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Review Article

Abstruse Side of Climate Change, Impact on Malaria: A Systematic Evidence Review Comparing Iran versus Globally

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Abstract

Background: Infectious outbreaks due to disrupted social and environmental conditions after climate change-induced events complicate disasters. This research aimed to determine the contentions of bioclimatic variables and extreme events on the prevalence of the most common Climate-Sensitive Infectious Disease (CSID); Malaria in Iran.

Methods: The present narrative systematic review study was conducted on the bioclimatic variable impact on the prevalence of malaria, as a common CSID. The search was conducted in 3 sections: global climate change-related studies, disaster related, and studies that were conducted in Iran. The literature search was focused on papers published in English and Persian from Mar 2000 to Dec 2021, using electronic databases; Scopus, Web of Science, PubMed, Google Scholar, SID, Magiran, and IranDoc.

Results: Overall, 41 studies met the inclusion criteria. The various types of climatic variables including; Temperature, rainfall, relative humidity, and hydrological events including; flood, drought, and cyclones has been reported as a predictor of malaria. The results of studies, inappropriately and often were inconsistent in both Iran and other parts of the world.

Conclusion: Identifying malaria outbreak risks is essential to assess vulnerability, and a starting point to identify where the health system is required to reduce the vulnerability and exposure of the population. The finding of most related studies is not congruent to achieve reliable information, more extensive studies in all climates and regions of the country, by climatic models and high accuracy risk map, using the long period of bioclimatic variables and malaria trend is recommended.

Keywords: Climate change; Natural disasters; Re-emerging diseases; Vector-borne disease; Malaria

Introduction

Climate change refers to "the long-term statistical changes in weather such as a change in the average weather conditions or the distribution of weather conditions around the average of long-term weather (for example, the extreme weather events" (1). Climatological disasters and extreme events are increasing in frequency and intensity while getting complicated by the outbreak of infectious diseases (2). Emerging Infectious diseases due to changes in geographic ranges and genetic change in the microorganisms is the unpleasant gift of climate change to human health (3). Climate change also increases the risk of emerging and re-emerging diseases by the spread of infectious diseases in areas that were previously disease-free or disease-controlled (4, 5). Re-emerging infectious diseases such as malaria is a potential global health emergency, endangered human health for many years (6).

Climate Change and Malaria

Malaria is a protozoan infection transmitted by mosquitoes of the genus *Anopheles*. The four common species of *Plasmodium* that infect humans appear to have evolved from a common ancestor during the early Tertiary period, some 60 million years ago (7). Malaria is considered one of the main CSID, meaning that Anopheles mosquitoes are sensitive to climatic conditions (8). Climate change is predicted to increase malaria to 1.6 million by 2030 and 1.8 million by 2050 and remains a health problem still in some parts of the world (9). There is evidence that shows the regional genetic structure of the Anopheles mosquito has changed due to extended drought periods and has the ability to adapt to severe climatic conditions (10). About 3.3 billion people worldwide are exposed to malaria each year (11). An increase in malaria cases was reported four to five times over non-disaster periods after the flood disasters (12).

Climate Change and Malaria in IRAN

Iran is located in West Asia and more than 80% of Iran is located in the arid and semi-arid region and has been strongly influenced by climate change (13). More than half of its region is at risk of floods (14), and it is estimated that the intensity of flash floods will increase in the future (15, 16). In 2019, during one month, 20 provinces of the country were affected by large and destructive floods and 19 infectious epidemics were reported (17). In such cases, the conditions for the transmission of vector-borne diseases and the risk of infectious outbreaks Increase dangerously (18). Re-emerging diseases such as water and vector-borne disease are considered important health problems in Iran (19, 20). Identifying malaria outbreak risks are essential to assess population vulnerability, and a starting point to identify where the health system is required to reduce the vulnerability and exposure of the population (9). There have been many studies around the world on the impact of climate change on malaria; however, there is a wide uncertainty among the findings.

We aimed to evaluate the impact of climate change-induced disasters on the outbreak of malaria.

