GSJ: Volume 13, Issue 4, April 2025, Online: ISSN 2320-9186

www.globalscientificjournal.com

Climate Factors and Malaria Transmission in Jacobabad: A Data-Driven Study

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Abstract:

District Jacobabad has water available in agricultural lands for most of the year due to the rice-growing season, monsoon rains, natural ponds, and stagnant sewerage water. These water sources create ideal breeding grounds for Anopheles mosquitoes, which are responsible for spreading malaria. The combination of standing water and warm climate increases the risk of mosquito-borne diseases, making malaria a persistent health challenge in the region. Effective drainage, water management, and mosquito control measures are essential to reduce the spread of malaria.District Jacobabad has endemic region for the Malaria Declare by Common Management Unit islamadabad and Ministry of National Health Pakistan

Malaria remains a pressing public health concern in Jacobabad, exacerbated by climatic conditions that favor the breeding and survival of malaria vectors. This study examines the relationship between climate factors such as temperature, rainfall, and humidity with malaria transmission trends in the district. Utilizing secondary data, this research aims to provide insights into how climate variability impacts malaria prevalence and explores potential mitigation strategies to control the disease effectively. The **hottest period** occurs between **April and July**, peaking around **May 29** at **112°F (44.4°C)**.The **cooler months** are from **December to February**, with temperatures dropping to **48°F (8.9°C) in January**. Annual Parasite Incidence (API) of 31 per 1,000 population in 2024, indicating a high malaria burden.

Monthly confirmed cases ranged from 2,477 (February) to 7,788 (November), showing a seasonal trend peaking post-monsoon.

INTRODUCTION

Malaria is a fascinating disease that has global reach and dynamic relationships with climate. This review focuses on malaria parasites responsible for 247 million of malaria cases in 2006, *Plasmodium vivax* and *P. falciparum* (WHO 2008). Climate is fundamentally linked to malaria incidence through the biological requirements of both the vector and parasitic agent.

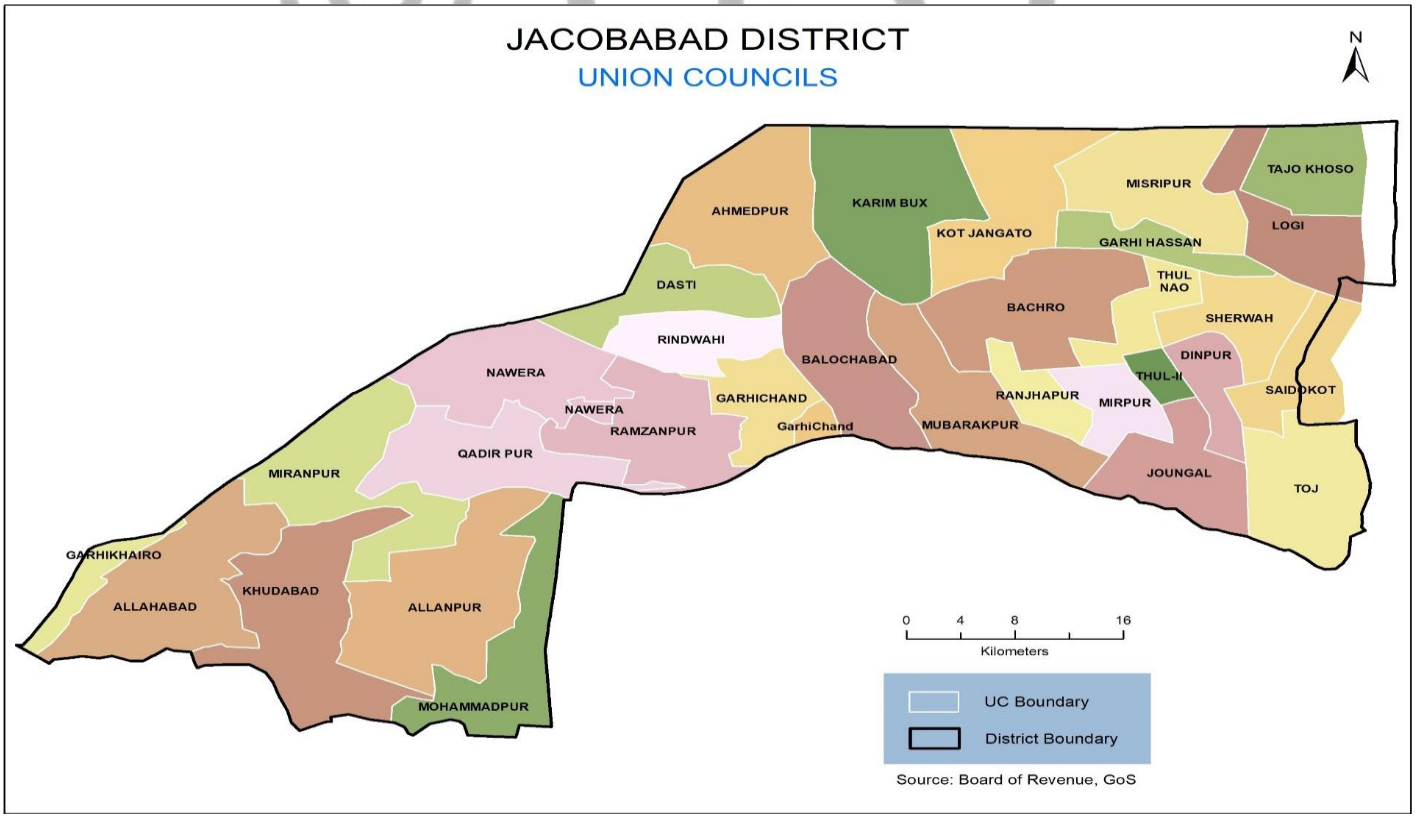
Mathematical models and laboratory experiments have identified the basic thresholds of temperature and humidity on mosquito and parasite development, and these climate underpinnings are essential to explaining the global geography of malaria (Craig et al 1999; Guerra et al 2008; Martens et al 1999; Rogers et al 2000).

