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CLINICAL SPECTRUM AND RISK FACTORS INFLUENCING PEDIATRIC MALARIA PUBLIC HEALTH CONCERN IN DISTRICT LOWER DIR

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ABSTRACT

Malaria poses a major health crisis in District Dir Lower, Khyber Pakhtunkhwa, Pakistan, disproportionately affecting children as a vulnerable population in the region. The annual prevalence of malaria among children stands at 81.35%. Monthly prevalence rates fluctuate, peaking in May (85.71%), June (84.44%), and July (86.00%), likely due to favourable environmental conditions such as higher humidity and the rainy season, which increase mosquito breeding. Conversely, the lowest prevalence is observed in March (68.57%) and December (75.76%). Gender-wise analysis indicates that male children have a higher

Vol. 2(2). DD. March-May, 2025
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Journal of Medical & Health Sciences Review

prevalence rate of 84.09% compared to female children at 78.42%. Age-wise data reveals that children aged 9-10 years have the highest prevalence at 83.69%, followed by those aged 1-4 and 5-8 years, each exhibiting a prevalence rate of 80.00%. *Plasmodium vivax* was the most prevalent species, accounting for 75.79% of the total positive cases, followed by *Plasmodium falciparum* at 15.08% and mixed infections at 3.94%. Seasonal variations show a higher prevalence during the summer months (83.03%) compared to winter (78.76%), aligning with increased mosquito activity in warmer temperatures. Tehsil-wise data indicates that Timergara has the highest prevalence at 15.2%, while Samar Bagh has the lowest at 9.6%. These findings underscore the need for targeted malaria control strategies, particularly during peak transmission periods and in areas with higher prevalence rates.

KEYWORDS: Pediatric Malaria, Public Health, District Lower Dir, Khyber Pakhtunkhwa, Climate change.

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1. INTRODUCTION

Malaria is a life-threatening parasitic disease transmitted by infected *Anopheles* mosquitoes, mainly in tropical regions. Despite being preventable and curable, it reportedly caused an estimated 247 million cases and 619,000 deaths globally in 2021 [1]. The Sub-Saharan African regions, notably Nigeria, Congo, Uganda, and Mozambique were the hardest hit, bearing the majority (95%) of these cases [2]. Children under the age of 5 accounted for 76% of malaria deaths [3]. Additionally, pregnant women face heightened risks, since malarial agents threaten maternal, fetal, and neonatal mortalities [4]. Epidemiological data suggests a disproportionately higher rate of morbidities and mortalities in low-income countries mainly due to environmental, socio-economic, and healthcare disparities [5]. Malaria is often clinically presented with nonspecific symptoms, including fever, chills, headache, fatigue, and hemolytic anemia, while severe cases may involve seizures, hypotension, and multi-organ failure [6,7]. The disease is transmitted by female *Anopheles* mosquitoes, particularly *An. arabiensis* and *An. gambiae*, which breed in stagnant water. The causative agent is a protozoan *Plasmodium* with *P. falciparum* and *P. vivax* being the most clinically significant, while *P. malaria* and *P. ovale* cause milder symptoms. The clinical spectrum ranges from mild febrile illness to fatal multi-organ failure [1,6]. Although rapid diagnostic tests (RDTs) have improved detection speed by identifying specific antigens and polymerase chain reaction (PCR) based assays are

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highly sensitive, however, diagnosis of malaria is preferably confirmed through blood analysis with microscopic examination of stained blood films, which remains the gold standard due to its sensitivity, less possibility to yield false negatives, cost-effectiveness and the ability to detect parasite species and their quantification [8]. Malaria transmission dynamics are shaped by macro-level climatic factors and micro-ecological conditions such as vector behaviour, host accessibility, and availability of aquatic breeding sites [9]. In Pakistan, monsoon rains, irrigation networks, and intensive agriculture amplify *Anopheles* mosquito proliferation, elevating regional transmission risk [10,11]. The malaria burden in Pakistan exhibits significant heterogeneity even within the same locality, with household-level disparities driven by socioeconomic status, type of housing, literacy, and access to healthcare [12,13]. School-aged children in endemic areas represent a high-risk demographic, experiencing both acute clinical impacts and chronic educational disruptions from recurrent infections. This vulnerable group serves as a critical reservoir for sustained transmission while facing compounded socioeconomic consequences [14]. Due to the high endemicity of malaria in specific regions of Pakistan and its disproportionately high burden among children, there remains a critical need to investigate localized prevalence patterns. The district of Lower Dir is characterized by its rural setting and environmental conditions favorable to mosquito proliferation [15], and lacks sufficient epidemiological data on pediatric malaria cases. Moreover, despite global efforts, data delineating the frequency of specific *Plasmodium* species among infected children in this region remain scarce. The current study, therefore, aims to assess the prevalence of malaria among children in District Lower Dir and to determine the frequency distribution of *P. falciparum* and *P. vivax* infections. The findings are expected to determine malaria prevalence, contribute to vector control strategies, strengthen surveillance, and target public health in malaria-endemic zones.

