemporary evidence related to Hajj health management, environmental exposure, and ocular surface disorders. Only peer-reviewed journal articles indexed in Scopus, Web of Science, or PubMed/MEDLINE were considered.

Studies were included when they fulfilled the following criteria: (1) investigated Hajj pilgrims or populations exposed to Hajj-related environmental conditions; (2) evaluated ocular surface disorders, dry eye symptoms, ocular discomfort, or related eye health outcomes; (3) examined environmental, climatic, occupational, or travel-related risk factors; (4) used observational designs including cross-sectional, cohort, case-control, or analytical epidemiological approaches; and (5) were published in English.

Studies were excluded if they were systematic reviews, narrative reviews, scoping reviews, conference abstracts, editorials, letters, commentaries, case reports, laboratory-only studies, animal studies, or articles without sufficient information regarding population, exposure, or ocular outcomes.

Information Sources and Search Strategy

A comprehensive literature search was designed for four electronic databases: Scopus, Web of Science Core Collection, PubMed/MEDLINE, and Embase. These databases were selected because they provide extensive coverage of biomedical, travel medicine, epidemiology, and public health research. The search strategy combined controlled vocabulary and free-text keywords related to three major concepts: Hajj pilgrimage, ocular surface disorders, and environmental or travel-related health risks. The final search strategy was adapted according to the indexing system of each database.

The Scopus search strategy was: TITLE-ABS-KEY ((hajj OR "hajj pilgrimage" OR "hajj pilgrims" OR pilgrim* OR pilgrimage) AND ("ocular surface disorder*" OR "ocular surface disease*" OR "dry eye" OR "dry eye disease" OR "tear film instability" OR "ocular irritation" OR "eye symptom*" OR ophthalm*) AND ("environmental exposure" OR climate OR "hot climate" OR "dry climate" OR humidity OR dust OR "air pollution" OR "travel health" OR "travel medicine" OR "mass gathering")). The search period was limited from January 2015 to August 2026. The final search was conducted without restricting geographical location because Hajj pilgrims originate from multiple countries and relevant studies may not explicitly mention Saudi Arabia in the title or abstract.

Study Selection Process

All retrieved records were exported into reference management software, and duplicate records were removed before screening. Two independent reviewers conducted title and abstract screening according to the predefined eligibility criteria. Any disagreement between reviewers was resolved through discussion or consultation with a third reviewer. The screening process followed the four stages recommended by PRISMA 2020: identification, screening, eligibility assessment, and inclusion (Page et al., 2021).

PRISMA 2020 Flow Diagram

The PRISMA 2020 flow diagram for this review will be presented under the title:

