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Research Article

Ecological Survey of Mosquito Species Diversity and Seasonal Variability in District Kohat: Implications for Vector Control

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Abstract

Mosquitoes are major disease vectors contributing substantially to global mortality, with over 3,500 species belonging to the family *Culicidae*. This study aimed to access the species diversity and seasonal variation of mosquitoes across four rural localities in District Kohat to support future surveillance and vector control strategies. A year-long survey was conducted using a combination of catching techniques, including nets, aspirators, light traps and spray catches. Collected specimens were preserved in 80% ethyl alcohol and taxonomically identified under a stereomicroscope using key standards. Statistical analysis was performed to correlate mosquito abundance with local climate variables, including temperature, rainfall, and relative humidity. The survey identified seven mosquito species belonging to three genera: *Culex* (76%), *Anopheles* (22%), and *Aedes* (2%). The dominant species were Culex *quinquefasciatus* (40%), *Culex mimeticus* (22%) and *Culex theileri* (14%). Among *Anopheles*, the species recorded were *Anopheles stephensi* (11%), *Anopheles culicifacies* (8%), *Anopheles annularis* (3%), while *Aedes* aegypti (2%) was the sole representative of its genus. Jarma village exhibited the highest diversity index (1.74) and shared similar species evenness (0.8) with Lachi area. Seasonally, the highest mosquito density (5,260) occurred in June, while the lowest (10) was recorded in January. Temperature acted as the primary regulator of mosquito abundance in study area, showing a strong positive correlation while rainfall and humidity remained weak drivers. Consequently, it was recommended that resource allocation prioritize climate-informed interventions and larval source reduction from early spring through autumn. Future research should integrate GIS-based climatic monitoring and molecular screening to map spatial risk zones and enhance precision of localized vector control to prevent the mosquito-borne diseases.

Keywords: Climate, Mosquitoes, Morphology, Pakistan, Vectors.

1. Introduction

The family *Culicidae* comprises approximately 3,500 mosquito species [1, 2] that are highly adaptive to human-modified ecosystems. These species most likely transmit various pathogens, including arboviruses that cause dengue, chikungunya and yellow fever; nematodes that cause lymphatic filariasis; and protozoa that cause malaria [3]. According to the World Health Organization [4], infections transmitted by arthropod vectors account for more than 700,000 deaths annually and place nearly 80% of the world's population at risk. Among these vectors, mosquitoes play a vital role in disease transmission [5].

Pakistan, with its predominantly rural population and growing urban economy, has a variety of mosquito species capable of transmitting several pathogens. One hundred and thirty four different mosquito species have been reported in the country, belonging to the subfamilies *Anophelinae* and *Culicinae* [6]. Of those species, 24 belong to the genus *Anopheles*. Notably, *Anopheles culicifacies* plays a key role in spreading malaria in rural areas, while *Anopheles stephensi* plays a similar role in urban areas [7-12].

Dengue fever, which affects 128 countries worldwide, is another major mosquito-transmitted disease, caused by *Aedes aegypti* and *Aedes albopictus* [13-15]. In Pakistan, dengue cases have surged from 22,938 in 2017 to 48,906 in 2021 [16, 17] and notably 25,932 cases reported between January 1 to 27 September, 2022 [18]. The Provinces of Khyber Pakhtunkhwa and Sindh are considered particularly vulnerable to dengue outbreaks [16-18].

Climatic conditions, such as rainfall, humidity, and temperature fluctuations, significantly influence mosquito populations, geographic distribution, and seasonal abundance [19]. The semi-arid to sub-tropical climate of Kohat District in

Pakistan is characterized by distinct thermal shifts and a bimodal rainfall pattern with high humidity that favors mosquito breeding. Investigations of mosquito diversity in both rural and urban environments, as well as its relationship with climatic variables, can provide valuable ecological and epidemiological insights. Such information is essential for developing vector surveillance and designing effective mosquito control strategies.