2. Materials and Methods

2.1. Study area

The present hospital-based descriptive cross-sectional study was conducted in District Lower Dir, Khyber Pakhtunkhwa, Pakistan (Figure 1), a region with a semi-arid climate prone to high temperatures and seasonal sandstorms, fostering malaria transmission [16]. District Lower Dir is situated in the Malakand Division of Khyber Pakhtunkhwa province, Pakistan (34°37'-35°07'N and 71°31'-72°14'E). The region features a diverse topography comprising the Hindu

Vol. 2(2). DD. March-May, 2025
ONLINE ISSN: 3007-309X
PRINT ISSN : 3007-3081
Journal of Medical & Health Sciences Review

Kush Mountain ranges, fertile river valleys, and extensive forest cover [17. Characterized by a humid subtropical climate, the area experiences four distinct seasons with significant temperature variations [18]. Summers (June-August) are hot with temperatures reaching 33°C and heavy monsoon rainfall averaging 264mm in August [19]. Winters (December-February) are cold, with January temperatures frequently dropping below freezing in higher elevations [20]. The annual precipitation averages 1270mm, supporting agricultural activities but also creating favorable conditions for vector-borne diseases [21,22]. The district's unique geographical features and climatic patterns significantly influence local livelihoods, agricultural productivity, and public health challenges.

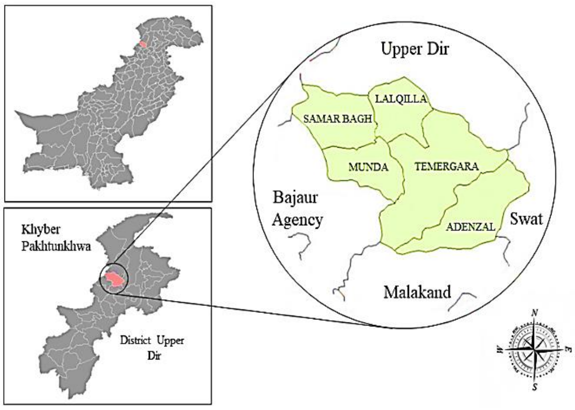

Figure 1: District Lower Dir, Khyber Pakhtunkhwa, Pakistan

2.2. Study Design

Current study aimed to determine the prevalence of *Plasmodium falciparum* and *Plasmodium vivax* infections among children aged ten years or younger, residing within the District Lower Dir. Data was collected from patients visiting 5 public sector hospitals over one year.

2.3. Study Population

A total of 815 children aged ≤10 years suspected of having malaria, visiting public sector hospitals in the District Lower Dir were recruited for the present study. Inclusion criteria comprised children up to ten years of age presenting with clinical suspicion of malaria, while individuals older than ten years, or those with co-existing severe illnesses that could confound clinical assessments, were excluded.

2.4. Sample and Data Collection

Blood samples were obtained via finger prick for microscopic examination and RDTs were utilized for confirmation of *Plasmodium* infection. Demographic and clinical details were recorded using structured questionnaires designed to record malaria prevalence and associated risk factors.

2.5. Identification of Parasites

Identification of the *Plasmodium* species was carried out by microscopic examination and RDTs. Thick and thin blood smears from the samples were prepared for microscopic analysis. Thin smears were fixed with methanol, stained with Giemsa diluted in distilled water, and examined under a microscope using immersion oil at 100x magnification. Standard morphological keys were used to identify different developmental stages of *P. vivax* and *P. falciparum*, and each slide was evaluated for 10–20 minutes [23]. RDTs detected malarial antigens based on antigen-antibody interactions, allowing rapid identification of infection, particularly in field settings where microscopy may not be feasible [24].