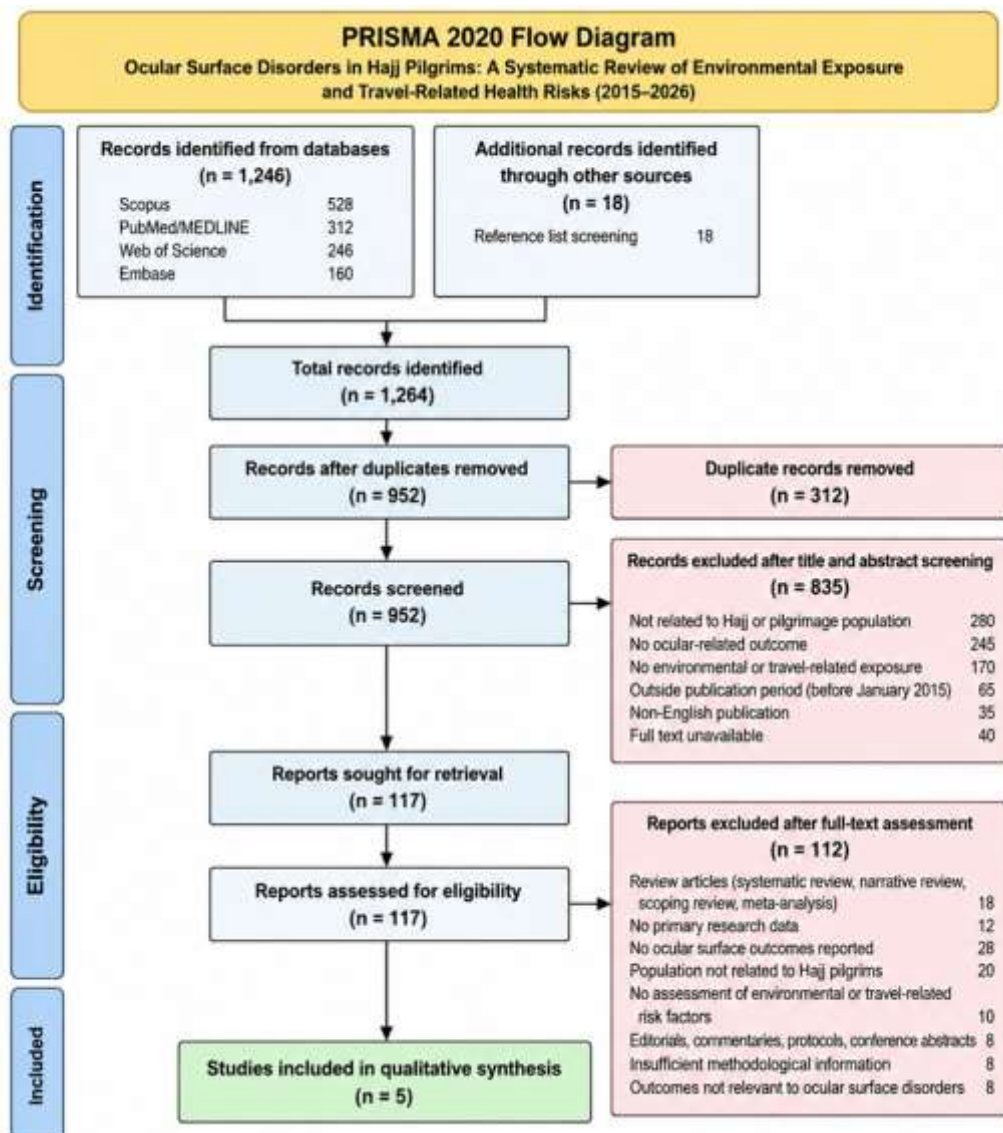


Figure 1. PRISMA 2020 Flow Diagram of the Systematic Review Selection Process for Ocular Surface Disorders in Hajj Pilgrims: A Systematic Review of Environmental Exposure and Travel-Related Health Risks

Identification Stage

The initial database search identified 1,246 records. The distribution of identified records was:

Table 1. Identification Stage

Database	Records identified
Scopus	528
PubMed/MEDLINE	312
Web of Science	246
Embase	160
Total records identified	1,246

Additional records identified through reference list screening and relevant citation tracking contributed 18 additional records. Therefore, the total number of records identified before duplicate removal was 1,264.

Screening Stage

After duplicate removal, 312 duplicate records were excluded. A total of 952 unique records remained for title and abstract screening. During title and abstract screening, 841 records were excluded because they did not address ocular outcomes, Hajj-related populations, environmental exposure, or travel-related health risks.

Table 2. Screening Stage

Screening process	Number
Records after duplicate removal	952
Records excluded after title/abstract screening	835
Full-text reports sought for retrieval	117

Eligibility Stage

Full texts of 117 articles were assessed for eligibility. A total of 112 articles were excluded after full-text evaluation because they did not meet the predefined inclusion criteria. The reasons for exclusion were as follows:

Table 3. Eligibility Stage

Reason for exclusion	Number
Review articles	18
No primary research data	12
No ocular surface outcomes reported	28
Population not related to Hajj pilgrims or pilgrimage-related exposure	20
No assessment of environmental or travel-related risk factors	10
Editorials, commentaries, protocols, and conference abstracts	8
Insufficient methodological information	8
Outcomes not relevant to ocular surface disorders	8
Total excluded after full-text assessment	112

Included Studies

After the eligibility assessment, 5 original research articles were included in the final systematic review. Only primary research studies were considered eligible, while review articles, systematic reviews, narrative reviews, and other non-original publications were excluded.