Malaria is one of the most important parasitic diseases and one of the most important health problems in a number of countries, particularly countries in tropical and subtropical regions of the world (Azizi, Janghorbani, & Hatami, 2011). Malaria is an acute or chronic infectious disease caused by intracellular protozoan parasites from the *Plasmodium* genus. The disease is endemic in many countries of the world. Its epidemiologic and entomologic characteristics, the existence of more than 400 species of mosquito vectors, its tendency to drug resistance and the diversity in human sensitivity to this disease, and social, cultural, political, economic, and eco- logical factors in infected countries make the control of this disease very difficult. Its economic burden has imposed many negative effects on public health (Hatami, 2009).

Malaria is moderately endemic in Pakistan; yet, its transmission is unstable with disease burden ranging from very high (some high-risk districts in Federally Administered Tribal Areas (FATA) and Balochistan fear epidemic outbreak) to almost naught (some districts in Punjab and Azad Kashmir) . Erratic malaria transmission patterns due to various factors like climatic changes, natural disasters (frequent flooding and irregular rainfall pattern), resource constraints, weak health infrastructure, poor socio-economic conditions, domestic unrest in many of the districts in FATA and Balochistan and limited access to healthcare delivery services and frequent migrations of people within the country and in the Pak-Afghanistan bordering area are amongst the key reasons for unstable malaria incidence in Pakistan . According to recent estimates, 29% of the total population in Pakistan lives in malaria high transmission districts, while 69% in the districts with low malaria transmission. There is need to explore in detail the malaria epidemiology in Pakistan, as meticulous studies based on modern statistical methods (e.g., Geographical Information System (GIS) based techniques), explaining dynamics of malaria in the country are barely adequate

Between 2001 and 2009, the global burden of malaria has increased to more than 34 million (Edlund et al., 2012). According to the latest estimates from the World Health Organization in 2015, there were 214 million new cases (in a range of 149-303 million) of this disease globally and about 438,000 deaths (in a range of 236,000-635,000) have hap- pened, and almost 306,000 deaths occurred in children below the age of 5 years (World Health Organization [WHO], 2015).

District Jacobabad has **water available in agricultural lands for most of the year** due to the **rice-growing season, monsoon rains, natural ponds, and stagnant sewerage water**. These water sources create **ideal breeding grounds for Anopheles mosquitoes**, which are responsible for spreading **malaria**. The combination of **standing water and warm climate** increases the risk of **mosquito-borne diseases**, making malaria a persistent health challenge in the region. Effective **drainage, water management, and mosquito control measures** are essential to reduce the spread of malaria.District Jacobabad has endemic region for the Malaria Declare by Common Management Unit islamadadabad and Ministry of National Health Pakistan