Materials and Methods

To conduct the premium rigor and trustworthiness, planning and documentation of a methodical approach based on the PRISMA-P checklist for Explanation and Elaboration of finding were done in the drafting and appraising stage of the study (21).

Search strategy

Literature search strategies were developed using medical subject headings (MeSH) and text words related to climate change and malaria. In the initial search of all English and Persian articles published from Jan 2001 to Jun 2022 in Web of Science, PubMed, Scopus, and Google scholar databases in English and SID, IranMedex and Magiran in Persian, were searched. To find related articles, the keywords and related Mesh Terms were used in building the Search Strategy.

Study protocol

All stages of research, including search, selection of articles, quality assessment, and data extraction were performed independently by two researchers. Data extraction was performed using the identical extraction form. The extracted information included first author, year of publication, Study location, Study Design, bioclimatic variable, Main Conclusion, and controversies.

Quality assessment

The quality of the articles was assessed using the STROBE checklist. For quality assessment or evaluation of the papers, the Strengthening the Reporting of Observational Studies in Epidemiology checklist was applied (22). The quality of documents for findings were assessed for risk of bias, consistency, and accuracy, using the Grading of Recommendations Assessment, Development, and Evaluation working group methodology.

Screening and Data extraction

By searching databases, 3482 (English database (n=3461) and Persian database (n=21)) studies were extracted. After the initial review, 984 articles were removed from the study due to duplication. Then, by reviewing the titles and abstracts of articles, 2186 articles were excluded because of irrelevant titles and investigating health components. Overall, 312 full-text articles assessed for eligibility and 271 article omitted in this stage (Not investigated the climate variables or disasters (n=80), Not related or focused on malaria (n=131), Articles not closely related to aim of this study (n=46), and finding is irrelevant (n=14)). Finally, 41 articles with all inclusion criteria were included in the review (Fig. 1).