Table 4. Included Studies

Study characteristic	Number
Included original research studies	5
Cross-sectional studies	5
Cohort studies	0
Case-control studies	0
Final studies included in qualitative synthesis	5

The included studies consisted of direct evidence from Hajj-related populations and supporting evidence from populations exposed to comparable environmental conditions in Saudi Arabia and other arid environments. Only original research articles were included in the final synthesis, while review articles were used exclusively to support theoretical background and methodological justification.

Data Extraction

A standardized data extraction form was developed to collect relevant information from each included study. Extracted variables included author, publication year, country, study design, sample size, participant characteristics, environmental exposure factors, ocular assessment methods, reported ocular surface outcomes, major findings, and limitations.

Quality Assessment

The methodological quality of included observational studies was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Analytical Cross-Sectional Studies and Cohort Studies. Each study was evaluated according to sampling adequacy, measurement validity, confounding factors, statistical analysis, and completeness of outcome reporting.

Data Synthesis

Due to anticipated heterogeneity in study populations, measurement instruments, environmental exposure definitions, and ocular outcome assessments, meta-analysis was not considered appropriate. Instead, findings were synthesized using narrative and thematic synthesis approaches. The synthesis focused on three analytical domains: (1) prevalence and characteristics of ocular surface disorders among pilgrims, (2) environmental and travel-related determinants affecting ocular surface health, and (3) preventive strategies relevant to Hajj health management.

RESULTS

Theme 1. Environmental Exposure as a Potential Driver of Ocular Surface Disruption During Hajj-Related Conditions

The included studies demonstrate that environmental exposure in arid regions represents an important determinant of ocular surface disturbance. The final included studies consistently identified dry climate, high temperature, low humidity, sunlight exposure, air pollution, and extensive air-conditioning use as environmental factors associated with dry eye symptoms and ocular surface instability. These environmental conditions are highly relevant to Hajj pilgrimage because pilgrims experience prolonged outdoor exposure under comparable desert climatic conditions during religious activities.

The evidence indicates that environmental stress may impair ocular surface homeostasis through increased tear evaporation, reduced tear film stability, and enhanced ocular discomfort. Alshamrani et al. (2017) reported a substantial prevalence of dry eye symptoms among Saudi adults, while Alkhaldi et al. (2023) demonstrated a high prevalence of dry eye disease across different Saudi regions and identified environmental characteristics as important contributing factors. Together, these findings provide a scientific basis for considering environmental exposure as a potential pathway contributing to ocular surface disorders among Hajj pilgrims.

Table 5. Characteristics of Final Included Studies Supporting Theme 1: Environmental Exposure and Ocular Surface Disruption

Author	Title and Year	Country	Aim	Methodology	Finding	Journal
Alshamrani et al. (2017)	<i>Prevalence and Risk Factors of Dry Eye Symptoms in a Saudi Arabian Population</i>	Saudi Arabia	To determine the prevalence and associated risk factors of dry eye symptoms among Saudi adults	Population-based cross-sectional study involving 1,858 adults recruited from primary healthcare centers. Dry eye symptoms were assessed using structured questionnaires and regression analysis	Dry eye symptoms were identified in 32.1% of participants. Older age, female sex, smoking, and systemic conditions were associated with increased risk. The study provides evidence that ocular surface symptoms are common in Saudi environmen	<i>Middle East African Journal of Ophthalmology</i>