2.6. Ethical Considerations

Before data and blood sample collection, written informed consent was obtained from the parents or legal guardians of each participant, and ethical approval was granted by the Department of Pharmacy, Kohat University of Science and Technology, in compliance with the Declaration of Helsinki. All information was anonymized and handled confidentially to ensure the privacy of participants.

2.7. Statistical Analysis

The prevalence rate of malaria was calculated using the formula:

$$\text{Prevalence rate} = \frac{\text{Number of patients with malaria}}{\text{Total number of patients diagnosed}} \times 100$$

Data was statistically analyzed using SPSS version 27. Descriptive statistics were used to summarize demographic and clinical characteristics, and prevalence rates were expressed as percentages. Any missing data was addressed using listwise deletion. Potential confounding

Vol. 2(2). DD. March-May, 2025
ONLINE ISSN: 3007-309X
PRINT ISSN : 3007-3081
Journal of Medical & Health Sciences Review

factors, such as patient age, gender, and seasonality of infection, were considered during analysis, although no formal multivariate regression or sensitivity analyses were performed due to the descriptive nature of the study. This structured methodology ensured the study's reproducibility and provided reliable baseline data on the burden of malaria in a vulnerable pediatric population in a resource-limited, high-risk region.

3. Results

The prevalence of malaria among children in District Lower Dir exhibits significant variation across different months, genders, age groups, species, seasons, and tehsils, underscoring the complex nature of malaria transmission in the region. **Month-wise prevalence** (Table 1) indicates a peak during the warmer months, with May (85.71%), June (84.44%), and July (86.00%) exhibiting the highest malaria rates, likely due to increased mosquito activity during the rainy season. Conversely, the lowest prevalence is observed in March (68.57%) and December (75.76%). Overall, the annual prevalence stands at 81.35%, reflecting the substantial burden malaria places on public health. **Gender-wise prevalence** (Table 2) reveals that male children are more affected than females, with a prevalence of 84.09% compared to 78.42% in females. This disparity may be linked to differences in outdoor activity or healthcare access. **Age-wise prevalence** (Table 3) shows that younger children (1-4 years and 5-8 years) have an 80% prevalence rate, with those aged 9-10 years exhibiting the highest prevalence (83.69%), suggesting higher exposure levels as children grow. The **species-wise prevalence** (Table 5) identifies *P. vivax* as the dominant malaria species, responsible for 75.79% of cases, followed by *P. falciparum* at 15.08%, and mixed infections at 3.94%. **Season-wise prevalence** (Table 4) shows a higher prevalence in summer (83.03%) compared to winter (78.76%), aligning with increased mosquito activity in warmer temperatures. Detailed data from **malaria cases across tehsils** (Table 6) shows prevalence rates ranging from 75.00% to 80.00% in various union councils, with some areas exhibiting higher rates during peak mosquito breeding seasons. The geographical distribution of malaria across the tehsils highlights regional differences in prevalence, further emphasizing the need for targeted interventions based on local environmental conditions and mosquito activity.

3.1. Month-wise Prevalence

The month-wise prevalence of malaria shows variability throughout the year, with a relatively higher burden during the warmer months (Table 1). The peak months are May (85.71%), June (84.44%), and July (86.00%), likely due to favorable environmental conditions such as higher humidity and the rainy season, which increases mosquito breeding. Conversely, the lowest prevalence is observed in March (68.57%) and December (75.76%). The overall prevalence for the year stands at 81.35%, indicating a substantial public health challenge in the district.

Table 1. Month-wise Prevalence of Malaria among Children in District Lower Dir

Month	**Total Samples (*n*)**	**Positive Cases (*n*)**	**Prevalence (%)**
January	300	225	75.00
February	280	210	75.00
March	350	240	68.57
April	380	310	81.58
May	420	360	85.71
June	450	380	84.44
July	500	430	86.00
August	480	390	81.25
September	420	350	83.33
October	390	330	84.62
November	380	310	81.58
December	330	250	75.76
Total	4312	3505	81.35

3.2. Gender-wise Prevalence

Gender-wise prevalence of malaria highlighted higher prevalence in male children as compared to the female children (84.09% vs 78.42%) who participated in the present study (Table 2).