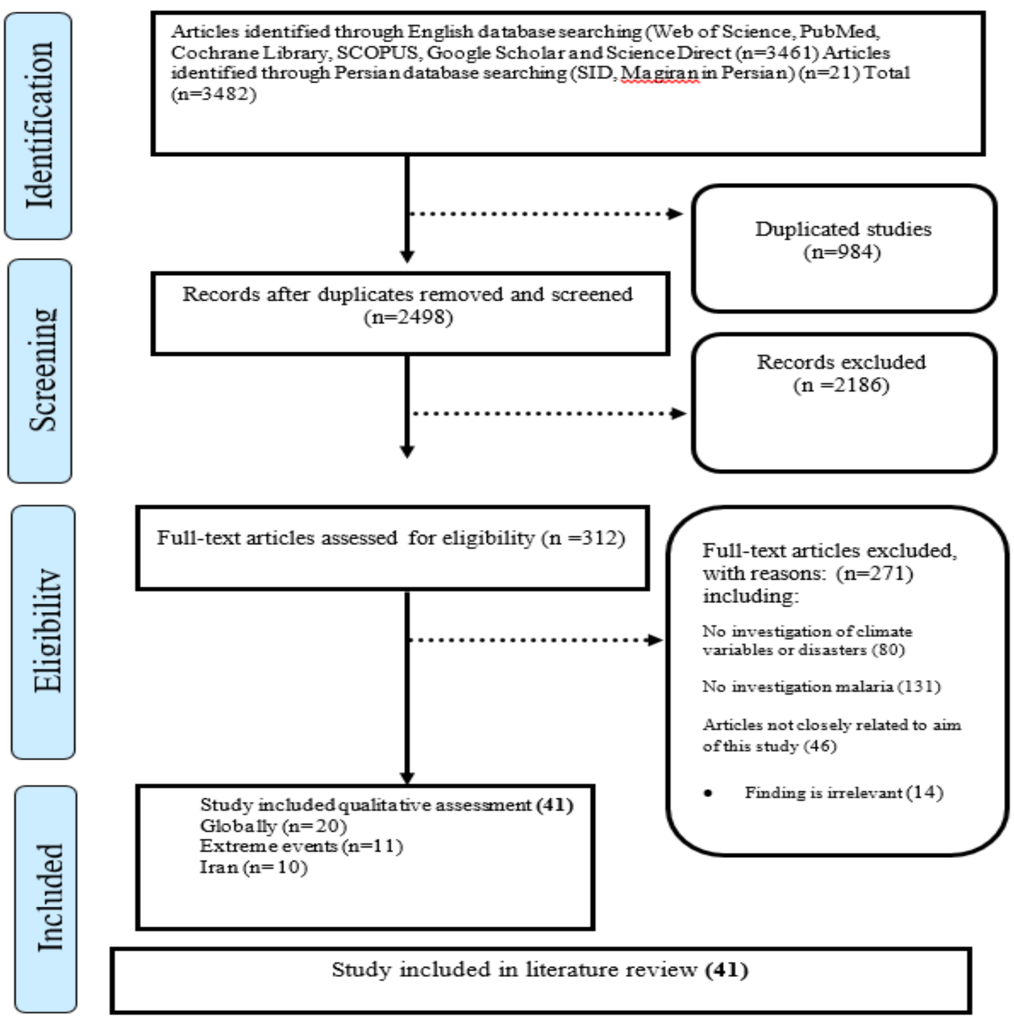

Fig. 1: PRISMA flowchart of the study selection process

Results

As shown in Tables 1, 2, and 3, to enhance comprehension, the study variables have been divided into three tables, which include climate variables (temperature and precipitation), worldwide disasters (flood, cyclone, drought, and earthquake), and research that has been conducted in Iran. The extracted articles were categorized by publication date, study area, climate variables, or extreme events, study design, findings, and controversy.

Forty-one relevant studies were considered in this study. Climatic variables including annual precipitation, drought, flooding, and higher temperatures are factors that can influence malaria transmission. Moreover, the reviewed studies have reported the relationship between malaria cases and disasters, including earthquakes, droughts, floods, and cyclones. Considering that each of the selected articles in this study has investigated one or more specific variables, therefore, the analysis of the studied variables was done separately and then the results were compared.

Table 1: General characteristics of the articles studied for climate change -related Malaria that were eligible for review

Study year	*Study location*	*Study Design*	*bioclimatic variable*	*Main Conclusion*	*Controversies*
Endo 2017 (23)	Africa	Combined modelling and observational study	Temperature	Increased temperature causes an increase in Malaria incidence in highlands regions, In the Sahel fringes; the temperature increase is not likely to exacerbate the malaria burden.	Dry conditions limit malaria transmission in the Sahel fringes.
Gunda 2017 (24)	Zimbabwe	Descriptive study surveys, Retrospective data analysis	Temperature	Preceding 1–4 months of change in temperature and precipitation is correlated with malaria incidence. The minimum temperature is significantly associated with malaria incidence at 1- and 2-month lag periods. Malaria incidence is significantly associated with precipitation at a 1-month lag period.	The minimum temperature is an influential climatic variable for malaria transmission.
Le PV 2019 (25)	Kenya	Descriptive study: surveys (cross-sectional) study	Temperature, Precipitation	An increase in soil moisture and decrease in air temperature causes an increase in malaria transmission.	Dry conditions limit malaria transmission.
Ferrao 2017 (26)	Mozambique	Time series analysis	Temperature, Precipitation	The mean temperature is a significant predictor of Malaria occurrence. Malaria occurrence has a strong association with rainfall six to eight weeks before.	Temperatures above 30 °C and below 16 °C have a negative impact on parasite development.
Williams 2010 (27)	Kenya	Descriptive	Temperature	The number of malaria cases has gone up with the increase in temperature in the highlands	-
Kipruto 2017 (28)	Kenya	Descriptive study, time series analysis	Temperature, Precipitation	Rainfall at a time lag of 2 months increased Malaria transmission and an increase in temperature at time lags of 0 and 1 month resulted in an increase in malaria cases in the riverine and highland zones.	-
Tompkins 2016 (29)	Uganda	Descriptive study: surveys (cross-sectional) study	Temperature, Precipitation	An increase in temperature and precipitation rate led to an increase in the prevalence of malaria.	-
Kim 2019 (30)	South Korea	Descriptive study: surveys (cross-sectional) study	Temperature, Precipitation	Climate change increases the prevalence of malaria	-
Kibret 2016 (31)	Sub-Saharan Africa	Descriptive Analytic study	Temperature	Climate change and the construction of large dams cause an increase in malaria in future.	Distance to water reservoirs is a risk factor and will Increase the cases of malaria in future.
Ssempiira 2018 (32)	Uganda	Descriptive observational study	Temperature, Precipitation	Altitude and distance to water bodies were negatively related to malaria incidence. A positive association observed between malaria incidence and day land surface temperature, rainfall.	Altitude and distance to water bodies are negatively related to malaria incidence.