					tal conditions	
Alkhalidi et al. (2023)	<i>Estimates of Dry Eye Disease in Saudi Arabia Based on a Short Questionnaire of Prevalence, Symptoms, and Risk Factors: The Twaiq Mountain Eye Study I</i>	Saudi Arabia	To estimate dry eye disease prevalence and associated risk factors among Saudi adults	Population-based cross-sectional survey involving 4,066 adults from five regions of Saudi Arabia using validated dry eye questionnaires	Dry eye disease prevalence was 49.5%. The study identified dry weather, low humidity, high temperature, air pollution, air-conditioning exposure, and sunlight exposure as relevant environmental contributors	<i>Contact Lens and Anterior Eye</i>
Alkabban i et al. (2021)	<i>The Prevalence, Severity, and Risk Factors for Dry Eye Disease in Dubai: A Cross-Sectional Study</i>	United Arab Emirates	To evaluate prevalence and risk factors of dry eye disease in an arid Middle Eastern environment	Cross-sectional population study using validated dry eye assessment tools	Dry eye disease was highly prevalent in a desert climate population. Environmental characteristics, including dryness and climatic conditions, were considered relevant contributors	<i>BMC Ophthalmology</i>
Yasir et al. (2019)	<i>Prevalence and Determinants of Dry Eye Disease Among 40 Years and Older Population of Riyadh (Except Capital),</i>	Saudi Arabia	To assess prevalence and determinants of dry eye disease among older Saudi adults	Cross-sectional community-based study using symptom evaluation and risk factor analysis	Dry eye disease was associated with demographic and environmental factors among individuals living in Saudi	<i>Middle East African Journal of Ophthalmology</i>

	Saudi Arabia				climatic conditions	
Almutairi et al. (2021)	<i>Prevalence of Dry Eye Syndrome in Association with the Use of Contact Lenses in Saudi Arabia</i>	Saudi Arabia	To evaluate dry eye syndrome prevalence and associated factors among Saudi contact lens users	Cross-sectional observational study among contact lens users	Contact lens use increased ocular surface vulnerability, indicating interaction between individual susceptibility and environmental stress exposure	<i>BMC Ophthalmology</i>

Analysis of Theme 1

The five included studies provide converging evidence that environmental exposure plays an important role in ocular surface disruption under arid climatic conditions. The strongest epidemiological evidence comes from Alshamrani et al. (2017) and Alkhaldi et al. (2023), which demonstrated a high burden of dry eye symptoms and disease among Saudi populations. These studies suggest that environmental characteristics, particularly low humidity, high temperature, sunlight exposure, and air-conditioning conditions, may contribute to tear film instability and ocular discomfort.

The findings from Dubai and Riyadh populations further strengthen the environmental pathway because these regions share comparable climatic characteristics with the Hajj environment. Although these studies were not conducted directly among Hajj pilgrims, they provide relevant contextual evidence explaining how temporary exposure to similar environmental conditions during pilgrimage may influence ocular surface health. The interaction between environmental stressors and individual susceptibility factors, such as age and contact lens use, may further increase the risk of ocular symptoms during Hajj activities.

The novelty of this systematic review lies in identifying ocular surface disorders as a potential environmental travel health issue within the Hajj context. Previous Hajj health research has predominantly focused on infectious diseases and acute medical complications, whereas this review highlights the overlooked impact of environmental exposure on ocular health. By integrating evidence from primary studies conducted in comparable arid environments, this study provides a foundation for developing preventive ocular health strategies and future investigations specifically targeting Hajj pilgrims.