Vol. 2(2). DD. March-May, 2025
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PRINT ISSN : 3007-3081

Journal of Medical & Health Sciences Review

This gender disparity may be influenced by factors such as exposure levels, access to healthcare, or behavioral differences between male and female children in terms of outdoor activity or sleeping habits.

Table 2. Gender-wise Prevalence of Malaria among Children in District Lower Dir

Gender	Total Samples (*n*)	Positive Cases (*n*)	Prevalence (%)
Male	2200	1850	84.09
Female	2112	1655	78.42
Total	4312	3505	81.35

3.3. Age-wise Prevalence

Age-wise prevalence of malaria is provided in Table 3. The data shows that children aged 1-4 years and 5-8 years exhibited high prevalence rates (80.00%), however, children aged 9-10 years exhibited the highest prevalence rates (83.69%). This age distribution indicates that younger children are at higher risk, potentially due to limited acquired immunity, while slightly older children may experience increased exposure.

Table 3. Age-wise Prevalence and Species-wise Distribution of Malaria among Children in District Lower Dir

Age Group (Years)	Total Cases (*n*)	*P. vivax* (*n*)	*P. falciparum* (*n*)	Mixed (*n*)	Total Positive (*n*)	Prevalence (%)
<1	250	180	50	20	200	80.00
1-4	1200	950	200	50	1200	80.00
5-8	1500	1200	250	50	1500	80.00
9-10	1362	940	150	50	1140	83.69
Total	4312	3270	650	170	3505	81.35

3.4. Species-wise Prevalence

Vol. 2(2). DD. March-May, 2025
ONLINE ISSN: 3007-309X
PRINT ISSN : 3007-3081
Journal of Medical & Health Sciences Review

The obtained data (Table 3) further suggests that *P. vivax* was the most prevalent species causing infection in children and accounted for 75.79% of positive cases, followed by *P. falciparum* at 15.08% and mixed infections at 3.94%.

3.5. Season-wise Prevalence

The seasonal distribution of malaria prevalence (Table 4) shows a marked difference between summer (83.03%) and winter (78.76%) prevalence. This aligns with the typical pattern of malaria transmission, which peaks during warmer months when mosquitoes are more active. Malaria transmission decreases in winter due to lower mosquito activity in cooler temperatures.

Table 4. Season-wise Prevalence of Malaria among Children in District Lower Dir

Season	Total Samples (n)	Positive Cases (n)	Prevalence (%)
Summer	2590	2150	83.03
Winter	1722	1355	78.76
Total	4312	3505	81.35

3.6. Species-wise Prevalence

Prevalence of malaria by species revealed that *P. vivax* was the dominant malaria species in District Dir Lower, contributing to 75.79% of total cases. Whereas *P. falciparum* which is known for causing more severe forms of malaria, represented 15.08%, and mixed infections account for 3.94% of recorded cases (Table 5). The predominance of *P. vivax* in this region suggests that control measures should focus on addressing this species, particularly in areas with high transmission rates.

Table 5. Species-wise Prevalence of Malaria among Children in District Lower Dir

Species	Total Cases (*n*)	Prevalence (%)
P. vivax	3270	75.79
P. falciparum	650	15.08
Mixed	170	3.94
Total	4312	81.35

Vol. 2(2). DD. March-May, 2025
ONLINE ISSN: 3007-309X
PRINT ISSN : 3007-3081

Journal of Medical & Health Sciences Review

3.7. Malaria Cases in District Lower Dir

Table 6 depicts a detailed breakdown of malarial cases across the seven tehsils of District Lower Dir, covering several union councils. The total cases are distributed among the tehsils as follows: Adenzai, Balambat, Khall, Lal Qilla, Munda, Samar Bagh, and Timergara, with varying prevalence rates depending on the specific area. The prevalence of malaria ranges from 75.00% to 80.00% in different union councils, with some areas showing higher prevalence in warmer months due to the mosquito breeding season. Figure 2 illustrates the comparative cases of malaria across the seven tehsils of District Lower Dir.