Despite its public health importance, a comprehensive information on mosquito species' diversity and seasonal abundance in district Kohat remained limited. In particular, systematic seasonal monitoring of mosquito populations has not been sufficiently documented. The local climate of Kohat is characterized by warm temperatures, seasonal rainfall, and periods of high humidity, that provides favorable conditions for mosquito breeding. Generating updated knowledge on species diversity and seasonal dynamics in this region can support the development of targeted vector control programs, contribute to improved public health planning, and reduce the socio-economic burden associated with mosquito-borne diseases. Therefore, the present study aimed to investigate the species composition and morphological characteristics and to analyze seasonal variations in mosquito abundance in selected localities of District Kohat, Khyber Pakhtunkhwa Province, Pakistan.

2. Materials and Methods

2.1 Study area

This study was conducted in District Kohat which is located in the southern region of Khyber Pakhtunkhwa Province, Pakistan (33°35'13"N, 71°26'29"E). The District covers an area of approximately 2,973 square miles and 1,768 feet above sea level. The climate is characterized by four distinct seasons: summer, winter, spring and autumn. The month of June is the hottest having an average temperature of 32.3°C, while January is the coldest month with an average temperature of 10.5°C. The average rainfall is 582 mm, annually. This study was conducted in four villages: Lachi, Usterzai, Togh Bala, and Jarma. These localities encompass diverse ecological settings, including agriculture fields, irrigation channels, stagnant water bodies, household storage containers, livestock shelters, and vegetated areas, all of which provide suitable breeding and resting habitats for mosquitoes.

2.2 Sampling

A total number of 10,740 adult mosquitoes were collected from indoor (bedrooms, livestock shelters) and outdoor (plants, stagnant water bodies, irrigation channels) localities. The sampling was done from January 2022 to December 2022. Collections were performed three times per month at each study site. Sampling was done during early evening time (17:00–20:00 h) to capture during the periods of peak mosquito activity.

The spray capture method was used to collect specimens indoors (bedrooms, livestock shelters and homes) using pyrethrum spray method. In this procedure, a pyrethroid-based insecticide was sprayed, and mosquitoes were collected 10 to 15 minutes later using forceps and aspirators. The outdoor collection was made from plants, vegetation and water habitats using hand nets, aspirators and light traps. The collected specimens were euthanized in killing jars containing cotton soaked with chloroform. Following collection, all the specimens were preserved in 80% ethyl alcohol, maintaining morphological features and minimizing tissue shrinkage or distortion as already reported in other study [20], till further analysis.

2.3 Identification

The preserved mosquitoes were examined under a stereomicroscope and identified to the species level following the taxonomic keys described in *The fauna of British India, including Ceylon and Burma* [21, 22].

2.4 Data analysis

Using the equation (1), relative abundance was computed [23].

$$\text{Relative abundance (\%)} = (l / L) \times 100 \quad \text{(Equation 1)}$$

Margalef's index of richness was used to determine mosquito species richness using equation (2) ($D_m g$) [24].

$$D_m g = (S - 1) / \ln N \quad \text{(Equation 2)}$$

Where, S represents the total number of species and N represents the total number of mosquitoes collected. The diversity of mosquitoes was determined by the Shannon-Weaver Index using equation (3) [25].

$$H = -\Sigma\, p_i \ln(p_i) \quad \text{(Equation 3)}$$

Where, p_i represents the proportion of mosquitoes of the i^{th} species in relation to the total number of mosquitoes.

2.5 Statistical analysis

The meteorological data, indicating temperature, rainfall and relative humidity, from January 2022 to December 2022 were retrieved from the Pakistan Metrological Department. The relationship between mosquito abundance and climate variables was analyzed by applying Spearman's correlation method.

3. Results

A total of 10,740 adult mosquitoes were collected during the study period, comprising 7,380 (69%) females and 3,360 (31%) males, indicating a clear predominance of female mosquitoes in the population. Taxonomic identification revealed seven species belonging to three genera, namely *Culex*, *Anopheles*, and *Aedes*. Among these, the genus Culex was the most dominant, accounting for 76% of the total collection, followed by *Anopheles* (22%) and *Aedes* (2%) (Table 1).

Within the genus *Culex*, *Culex quinquefasciatus* was the most abundant species (40%), followed by *Culex mimeticus* (22%) and *Culex theileri* (14%).