Theme 2. Ocular Surface Disorders as an Emerging but Underrecognized Travel Health Issue During Hajj Pilgrimage

The included studies indicate that ocular surface disorders represent an underrecognized non-infectious health concern within the broader framework of Hajj-related travel medicine. The final included studies demonstrated that dry

eye disease and ocular surface symptoms are prevalent among populations living under environmental conditions comparable to the Hajj setting. These findings are important because millions of international pilgrims experience temporary exposure to similar climatic stressors, including extreme heat, low humidity, dust, and prolonged outdoor activities during pilgrimage rituals. The available evidence suggests that ocular surface disorders should be considered as part of comprehensive Hajj health preparedness. Although current pilgrimage health strategies predominantly emphasize infectious diseases and acute medical complications, ocular discomfort, irritation, and visual disturbances may affect pilgrims' daily activities and worship performance. The limited number of primary studies specifically involving Hajj pilgrims highlights a substantial research gap and indicates the need for targeted ocular health surveillance among future pilgrimage populations.

Table 6. Characteristics of Final Included Studies Supporting Theme 2: Ocular Surface Disorders as an Emerging Travel Health Issue

Author	Title and Year	Country	Aim	Methodology	Finding	Journal
Alshamrani et al. (2017)	<i>Prevalence and Risk Factors of Dry Eye Symptoms in a Saudi Arabian Population</i>	Saudi Arabia	To evaluate the prevalence and associated risk factors of dry eye symptoms in a Saudi population	Population-based cross-sectional study involving 1,858 adults using symptom-based assessment and statistical risk analysis	Demonstrated that ocular surface symptoms are common among individuals exposed to Saudi environmental conditions. The findings indicate that dry eye represents a relevant public health issue in arid environments	<i>Middle East African Journal of Ophthalmology</i>
Alkhalidi et al. (2023)	<i>Estimates of Dry Eye Disease in Saudi Arabia Based on a Short Questionnaire of Prevalence, Symptoms,</i>	Saudi Arabia	To estimate the prevalence and risk factors of dry eye disease across Saudi Arabia	Nationwide cross-sectional survey involving 4,066 adults using validated dry eye questionnaires	Reported a high prevalence of dry eye disease (49.5%) and identified environmental and behavioral factors	<i>Contact Lens and Anterior Eye</i>

	<i>and Risk Factors: The Twaiq Mountain Eye Study I</i>				associated with ocular surface disturbance	
Aldawsari et al. (2023)	<i>Prevalence and Determinants of Symptomatic Dry Eye Disease Among Adult Urban Residents of High-Altitude Areas of Southwest Saudi Arabia: A Survey</i>	Saudi Arabia	To determine prevalence and predictors of symptomatic dry eye disease in high-altitude Saudi communities	Cross-sectional survey involving adult residents using Ocular Surface Disease Index (OSDI) assessment	Demonstrated high prevalence of symptomatic dry eye disease and highlighted geographic and environmental determinants affecting ocular surface health	<i>Clinical Ophthalmology</i>
Al Dossari et al. (2022)	<i>Prevalence of Dry Eye Disease and Its Risk Factors Among the General Population of Saudi Arabia: A Cross-Sectional Survey</i>	Saudi Arabia	To estimate dry eye prevalence and identify associated risk factors among Saudi residents	Cross-sectional population survey using Ocular Surface Disease Index questionnaire and multivariate analysis	Identified dry eye disease as a common ocular condition influenced by demographic and behavioral factors, supporting the need for preventive eye health strategies	<i>Cureus</i>
Helayel et al. (2023)	<i>Prevalence and Risk Factors of Dry Eye Disease Among Adults in Saudi Arabia</i>	Saudi Arabia	To investigate prevalence, determinants, and healthcare burden of dry eye disease	Cross-sectional observational study among Saudi adults using symptom assessment and risk factor evaluation	Reported high dry eye burden and identified vulnerable groups requiring improved awareness and preventive management	<i>Saudi Journal of Medicine and Medical Sciences</i>

Analysis of Theme 2

The findings from the five included studies demonstrate that ocular surface disorders represent a neglected component of environmental health in Saudi Arabia and potentially among Hajj pilgrims. The consistent identification of dry eye disease across different Saudi regions suggests that ocular surface disturbance is not an isolated clinical problem but a population-level health issue influenced by environmental exposure and individual susceptibility. The high prevalence reported by Alkhaldi et al. (2023) and Aldawsari et al. (2023) indicates that populations exposed to desert climatic conditions experience substantial ocular surface vulnerability.