The role of the Anopheles mosquito as a vector

The climate malaria story begins with an examination of the isolated effects of temperature on the agent and vector. The rate at which parasitic replication occurs inside a mosquito vector has an L-shaped relationship with temperature. At 18˚C *P. falciparum* requires 56 days to complete sporogony, a period of time also called extrinsic incubation, which is an unlikely life span for an adult mosquito, but as temperature increases from 22˚C to 28˚C the development time drops from about 20 days to eight days (Craig 1999). The temperature range for *P. vivax* transmission is slightly larger (18˚–30˚C) than *P. falciparum* (20˚–30˚C) and sporongony requires a day or two less at matched temperatures (Hamoudi and Sachs 1999). Raising the temperature from 20˚C and 30˚C considerably shortens the extrinsic incubation period from 18 to eight days in the malaria transmission cycle (Gilles and Warrell 1993). When temperatures exceed 30˚C the limiting factor in transmission is no longer the parasite – the weakened mosquito vectors begin to suffer high mortality and population turnover (Le Seuer 1991; Maharaj 1995). At temperatures above 40˚C mosquitoes desiccate and daily survival is zero in the laboratory (Martens 1997).

Even within the ideal *Anopheles* temperature window, small temperature changes can result in large biological changes. A study in the Kenyan highlands shows that just a half-degree centigrade rise in temperature from 1950 to 2002 can increase *Anopheles gambiae* mosquito population by 30–100 percent (Pascual et al 2006). Afrane et al. find a 1.8˚ C rise throughout the dry season drops the duration of the first and second gonotrophic stages by 1.7 days (59 percent) and 0.9 days (27 percent) respectively (2005). Temperature increases in the 'sweet spot' between 27˚C and 30˚ C, would lead to shortened latent periods and theoretically not compromise vector survivability. However, maximum and minimum daily temperatures may be more important than changes in mean temperature for the crepuscular active mosquito.The temperature theme often correlates with the role of precipitation as the *Anopheles* mosquitoes require some amount of humidity to avoid desiccation as adults and precipitation to create pools of water near or on which females lay their eggs. When seasonal rainfall triggers an abundance of vectors malaria incidence tends to rise. Rainfall peaks two to three months prior to malaria incidence in Africa and has been used with an early warning system that forecasts the timing and intensity malaria epidemics (Bomblies et al 2008; Eisele et al 2005; Thomas et al 2006; Ceccato et al 2007; WHO 2001; WHO 2004). In the Amazon, it appears that seasonal rainfall may suppress incidence for a longer period in areas with more wetlands (Olson et al 2009). While rainfall can affect the date of peak malaria incidence, total annual rainfall does not necessarily reflect annual incidence. In Madhya Pradesh, India, a longitudinal study over four decades showed no clear relationship between malaria incidence and annual rainfall (Singh and Sharma 2002). Hence, there is no consensus in the literature on general precipitation and humidity limits. Gilles and Warrell suggest the best environments maintain 60 percent mean relative humidity (1993). Craig et al. examine eight sites spread throughout Africa and determine that sites with stable transmission have at least 80 mm of rainfall per month (1999).Others use an annual index that counts the number of months with 60 mm of rainfall or more each month or an arbitrary minimum of 1.5 mm of precipitation a day (Kleinschmidt et al 2001; Martens et al 1995). The normalized difference vegetation index (NDVI), a satellite measure of greenness and a proxy measure for precipitation, is also used as a significant predictor of malaria in southern Africa and Kenya (Craig et al 1999; Hay et al 1998; Patz et al 1998; Ceccato et al 2007).

Climate Profile of District Jacobabad

Jacobabad is known for its extreme climatic conditions, often recording some of the highest temperatures in the world. Average temperature ranges across different seasons, hottest period occurs between April and July, peaking around May 29 at 112°F (44.4°C),the cooler months are from December to February, with temperatures dropping to 48°F (8.9°C) in January.

Seasonal Breakdown:

- Winter (December - February): The temperature is relatively cool, with lows around 48-56°F (8.9-13.3°C) and highs between 71-79°F (21.7-26.1°C).
- Spring (March - May): Temperatures rise sharply, reaching 77-112°F (25-44.4°C).
- Summer (June - August): The heat persists, with highs around 103-112°F (39.4-44.4°C).
- Autumn (September - November): Temperatures gradually decline, cooling down to 55-79°F (12.8-26.1°C) by November.

Key Temperature Points:

- Hottest Day: May 29 (112°F / 44.4°C).
- Coldest Day: January 6 (48°F / 8.9°C).
- Notable Peaks: April 24 and July 16 both show 103°F (39.4°C) highs.