Table1. Species composition and abundance of mosquitoes collected from study area.

Species	Localities			
	Jarma Nos. (%)	Usterzai Nos. (%)	Lachi Nos. (%)	Togh Bala Nos. (%)
Culex quinquefasciatus	930 (31)	1,300 (42.3)	1,060 (37)	990 (53)
Culex mimeticus	620 (21)	870 (28.3)	550 (19.4)	350 (19)
Culex theileri	540 (18)	300 (10)	400 (14.1)	250 (13)
Anopheles stephensi	390 (13)	250 (8)	380 (13.4)	150 (8)
Anopheles culicifacies	240 (8)	180 (6)	360 (13)	70 (4)
Anopheles annularis	150 (5)	100 (3.2)	50 (2)	0
Aedes aegypti	110 (4)	70 (2.2)	30 (1)	50 (3)
Total Nos.	2,980 (28)	3,070 (29)	2,830 (26)	1,860 (17)

Table 2. Relative abundance and sex ratio of mosquitoes collected from study area.

Species	Abundance	Relative abundance (%)	Relative abundance status (RA)*	Male	Female	Sex ratio (male: female)
Culex quinquefasciatus	4,280	40	Dominant	1,260	3,020	2.39
Culex mimeticus	2,390	22	Dominant	830	1,560	1.87
Culex theileri	1,490	14	Dominant	500	990	1.98
Anopheles stephensi	1,170	11	Dominant	310	860	2.77
Anopheles culicifacies	850	8	Sub dominant	320	530	1.65
Anopheles annularis	300	3	Sub dominant	60	240	3.66
Aedes aegypti	260	2	Satellite	80	180	2.25

*Satellite species (RA< 3%), Sub-dominant species (RA=3-10%), Dominant species (RA >10%).

Table3. Species diversity, richness and evenness of mosquitoes in study area.

Locality	**Species diversity**	**Species richness**	**Species evenness**
Jarma	1.74	1.05	0.89
Usterzai	1.52	1.05	0.78
Lachi	1.61	1.06	0.82
Togh Bala	1.34	0.95	0.69

Table 4. Spearman's correlation values between mosquito abundance and climatic variables.

Parameters	Abundance	
	ρ -value	P-value
Temperature	0.93	0.00001
Relative humidity	-0.097	0.76
Precipitation/ rain fall	0.29	0.34

Among *Anopheles*, *Anopheles stephensi* (11%) was the leading species, followed by *Anopheles culicifacies* (8%) and *Anopheles annularis* (3%). The genus *Aedes* was represented solely by *Aedes aegypti* (2%) (Table 2). Based on relative abundance classification, four species were categorized as dominant, two as subdominant, and one as a satellite species, reflecting a clear hierarchical distribution of mosquito species in the study area.

Spatial variation in mosquito distribution across the four study localities revealed notable differences. The highest number of mosquitoes was recorded in Usterzai (3,070; 29%), followed closely by Jarma (2,980; 28%), while Lachi (2,830; 26%) and Togh Bala (1,860; 17%) exhibited comparatively lower abundances (Table 1). *Culex quinquefasciatus* consistently remained the dominant species across all localities, particularly in Togh Bala, where it accounted for

53% of the total catch. In contrast, *Anopheles annularis* was absent in Togh Bala, indicating localized ecological constraints affecting species distribution.

Diversity indices further highlighted spatial heterogeneity among the study sites. The highest species diversity was observed in Jarma (H = 1.74), followed by Lachi (H = 1.61) and Usterzai (H = 1.52), whereas Togh Bala exhibited the lowest diversity (H = 1.34) (Table 3). Species richness was relatively similar across sites, ranging from 0.95 to 1.06, while species evenness varied more substantially, with the highest evenness recorded in Jarma (0.89) and the lowest in Togh Bala (0.69). These findings suggest that although species numbers were comparable, their distribution was more balanced in some localities than others.

Seasonal variation in mosquito abundance demonstrated a clear temporal pattern. Mosquito populations began to increase gradually from March, peaked sharply in June (5,260 individuals), and exhibited a secondary peak in August. The lowest abundance was recorded during the winter months, particularly in January and February, where mosquito activity was minimal. Following the peak season, a steady decline in population was observed from September to December, indicating strong seasonal regulation of mosquito dynamics.