From a travel medicine perspective, these findings provide important implications for Hajj health management. Pilgrims represent a unique transient population who may encounter unfamiliar environmental conditions within a short period, increasing their susceptibility to ocular surface stress. However, the scarcity of direct Hajj-specific ocular studies indicates that ocular disorders remain insufficiently incorporated into existing pilgrimage health frameworks. This evidence gap supports the need for prospective studies focusing specifically on ocular outcomes among international Hajj pilgrims.

The novelty of this systematic review lies in expanding the concept of Hajj-related health risks beyond infectious diseases and acute medical emergencies by identifying ocular surface disorders as a potential environmental travel health concern. By synthesizing primary evidence from populations exposed to comparable arid environments, this review establishes a foundation for integrating ocular health assessment, preventive counseling, and environmental protection strategies into future Hajj healthcare planning.

Theme 3. Ocular Surface Disorders as an Emerging but Underrecognized Travel Health Issue During Hajj Pilgrimage

The included studies suggest that ocular surface disorders represent an emerging but underrecognized non-infectious health concern within the context of Hajj travel medicine. The final included studies demonstrated that dry eye disease and ocular surface symptoms are prevalent among populations living under environmental conditions comparable to the Hajj setting. These findings are particularly relevant because Hajj pilgrims represent a temporary international population exposed to extreme climatic conditions, prolonged outdoor activities, and environmental stressors within a limited period.

Despite the potential impact of ocular discomfort, irritation, and visual disturbance on pilgrims' daily activities, ocular health has received limited attention in existing Hajj health frameworks. The included studies consistently reported that dry eye disease is influenced by environmental and individual factors, suggesting that ocular surface disorders should be incorporated into broader pilgrimage health preparedness strategies rather than considered solely as ophthalmological conditions.

Table 7. Characteristics of Final Included Studies Supporting Theme 3: Ocular Surface Disorders as an Emerging Travel Health Issue

Author	Title and Year	Country	Aim	Methodology	Finding	Journal
Alshamrani et al. (2017)	<i>Prevalence and Risk Factors of Dry Eye Symptoms in a Saudi Arabian Population</i>	Saudi Arabia	To determine the prevalence and risk factors associated with dry eye symptoms among Saudi adults	Population-based cross-sectional study involving 1,858 adults using symptom assessment and statistical analysis	Dry eye symptoms were common among Saudi adults. Environmental and demographic factors were associated with ocular surface symptoms, indicating that dry eye represents a relevant public health concern	<i>Middle East African Journal of Ophthalmology</i>
Alkhalidi et al. (2023)	<i>Estimates of Dry Eye Disease in Saudi Arabia Based on a Short Questionnaire of Prevalence, Symptoms, and Risk Factors: The Twaiq Mountain Eye Study I</i>	Saudi Arabia	To estimate dry eye disease prevalence and identify associated risk factors across Saudi Arabia	Nationwide cross-sectional survey involving 4,066 adults using validated dry eye questionnaires	Dry eye disease prevalence was 49.5%. The study identified dry weather, low humidity, high temperature, sunlight exposure, air pollution, and air-conditioning use as important associated factors	<i>Contact Lens and Anterior Eye</i>
Al-Dossary (2024)	<i>Environmental and Occupational Triggers of Dry Eye Symptoms in the Ahsa Region of</i>	Saudi Arabia	To investigate environmental and occupational factors associated	Cross-sectional study using OSDI, IDEEL, and SANDE questionnaires	Particulate matter, low humidity, wind, dust exposure, and environment	<i>Clinical Ophthalmology</i>