Table 1: Continued …

Rouamba 2019 (33)	Burkina Faso	Descriptive observational Analytic study	Temperature, Precipitation	Rainfall and temperature were positively and significantly associated with malaria incidence, with a lag time of 9 and 14 wk.	Temperature is positively and significantly associated with malaria cases.
Diouf 2020 (34)	West Africa	Observational Descriptive study	Temperature, Precipitation	High temperatures lead to high malaria transmission. The malaria outbreaks accurse 1–2 months after the rainfall peak.	-
Wanjala 2016 (35)	Africa Kenya	Observational analytic study	Temperature, Precipitation	The prevalence of malaria has increased in highlands of Africa that have become warmer and wetter due to climate change.	-

Table 2: General characteristics of the articles studied for global disaster-related Malaria that were eligible for review

Study year	*Study location*	*Study Design*	*bioclimatic variable*	*Main Conclusion*
Moreno, 2006 (36)	Latin America	Observational analytic study	Flood	Climate extremes increase the incidence rate of malaria.
Hashizume, 2006 (37)	Mozambique	Experimental Observational study	Flood, Cyclone	Floods caused malaria cases raised to, 6-fold to pre-disaster, with 26,788 cases 6 weaks after floods in the affected population.
Ding, 2014 (38)	China	Mixed method case-crossover study and Stratified Cox models	Flood	Flooding and waterlogging play an important role in the epidemic of malaria during the flood season. Flooding and waterlogging were significantly associated with an increased risk of malaria.
Kondo, 2002 (12)	Mozambique	Epidemiological study	Flood	The incidence of malaria increased by four to five times over non-disaster periods
El Sayed, 2000 (39)	Sudan	Descriptive analytic study	Flood	Increased risk of malaria epidemics, particularly in the aftermath of seasonal flooding
Sáenz, 2012 (40)	Costa Rica	Epidemiologic investigation	Flood, Earthquake	Increases in the incidence of malaria as high as 1,600% and 4,700% above the average monthly rate for the pre-earthquake period
Wakuma, 2009 (41)	Ethiopia	Qualitative approach, content analysis	Flood	Malaria was one main impact of flooding on the affected population health
WHO, 2005 (42)	Dominican	WHO report	Flood	Flooding in the Dominican Republic in 2004 led to malaria outbreaks.
Gagnon, 2002 (43)	South America	Observational analytic study	Flood, Drought	Flooding engenders malaria epidemics in the dry coastal region of northern Peru, while droughts favor the development of epidemics in Colombia and Guyana, and epidemics lag a drought by 1 year in Venezuela.
Kent, 2007 (44)	Zambia	Descriptive analytic	Drought	Reduced mosquito activity and numbers of malaria cases during the period of drought were reported. Numbers of anopheles rebounded strongly when the rains returned in 2005-2006.
Stanke, 2007 (45)	Worldwide	Systematic review	Drought	The decreases in malaria prevalence and incidence are likely due to the disappearance of the malaria vector as a result of severe droughts.

The most important reported risk factors for malaria outbreaks are; mean temperature and rainfall as climate variables and floods as extreme events. Studies in Africa, Asia, and South America have shown that malaria incidence increases with increasing temperature in temperate and high-altitude areas where are disease-free from malaria (25-35). Some studies have also found a bell-shaped relationship between malaria intensity and temperature around 28 °C (between 18 °C and 32 °C with a monthly rainfall of at least 80 mm) (23, 25-27). Rainfall has been reported to have an increasing impact on malaria when it is accompanied by an increase in temperature in highland and temperate zones (33, 35-42).