Correlation analysis revealed that temperature was the primary driver of mosquito abundance, showing a strong positive and statistically significant relationship ($\rho_s = 0.93$, $P < 0.001$) (Table 4; Figures 1–3). In contrast, rainfall exhibited a weak positive correlation ($\rho_s = 0.29$, $P = 0.34$), while relative humidity showed a weak negative correlation ($\rho_s = -0.097$, $P = 0.76$). These results indicate that temperature plays a dominant role in influencing mosquito population fluctuations in the study area, whereas rainfall and humidity have comparatively limited effects.

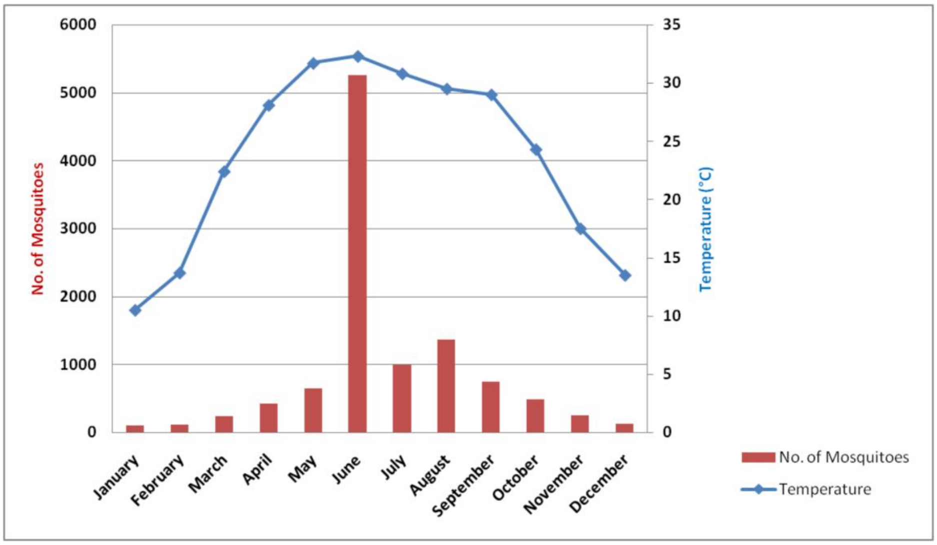

Figure 1. Relationship between temperature and mosquito abundance in Kohat, Jan-Dec, 2022.

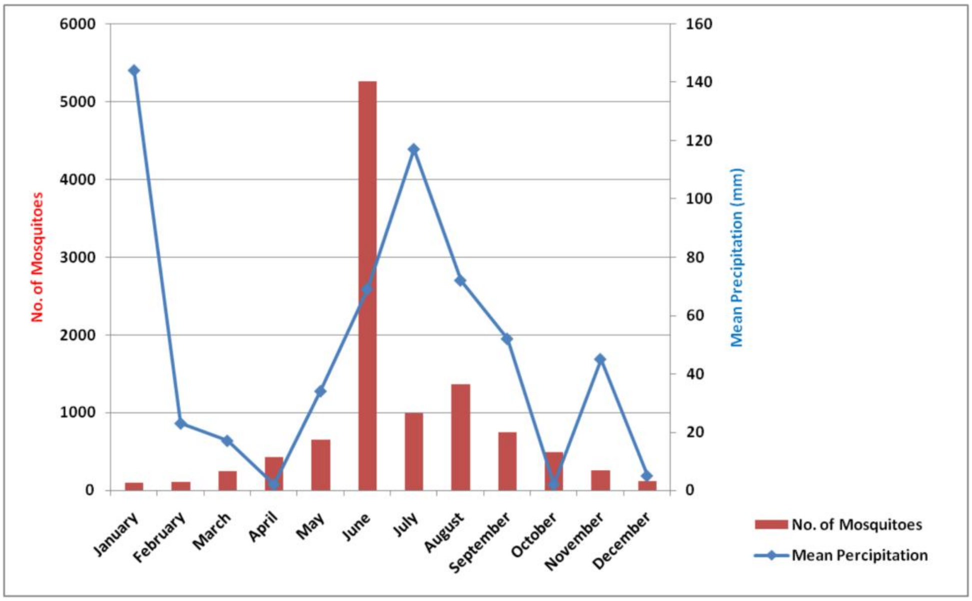

Figure 2. Relationship between precipitation and mosquito abundance in Kohat, Jan-Dec, 2022.