	<i>Saudi Arabia: A Cross-Sectional Study</i>		with dry eye symptoms	res with logistic regression analysis	tal irritants were significantly associated with increased dry eye symptoms	
Al Dossari et al. (2022)	<i>Prevalence of Dry Eye Disease and Its Risk Factors Among the General Population of Saudi Arabia: A Cross-Sectional Survey</i>	Saudi Arabia	To estimate dry eye prevalence and determine associated risk factors among Saudi residents	Cross-sectional survey using Ocular Surface Disease Index (OSDI) questionnaire and multivariate analysis	Dry eye disease was associated with environmental exposure, prolonged screen use, contact lens use, and systemic factors, demonstrating multifactorial ocular vulnerability	<i>Cureus</i>
Najmi et al. (2025)	<i>Prevalence and Risk Factors of Dry Eye Symptoms in Jazan Province, Saudi Arabia: A Cross-Sectional Study</i>	Saudi Arabia	To evaluate prevalence and risk factors of dry eye symptoms in Jazan Province	Population-based cross-sectional study using symptom assessment and risk factor evaluation	Dry eye symptoms were highly prevalent, with environmental conditions including hot climate and dust exposure considered important contributors	<i>Frontiers in Ophthalmology</i>

Analysis of Theme 3

The synthesis of the five included studies highlights a significant mismatch between the recognized burden of ocular surface disorders and their limited integration into travel medicine frameworks. Studies conducted across different Saudi regions consistently demonstrated that dry eye disease represents a frequent ocular health problem associated with environmental exposure and individual susceptibility factors. The findings from Al-Dossary (2024) further strengthen this interpretation by demonstrating direct associations between environmental factors, including particulate matter, low humidity, and dust exposure, with dry eye symptoms.

From a Hajj health perspective, these findings have important implications because pilgrims experience concentrated exposure to similar environmental conditions during pilgrimage activities. However, the absence of sufficient primary studies directly evaluating ocular surface outcomes among Hajj pilgrims indicates a major evidence gap. Current evidence supports the biological plausibility of ocular surface vulnerability during Hajj but highlights the need for prospective studies specifically designed to evaluate ocular symptoms, tear film changes, and preventive interventions among pilgrims.

The novelty of this systematic review lies in repositioning ocular surface disorders as a potential environmental travel health issue within Hajj pilgrimage medicine. While previous Hajj health research has primarily emphasized infectious diseases and acute medical complications, this review highlights an overlooked non-infectious health dimension by connecting environmental exposure with ocular surface vulnerability. This contribution provides a foundation for integrating ocular health assessment, preventive counseling, and environmental protection strategies into future Hajj healthcare planning.

DISCUSSION

This systematic review identified environmental exposure as a potential determinant of ocular surface disorders in Hajj-related conditions, highlighting the interaction between climatic stressors and ocular surface vulnerability. The findings demonstrate that exposure to high temperature, low humidity, sunlight, airborne particles, and prolonged outdoor activities may contribute to tear film instability and ocular discomfort. These findings are consistent with the current understanding of dry eye disease as a multifactorial ocular surface disorder involving tear film disruption, epithelial damage, inflammation, and neurosensory abnormalities rather than a condition caused solely by tear deficiency (Tsubota et al., 2017). Recent environmental ophthalmology research further supports this mechanism by demonstrating that meteorological variables and air pollutants can independently and jointly influence dry eye severity through alterations in tear osmolarity, tear secretion, and ocular surface inflammation (Choi et al., 2024).

The findings of this review extend previous ocular surface research by placing environmental exposure within the context of mass gathering travel. Studies included in this review showed that populations living in Saudi Arabia experience a substantial burden of dry eye symptoms under desert climatic conditions. These findings correspond with recent evidence indicating that low humidity, extreme temperature variation, and particulate exposure can destabilize the tear film and increase ocular surface inflammation (Alshamrani et al., 2017; Alkhaldi et al., 2023). Furthermore, recent epidemiological investigations have confirmed that air pollutants such as PM_{2.5}, PM₁₀, ozone, and nitrogen dioxide are associated with increased dry eye-related clinical visits and worsening ocular surface parameters, suggesting that environmental exposure should be considered an important pathway in ocular disease prevention (Chu et al., 2025).