Rainfall distribution throughout the year.

The average monthly rainfall in Jacobabad throughout the year is below.

Rainfall Trends:

Dry Season (October - May):

- Rainfall is minimal, ranging between 0.0 to 0.3 inches.
- The driest period is October (0.0 inches), followed by May (0.1 inches).
- The months of January, March, and December have slightly higher rainfall (0.1 - 0.3 inches).

Monsoon Season (June - September):

- Peak rainfall occurs in August (0.8 inches).
- July and September also receive 0.5 inches of rain each.
- The wettest period falls between July and early September due to the South Asian monsoon influence.

Jacobabad experiences very little rainfall overall, making it an arid/semi-arid region, Most of the annual rainfall is concentrated in just a few months, mainly July, August, and September, The rest of the year remains dry, contributing to extreme heat conditions during the summer, the harsh climate of Jacobabad, with scorching summers and very low annual precipitation, making water availability a key concern in the region.

Humidity levels and their variation.

Dry Season (October - May):

- From January to early June, Jacobabad remains mostly dry, with very low humidity levels.
- February 1 shows 0% humidity discomfort, meaning the air feels comfortable or dry.
- There is almost no mugginess during this period.

Monsoon and High Humidity (June - September):

- Humidity starts increasing in June, reaching 18% discomfort by June 10.
- Peak humidity is on July 31, at 71%, making it muggy and uncomfortable.
- August is the most oppressive month, with some periods even classified as “miserable”.
- By September 15, humidity drops to 18%, signaling the end of the monsoon season.

Comfortable Humidity: Mostly from November to May, Muggy Conditions: June to September, with peak discomfort in July and August, Oppressive and Miserable Humidity, July and early August, coinciding with peak temperatures and monsoon rains.

Jacobabad is generally dry, except during the monsoon months (June-September),The combination of high temperatures and high humidity in July-August makes the climate extremely harsh,After mid-September, the humidity levels rapidly decline, bringing relief from the oppressive conditions,the challenging weather conditions in Jacobabad, where extreme heat and seasonal humidity create an uncomfortable living environment, especially in summer.

Malaria Epidemiology in Jacobabad: A Secondary Data Analysis

Malaria Epidemiology in Jacobabad: A Secondary Data Analysis
Jacobabad reported an Annual Parasite Incidence (API) of 31 per 1,000 population in 2024, indicating a high malaria burden. Monthly confirmed cases ranged from 2,477 (February) to 7,788 (November), showing a seasonal trend peaking post-monsoon.

Age Groups: Children under 5 and adults aged 15–45 years are the most affected.

Gender: Males show slightly higher case numbers, linked to outdoor work exposure.

Socio-economic Status: Low-income and rural populations face greater risk due to poor housing, lack of drainage, and limited access to healthcare.
Malaria transmission in Jacobabad has shown seasonal spikes and intermittent outbreaks, especially in years with heavy monsoon rains or flooding. Despite control efforts, endemic transmission continues, particularly in agricultural and waterlogged areas,District Jacobabad Need integrated malaria control strategies, including vector management, public health education, improved diagnostics, and climate-based early warning systems.

Malaria Epidemiology in Jacobabad: Seasonal Impact

High malaria incidence coincides with warm and humid months (May to October), driven by Temperature Peaks (Above 100°F), Enhancing mosquito breeding, Rainfall (Jul–Sep) Creating stagnant water in rice fields, natural ponds, and poor drainage areas, Humidity (Above 60–70% in July–August) Prolonging mosquito life and aiding parasite development.

Transmission Peaks Post-Monsoon: Highest confirmed cases seen in November (7,788), suggesting a lag effect after heavy rain and breeding during the monsoon.

- Vector Ecology: Waterlogged agricultural land (especially from rice cultivation), open sewerage, and poor water management act as ideal breeding sites for Anopheles mosquitoes.
- Species Breakdown:

Plasmodium vivax (PV) dominates, often associated with relapsing infections and moderate symptoms, Plasmodium falciparum (PF), though less prevalent, poses greater risk of severe malaria.

The convergence of climatic conditions, environmental factors, and agricultural practices strongly contributes to seasonal malaria transmission in Jacobabad. Integrated strategies targeting vector control, early diagnosis, and climate-resilient planning are essential for effective malaria management in the district.

Relationship between Climate Factors and Malaria Transmission

The city is famous for its consistently high temperatures and holds the record for the highest temperature recorded in Pakistan.