Table 3: General characteristics of the articles studied for Malaria in Iran that were eligible for

Study year	*Study location*	*Study Design*	*bioclimatic variable*	*Main Conclusion*	*Controversies*
Hanafi 2019 (46)	Iran	Analytical descriptive study using climatic models	All 19 Bioclimatic variables (Bio 1-19)	The most effective environmental variables on the model were different among the malaria vectors, the total high-risk areas for almost all studied species are expected to decrease, and the risky areas might change spatially to newly populated areas.	-
Morianzadeh 2016 (47)	Iran, Kerman	Observational analytic study	Temperature, Humidity, Precipitation	The outbreak of disease is dependent on annual and monthly temperature, humidity, and precipitation. The disease increases with temperature up to the 40-c° threshold. The epidemic is decreasing with increasing relative humidity and precipitation.	Malaria is decreasing with increasing relative humidity and precipitation.
Mohammadkhani2016 (48)	Iran Kerman	Descriptive study survey.	Temperature, Humidity, Precipitation	The most effective meteorological factor in the incidence of malaria is temperature. An increase in mean, maximum, and minimum monthly temperature led to a rise in the incidence rate of malaria, Humidity and Rainfall have no significant effect.	Humidity and Rainfall have no significant effect.
Mohammadkhani 2018 (49)	Iran Sistan and Baluchestan	Descriptive study survey.	Temperature, Humidity, Precipitation	The incidence of malaria had a significant positive correlation with the average, minimum, and maximum monthly temperatures and a negative correlation with rainfall and low humidity (<60%).	-
Halimi 2014 (50)	Iran	Retrospective descriptive study	Temperature, Humidity, Precipitation	The outbreak of malaria was reported one year after increased precipitation and weather humidity factors are more important than temperature factors in the prevalence of Malaria. Precipitation has been the most important climatic factor and the outbreak of malaria has a high correlation with precipitation. The humidity index had a low correlation with the outbreak of Disease.	Humidity index had a low correlation with the outbreak of Disease.
Halimi 2016 (51)	Iran	Retrospective descriptive study	Precipitation	There is a positive association between El Nino oscillation and rainfall.	-
Halimi 2013 (52)	Iran	Analytic observational study	Temperature, Humidity, Precipitation	The northern and southern coastal areas of the country are the most susceptible to malaria outbreaks based on climatic factors including rainfall, temperature, and humidity. The mountainous parts of the west of the country have the lowest conditions for the spread of disease.	Mountainous parts have the lowest potential for the spread of disease.
Mozaffari 2012 (53)	Iran, Chabahar	Descriptive study	Temperature, Humidity, Precipitation	The study showed a high positive correlation between malaria cases with temperature and relative humidity and a negative correlation with rainfall.	Malaria has a negative correlation with rainfall.
Barati 2012 (54)	Iran	Analytic observational study	Temperature, Humidity, Relative humidity	There was a significant relationship between malaria transmission and temperature. There is no significant relationship between relative humidity and malaria prevalence. There is a positive relationship between the prevalence of the disease and the altitude of the study area.	There is no significant relationship between relative humidity and malaria prevalence.

However, the results for Iran are controversial, with two studies showing a negative correlation between rainfall and malaria incidence in Iran (46, 52).Although the controversial reports are not limited to the precipitation factor.

Flash floods were the most common hydrologic disaster associated with an increase in malaria incidence rates (35- 44). In short, global warming, an increase in average temperature, heavy rainfall, and subsequent flooding are reported as a main important predictors of malaria epidemics in Iran. In Chabahar, Kerman, Sistan, and Baluchistan - the main endemic malaria areas in Iran - a correlation between rising average temperature and malaria cases has been found. Despite the global findings, studies reported the negative impact of rainfall on the prevalence of malaria in Iran (46-54). Malaria outbreaks following floods and other hydrological disasters have not been reported in Iran. Hormozgan, Bushehr, Khuzestan, Gilan, and Mazandaran provinces have the best climatic conditions for the spread of malaria in Iran (51).