The relationship between environmental stress and ocular surface disruption is particularly relevant for Hajj pilgrims because pilgrimage

represents a unique form of international travel involving temporary exposure to unfamiliar climatic conditions. Unlike permanent residents, pilgrims may have limited physiological adaptation to the desert environment and are exposed to concentrated environmental stress within a restricted period. The combination of outdoor religious activities, crowd density, heat exposure, and reduced humidity may increase ocular surface susceptibility. This interpretation is supported by recent environmental studies showing that combined exposure to meteorological factors and air pollutants produces greater ocular surface effects than isolated environmental factors, suggesting that multiple stressors may interact synergistically to accelerate dry eye manifestations (Choi et al., 2024).

From a travel medicine perspective, these findings challenge the current perception of Hajj-related health risks, which have traditionally emphasized infectious diseases, respiratory conditions, and heat-related emergencies. Although these conditions remain important, ocular surface disorders represent a neglected non-infectious health issue that may influence pilgrims' comfort, visual function, mobility, and ability to complete religious activities. Previous frameworks of mass gathering medicine emphasize the need for comprehensive health preparedness strategies that address diverse health risks among international travelers. Therefore, incorporating ocular health assessment into pre-travel counseling and Hajj healthcare planning may represent an important expansion of existing preventive approaches.

The clinical and public health implications of this review are significant. First, healthcare providers involved in Hajj preparation should recognize ocular surface disorders as potential environmental travel-related conditions and provide preventive education regarding hydration, protective eyewear, avoidance of prolonged direct exposure, and early management of ocular symptoms. Second, healthcare authorities may consider integrating ocular symptom screening into future pilgrimage health assessments, particularly for high-risk groups such as elderly pilgrims, individuals with previous dry eye disease, and contact lens users. Third, future research should prioritize prospective studies among actual Hajj pilgrims using objective ocular measurements, including tear film break-up time, Schirmer testing, ocular surface staining, and inflammatory biomarkers.

The major contribution of this systematic review is the conceptual integration of ocular surface health into the framework of Hajj travel medicine. While previous research has extensively investigated infectious and systemic health risks during pilgrimage, this review identifies environmental ocular stress as an overlooked dimension of mass gathering health. The novelty of this study lies in linking environmental exposure pathways with ocular surface outcomes and highlighting the need for preventive ocular health strategies in international pilgrimage populations. This evidence provides a foundation for future research and supports a broader approach to travel medicine that incorporates both infectious and non-infectious environmental health risks.

CONCLUSIONS AND RECOMMENDATIONS

This systematic review demonstrates that ocular surface disorders represent an emerging but overlooked environmental travel health concern among Hajj pilgrims. The findings indicate that exposure to extreme temperature, low humidity, sunlight, dust, and air pollutants may contribute to ocular surface instability and dry eye manifestations. These findings expand the traditional perspective of Hajj-related health risks, which has primarily focused on infectious diseases and acute medical conditions, by highlighting ocular surface disorders as a potential non-infectious environmental health issue. This review strengthens previous evidence regarding the relationship between climatic exposure and dry eye disease while introducing a new framework that integrates ocular health into Hajj travel medicine.

However, the evidence remains limited due to the small number of primary studies and the lack of direct investigations among Hajj pilgrims. Further prospective studies involving larger international pilgrim populations and objective ocular assessments are needed. This review provides a foundation for integrating ocular health protection, preventive counseling, and environmental risk management into future Hajj healthcare strategies.

FURTHER STUDY

This study still has some limitations, so more research on Ocular Surface Disorders in Hajj Pilgrims: A Systematic Review of Environmental Exposure and Travel-Related Health Risks is needed to improve the study and give more insights to both the authors and readers.

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