- Temperature Variations: Extreme heat from April to July (reaching 112°F in May) accelerates mosquito breeding and survival, increasing malaria transmission risks.
- Rainfall Patterns: The monsoon season (July–September) brings stagnant water in agricultural fields, natural ponds, and sewerage areas, creating ideal conditions for Anopheles mosquito breeding.
- Humidity Levels: High humidity in July and August (peaking at 71%) enhances mosquito lifespan and transmission efficiency, prolonging malaria outbreaks.

The combination of high temperatures, seasonal rains, and increased humidity makes Jacobabad vulnerable to malaria outbreaks, requiring effective water management and mosquito control measures.

Seasonal Trends in Malaria Cases.

Malaria Cases Trend in Jacobabad (2024)

- Peak Cases: November (7,788 confirmed, 22,373 suspected) and December (5,923 confirmed, 24,778 suspected) indicate the highest malaria burden, likely due to post-monsoon water stagnation.
- Monsoon Impact (June–September): Confirmed cases remain high (3,496–4,920), correlating with increased rainfall and humidity.
- Lowest Cases: February (2,477 confirmed, 8,695 suspected), coinciding with lower temperatures and dry conditions.

Malaria transmission is seasonal, peaking post-monsoon, emphasizing the need for vector control and surveillance during high-risk months.

Month-Wise Malaria Cases in Jacobabad.

District Jacobabad 2024				
S#	Month	Suspected cases	Confirmed Cases	Sessional impact/Malaria Trend
1	January	9,900	32,34	Moderate cases, dry season.
2	February	8,695	2,477	Lowest malaria burden due to cool weather.
3	March	12,946	2,768	Slight increase as temperatures rise.
4	April	12,863	3,292	Cases rise with warming temperatures.
5	May	14,066	4,527	Higher cases due to pre-monsoon conditions.
6	June	13,616	3,496	Monsoon begins, increasing risk.
7	July	12,162	2,932	Continued transmission with humidity.
8	August	12,166	3,227	Peak humidity, sustained cases.
9	September	17,622	4,920	Post-monsoon surge.
10	October	19,977	5,153	High malaria burden post-monsoon.
11	November	22,373	7,788	Highest malaria cases, water stagnation.
12	December	24,778	5,923	Most suspected cases, extended transmission.

- Lowest cases: February (dry, cold season).
- Highest cases: November and December (post-monsoon stagnation).
- Monsoon Impact: June–September sustains high transmission.

Targeted malaria control efforts should focus on post-monsoon months to reduce the burden.Impact of Climate Change on Malaria Transmission Global climate change is altering weather patterns and disease dynamics.

Impact of Climate Change on Malaria Transmission

Global climate change is significantly influencing the epidemiology of vector-borne diseases, including malaria. In Jacobabad, where malaria remains endemic, climate shifts are expected to reshape disease patterns and intensify transmission.

• Expansion of Malaria-Endemic Zones:

Rising global temperatures may allow malaria vectors—especially *Anopheles* mosquitoes—to survive in previously unsuitable regions. Warmer climates can shorten the parasite's incubation period inside the mosquito, accelerating transmission rates.

• Altered Mosquito Breeding Cycles:

Climate variability, such as erratic rainfall and extended warm seasons, affects mosquito breeding habitats. In Jacobabad, heavy monsoon rains followed by stagnant water in rice fields and urban drainage increase breeding opportunities, while prolonged hot seasons support faster mosquito development.

• Future Projections for Jacobabad:

Climate models suggest that Jacobabad will continue to face:

- Longer transmission seasons due to sustained high temperatures and humidity.
- More intense outbreaks, especially during post-monsoon periods (July–November).
- Higher risk of PF transmission, associated with severe malaria, under extreme weather conditions.

  The interplay between climate change and malaria dynamics necessitates proactive adaptation strategies. Strengthened surveillance, climate-informed public health planning, and resilient health infrastructure will be crucial in managing future malaria risks in Jacobabad.

Public Health Response and Mitigation Strategies Efforts to control malaria in Jacobabad rely on various strategies.

Public Health Response and Mitigation Strategies

Efforts to control malaria in Jacobabad are multi-pronged, combining government initiatives, NGO support, and community participation to reduce transmission and improve outcomes.