Discussion

Emerging and re-emerging diseases such as malaria are considered a serious threat to human health as global warming continues and climate change has intensified in recent decades. Climate change affects the hydrological dynamics of the environment as well as the nutrient quality of leaf litter, which serves as food for mosquito larvae (55, 56). The relationship between temperature and precipitation variability and malaria dynamics has been demonstrated in numerous studies (30-45). Although malaria occurs seasonally, cultural and socioeconomic conditions play a critical role in monitoring the prevention behaviors and health habits of communities (56). According to studies, environmental variables are responsible for 90% of malaria cases (57, 58). Other factors such as inadequate prevention strategies, poor sanitation, inadequate drainage systems, population displacement, and migration also contribute to the occurrence of this disease (59). However, poverty, inequality, and development remain the most important determinants of infectious disease and malaria incidence in communities. In Singapore, for example, malaria has been eradicated because of extensive socioeconomic development (60, 61).

The rise in temperature of 2 °C in the last 30 years in the mountainous region of Kenya has resulted in a sevenfold increase in the disease (27). Temperate and mountainous regions in the world's "malaria belt," where temperatures have risen to more than 18 degrees due to global warming, are most likely to experience outbreaks for the first time (58). According to studies, malaria-endemic regions disappear above 1,800-2,000 m (62, 63). A limiting factor is probably the appropriate temperature required for effective extrinsic incubation (64). This opportunistic vector has survived 60 million years on Earth, despite severe climate changes, freezing, and prolonged drought, and can survive under the harshest environmental conditions (10). Malaria appears to be an unflashy guest for people living in high-altitude, disease-free, or non-endemic regions associated with global warming (65). The southern region of Iran is likely to experience longer maximum temperature intervals, prolonged droughts, and greater frequency and intensity of flooding in the coming decades (66). Several studies around the world have reported an increase in cases 1-4 months after rainfall under the same climatic conditions (28, 33, 34) Confirmatory results are reported from studies related to drought (43-45). Some Iranian studies yielded conflicting results. The western highland regions of Iran have the lowest potential risk for malaria outbreak, while the northern and southern coastal regions have the highest potential risk (50). The best climatic and environmental conditions for malaria carriers to grow and multiply are in mountainous regions (67, 68). Most studies conducted in Africa, Asia, and South America have demonstrated a significant relationship between rainfall and an increase in malaria rates (28-35). A study in Chabahar showed a negative relationship between the number of cases and annual rainfall. The climate of the investigated areas is hot and dry and the amount of rainfall is very low, evaporation of precipitation also happens very quickly. On the other hand, flash floods in this dry climate quickly destroy the larvae's habitat. Therefore, the rain has been associated with a decrease in the number of cases (53). As a coastal city, Chabahar is affected by the monsoon season, as are countries in this region such as India and Pakistan. Studies in these countries have reported an increase in malaria outbreaks one to three months after monsoon flash floods (69, 70). Malaria outbreaks following floods and other hydrological disasters have not been reported in Iran, heretofore. Although just in 2019, 19 infectious epidemics were reported due to large and destructive floods in Iran (17). Global malaria outbreaks and climate change are significantly linked, although the causal mechanisms are not fully understood (71-73). Contradictory results are not strong enough to convince policymakers to allocate resources to implement comprehensive planning, containment, and prevention strategies. Therefore, extensive long-term research using bioclimatic variables and climate models is needed.

Conclusion

Climate change related disasters will happen more frequently and with higher severity in Iran. As a result, malaria and other re-emerging infectious diseases will become a significant health concern, spaciously after disasters. Increasing intensive rainfalls and following distracting flash-floods in free-malaria areas are changing the malaria outbreak patterns. The adaptation and mitigation plans can reduce vulnerability to CSID. Consequently, developing and implementing adaptation strategies should be considered a milestone. More in-depth research with highly accurate climate models and using the long-term period bioclimatic variables is recommended.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interest.

Data availability

Supplementary materials are not published. They might be sent to the respected readers in cases of logical application from the corresponding author.

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