Table 6. Malaria Cases across Seven Tehsils of District Lower Dir, Khyber Pakhtunkhwa, Pakistan

Tehsil	Union	January (n)	February (n)	March (n)	April (n)	May (n)	June (n)	July (n)	August (n)	September (n)	October (n)	November (n)	December (n)	Prevalence
Adenzai	Asbanr	15	12	18	20	22	18	22	21	17	18	16	15	75.00
	Badwan	14	11	16	18	21	16	19	17	15	18	15	16	75.45
	Chakdara	16	14	17	21	23	19	24	19	20	22	20	20	74.62
	Khadakzai	13	10	12	18	16	14	15	15	12	14	13	14	74.00
	Tazagram	14	13	15	18	20	16	19	18	17	18	15	15	75.00

Vol. 2(2). DD. March-May, 2025
ONLINE ISSN: 3007-309X
PRINT ISSN : 3007-3081

Journal of Medical &
Health Sciences Review

	Khall						Balambat			
Khall	Khall	Rabat	Koto	Munjai	Lajbook	Hayaserai	Balambat	Ouch	Kotigram	Khanpur
14	15	12	11	11	12	12	13	12	10	14
12	13	11	10	9	9	10	12	10	9	12
14	15	13	12	10	12	13	15	13	12	16
17	18	15	14	13	15	16	17	15	13	17
19	20	16	15	14	16	18	20	16	14	18
16	18	15	13	12	14	15	16	14	12	19
18	21	17	16	15	17	18	20	16	13	22
16	19	16	15	14	16	16	19	14	12	20
14	18	14	13	12	13	14	18	13	10	17
16	19	16	14	13	15	16	19	14	13	18
15	17	15	13	12	14	15	18	13	12	18
16	18	16	14	13	15	15	18	13	12	18
75.00	75.45	77.78	75.00	75.00	76.67	77.78	80.00	76.67	75.00	77.27

Vol. 2(2). DD. March-May, 2025
ONLINE ISSN: 3007-309X
PRINT ISSN : 3007-3081

Journal of Medical & Health Sciences Review

		Munda					Lal Qilla			
Munda	Mia Kalai	Khazana	Zaimdara	Kotkai	Gall	Lal Qilla	Maidan	Sultan Khel	Tormang-II	Tormang-I
12	11	11	11	13	12	16	15	12	13	13
10	9	9	10	12	11	14	13	10	11	11
13	12	12	12	14	13	18	16	13	14	14
15	14	14	14	16	16	21	18	16	17	16
17	16	15	15	18	18	23	20	17	18	18
14	13	13	13	15	17	20	18	15	15	15
17	16	15	16	18	19	23	21	16	17	17
15	14	14	14	17	17	21	19	15	16	16
14	13	13	13	16	16	19	17	13	14	15
15	14	14	15	17	17	21	18	15	16	16
14	13	13	14	16	15	20	17	13	15	15
15	14	14	14	16	16	20	18	14	15	16
75.00	75.56	76.67	75.00	78.00	77.78	79.17	77.27	75.00	75.56	76.67

Vol. 2(2). DD. March-May, 2025
ONLINE ISSN: 3007-309X
PRINT ISSN : 3007-3081

Journal of Medical &
Health Sciences Review

Samar	Darangai	13	11	14	16	17	16	18	16	14	16	15	16	76.00
	Kambat	12	11	13	15	17	14	16	15	14	16	14	15	76.67
	Mayar	11	10	12	14	16	13	15	14	13	14	13	14	75.00
	Maskini	10	9	11	13	15	12	13	12	10	12	11	12	75.71
	Sadbar Kali	11	9	12	14	16	13	16						

Vol. 2(2). DD. March-May, 2025
ONLINE ISSN: 3007-309X
PRINT ISSN : 3007-3081
Journal of Medical &
Health Sciences Review