• Government and NGO-Led Control Programs:

National and provincial health departments in collaboration with international partners have implemented structured malaria control programs. In Jacobabad, these include diagnosis and treatment facilities, routine surveillance, and case reporting. A significant contributor is the Sindh Rural Support Organization (SRSO), which has been actively working since 2023, providing Anti-Malarial Drugs (AMDs) and conducting public awareness campaigns to educate communities on prevention and early detection.

• Vector Control Measures:

Key strategies focus on reducing mosquito populations and human-vector contact:

- Insecticide-Treated Nets (ITNs): Distributed to vulnerable households, especially in high-transmission seasons, to prevent bites during nighttime.
- Indoor Residual Spraying (IRS): Regular spraying of insecticides inside homes is carried out to kill mosquitoes resting on walls, thereby breaking the transmission cycle.

• Community Awareness and Healthcare Interventions:

Awareness campaigns and health education initiatives play a critical role in behavior change. Community Health Workers and Lady Health Workers conduct door-to-door sessions to promote:

- Timely treatment-seeking behavior,
- Proper usage of nets and repellents,

- Recognition of symptoms for early case detection.
-

An integrated approach combining prevention, treatment, and education has shown positive outcomes in reducing malaria incidence. Continued collaboration between public health bodies, NGOs like SRSO, and local communities remains vital for long-term success.

Challenges in Malaria Control Due to Climate Variability Despite efforts to combat malaria, several challenges persist, including:

Climate variability adds another layer of complexity to malaria control efforts. As temperatures rise or rainfall patterns change, mosquito populations can thrive in new areas or become more resilient. These challenges are exacerbated by several factors:

1. Increased Mosquito Habitats: Changes in rainfall can lead to the creation of more stagnant water bodies, ideal breeding grounds for mosquitoes. Warmer temperatures also accelerate mosquito development, leading to faster disease transmission.
2. Evolving Vector Behavior: Climate change can alter the behavior of mosquito vectors, such as the Anopheles species, making them more active during different times of the day or more capable of surviving in previously inhospitable areas.
3. Antimalarial Resistance: As climate shifts, the persistence of resistance to antimalarial drugs could spread to new regions, making treatment less effective and requiring more sophisticated and expensive interventions.
4. Disruption of Health Services: Extreme weather events like floods or droughts can damage healthcare infrastructure, making it harder for people to access diagnostic services, preventive measures (like insecticide-treated bed nets), or effective treatments.
5. Economic Impacts: Climate variability affects local economies, leading to increased poverty and reduced access to healthcare. Malaria prevention and control measures become less affordable for affected populations, further perpetuating the cycle of disease.

Addressing these challenges requires a multi-faceted approach, including strengthened healthcare systems, improved vector control strategies, and better surveillance systems to track and respond to climate-related shifts in malaria transmission. Additionally, addressing the socioeconomic and environmental drivers of malaria could help reduce vulnerability in high-risk areas.

Conclusion and Recommendations

Conclusion:

This study highlights a clear relationship between climatic factors and malaria transmission in Jacobabad. Data indicates that:

- High temperatures and humidity during summer months (especially June to September) create ideal conditions for *Anopheles* mosquito breeding and malaria transmission.
- Rainfall, though limited, contributes to stagnant water accumulation in rice fields, natural ponds, and sewerage systems, further promoting mosquito proliferation.
- Malaria incidence peaks during and after the monsoon and rice cultivation season, aligning with the climate data and confirming environmental influence on case surges.
- In 2024, over 49,000 confirmed malaria cases and 181,000 suspected cases were reported, with a notable burden from *Plasmodium vivax* (59%) and *Plasmodium falciparum* (39%), reinforcing the significance of sustained control efforts.
- The Annual Parasite Incidence (API) of 31 per 1,000 population reflects a high endemicity in the district.

Recommendations:

- Strengthen Climate-Based Disease Surveillance:
  - Develop predictive models integrating weather patterns with malaria case trends.
  - Use real-time climate data to anticipate outbreaks and pre-position resources.
- Enhance Public Health Infrastructure:
  - Improve diagnostic facilities and case management capacity, especially in rural areas.
  - Expand access to Anti-Malarial Drugs (AMDs), especially during high-risk months.

Integrate Climate Resilience into Malaria Programs:

- Adapt malaria strategies to include environmental and agricultural practices.
- Promote climate-resilient housing, drainage systems, and water management in endemic zones.

Sustain and Scale Community Interventions:

- Continue the efforts of organizations like Sindh Rural Support Organization (SRSO) in public awareness and AMD distribution.
- Empower local health workers to strengthen early detection and community participation.

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