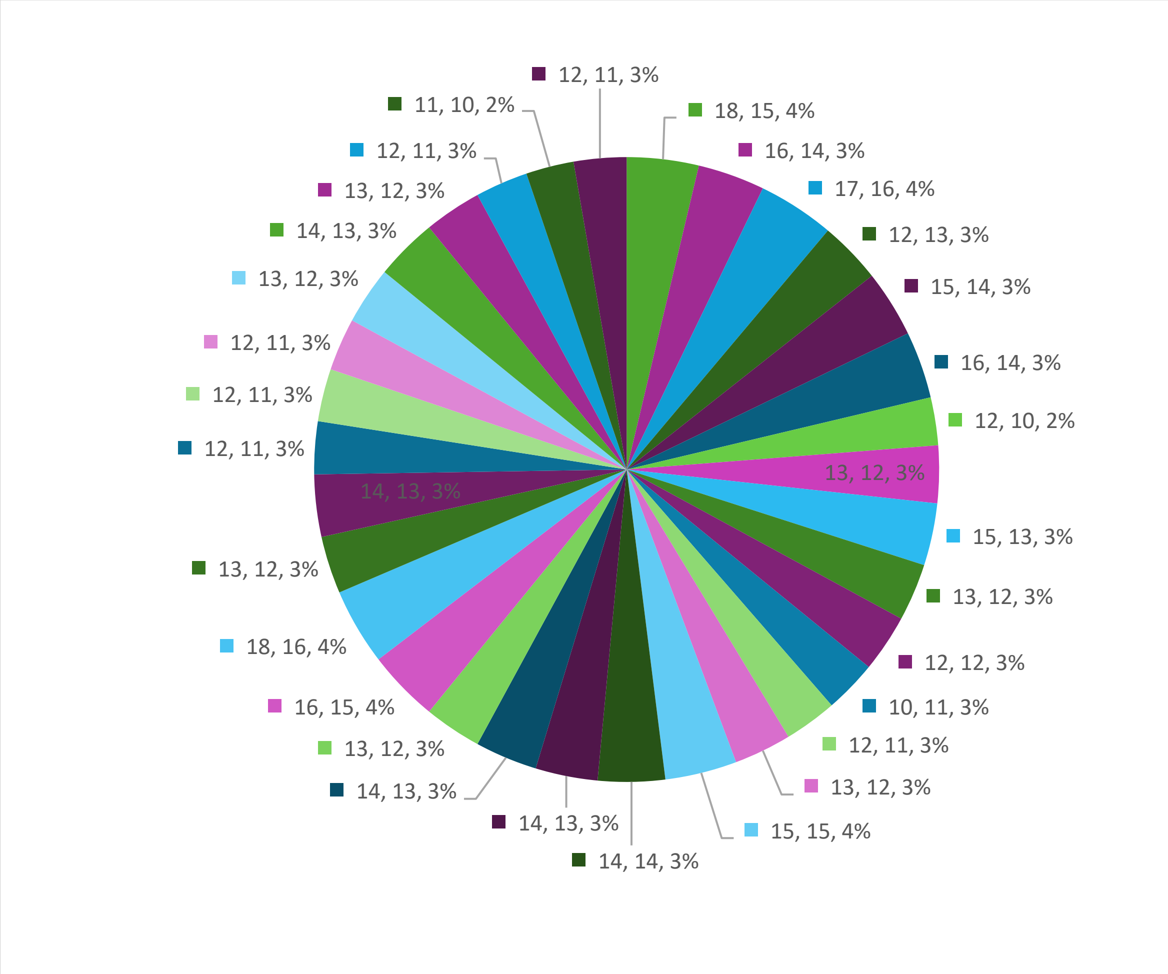

Figure 2. A comparative of malarial cases across the seven tehsils of District Lower Dir

Discussion

Current study revealed that there was a significant monthly variation in malaria prevalence. Peak transmissions were recorded during the warmer months (May 85.71%; June 84.44%; July 86.00%). These months characteristically fall into the monsoon season which provides an optimal environment and ideal conditions for mosquito breeding [16]. These observations correlate with earlier studies in KPK documenting increased transmission linked to monsoon rains (June–September), elevated temperatures (25–30°C), and humidity (>60%), which accelerated mosquito breeding, parasite development, and increased vector activity [22, 25]. The lower prevalence in winter could be a result of decreased mosquito activity during colder temperatures, which further highlights the importance of seasonal variation in transmission. These findings emphasize the need for seasonally targeted interventions, particularly in high-burden months, as recommended in meta-analyses of Pakistani malaria data (2006–2021) by tailored interventions during the warmer months. [22].

Findings suggested that malaria was widespread in District Dir Lower, particularly during the summer months. The high prevalence of *P. vivax* in this region is consistent with the trend seen in many other parts of Pakistan, where *P. vivax* is the dominant species [26,27,28]. *P. vivax* hypnozoites cause recurrent infections, which may lead to sustaining transmission even in low-season months [29]. Although *P. falciparum* was found to be less prevalent in the current study, it still poses a threat due to its association with severe cases (cerebral malaria, anemia) [30.31] and chloroquine resistance [32,33] necessitating vigilance [34]. Efforts to control *P. vivax* should be paired with strategies to mitigate the impact of *P. falciparum*. However
The age distribution suggests that young children are most vulnerable to malaria, likely due to their weaker immune systems [35,36]. The prevalence of malaria among children under five years supports the need for targeted interventions such as insecticide-treated nets (ITNs) and indoor spraying in these age groups. It has been reported that environmental and socioeconomic factors, particularly rural residency, lack of bed nets, and low maternal education can exacerbate the risk [37,38]. The gender difference in prevalence may be due to boys spending more time outdoors, where they are more exposed to mosquito bites, while girls might have more restricted movements. In KPK gender roles limit girls' outdoor mobility, reducing their Anopheles bite frequency [39]. Furthermore, wider gender disparities in KPK lead to underreported female cases [40]. The gender disparities align with global patterns. Similarly, in sub-Saharan Africa, boys aged 5–15 had a higher malaria risk than girls, linked to outdoor activities such as farming, fishing, and playing which increased mosquito exposure [41,42]. A 2022 study in India reported similar trends, with boys (6–14 years) showing 18% higher prevalence than girls, correlating with school and play-related outdoor time [43].

Conclusion

The findings from the present study underscore the importance of addressing malaria in District Lower Dir, where both environmental factors (such as climate) and socio-economic factors (such as gender roles) contribute to the high prevalence of the disease in children. The high prevalence rates during summer months highlight the urgent need for more effective vector control measures, including the widespread use of ITNs and IRS. The higher rates of malaria among children, especially in the 1-8 years age group, indicate a critical area for intervention. Additionally, *P. vivax* continues to be the primary strain affecting the population, which calls for targeted treatment protocols to combat this species effectively. The seasonal variation in prevalence should also be taken into account when planning intervention strategies, with a focus on the summer months.

Recommendations

1. Strengthening Vector Control Programs: Expand the use of insecticide-treated nets (ITNs) and indoor residual spraying (IRS), especially during the high-risk summer months. Increasing community access to these tools is crucial for reducing mosquito exposure.
2. Improved Surveillance and Data Collection: Establish a more comprehensive surveillance system to track malaria cases in real-time, particularly during the peak transmission season from April to October. This will help in timely interventions.
3. Public Awareness Campaigns: Launch community-based awareness programs focusing on preventive measures, such as the importance of using ITNs and eliminating mosquito breeding sites. These programs should also emphasize seeking early diagnosis and treatment.
4. Targeted Health Interventions for Vulnerable Groups: Focus health interventions on the most vulnerable populations, such as children under five years and pregnant women, who are at higher risk of severe malaria outcomes. Ensure access to **prophylactic treatments** for pregnant women and early diagnosis for children.
5. Increased Research on Malaria Resistance: Monitor the emergence of drug resistance, particularly to *P. vivax*, and ensure that treatment protocols evolve in response to any changes in resistance patterns. Research into alternative treatments and vaccines is essential.
6. Climate and Environmental Management: Implement climate adaptation strategies to reduce malaria transmission. This could include improving drainage systems to minimize standing water and increase the effectiveness of insecticide spraying in high-risk areas.

Author Contributions:

Fawad Khan[1] (Conceptualization, Methodology, Writing - Original Draft, Review & Editing) Najiya al Arifa[2] (Data Collection, Formal Analysis, Writing - Original Draft) Saffora Riaz[2] (Data Collection, Writing - Original Draft) Robeela Shabbir[3] (Writing - Review & Editing, Supervision) Asad Qamar Abbas Khan [4](Data Collection, Formal Analysis) Hamna Tariq[5] (Data Collection, Writing - Original Draft) Ali Hassan[6] (Writing - Review & Editing, Supervision) Zainab Tariq[7] (Data Collection, Writing - Review & Editing)

Conflicts of Interest:

The authors declare no conflict of interest regarding the publication of this article.

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Future Research Gaps:

While this study provides insight into the clinical spectrum and risk factors influencing pediatric malaria in District Lower Dir, future research should focus on:

1. Longitudinal studies to track the impact of malaria prevention strategies over time.
2. Investigating the role of environmental factors and climate change in malaria transmission.
3. Evaluating the effectiveness of local malaria control programs in reducing incidence.
4. Studying the genetic diversity of Plasmodium strains in this region and their association with drug resistance.

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