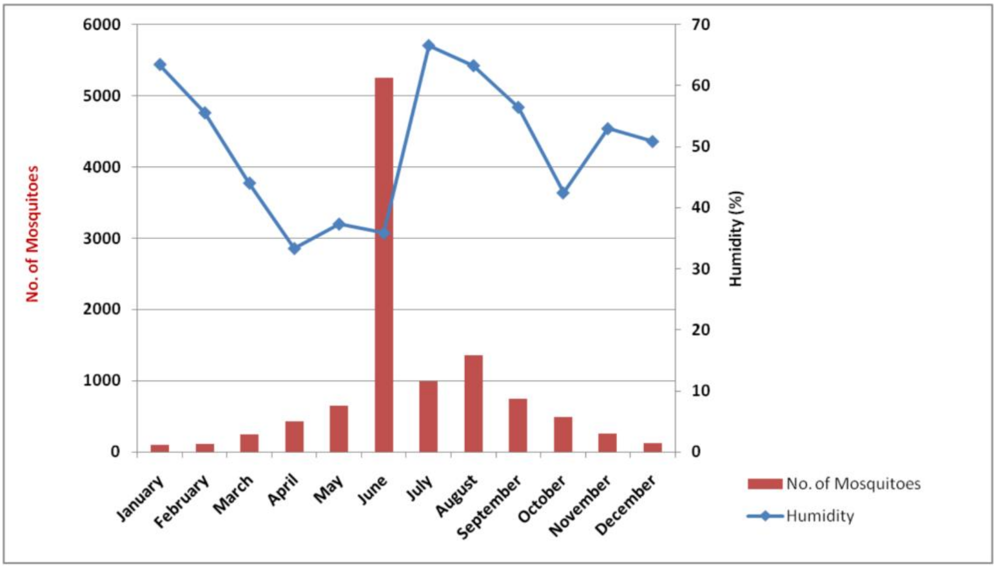

Figure 3. Relationship between humidity and mosquito abundance in Kohat, Jan-Dec, 2022.

4. Discussion

The current study investigated the abundance and diversity of mosquito species in selected areas of District Kohat and examined their relationship with environmental and seasonal factors, providing insights for targeted vector control strategies. A total of seven species belonging to the genera *Culex, Anopheles,* and *Aedes* were recorded, with specific species like: *Culex mimeticus*, *Culex theileri*, *Anopheles stephensi*, *Anopheles culicifacies*, *Anopheles annularis*, and *Aedes aegypti*. The presence of *Aedes aegypti* poses a persistent risk for dengue fever and chikungunya, while various *Anopheles* species serve as primary vectors for malaria. Furthermore, the detection of *Culex* mosquitoes indicates potential transmission cycles for West Nile fever and lymphatic filariasis. This study demonstrated a predominance of the genus *Culex*, especially *Culex quinquefasciatus*, throughout the sampling period. The dominance of *Culex* species was frequently reported in other ecological surveys across Pakistan, suggesting that this genus possesses a high degree of ecological adaptability and thrives in both rural and urban environments [9,11,24].

Our study limits the different disease outbreaks or incidence rates caused by these vectors in the study area. However, the seasonal abundance and distribution of these specified species could help implementing effective control strategies in the area. Historical records from Kohat and Hangu Valley in the 1960s reported 35 species (13 *Anophelines*, 22 *Culicines*) [26], and the more recent study in the southern belt of Khyber Pakhtunkhwa reported 14 mosquito species within the Kohat region [27]. The comparatively lower species richness recorded in our study (seven species) may be attributed to several factors. Anthropogenic alterations to ecosystems such as rapid urbanization, expansion of sewage system and subsequent reduction of freshwater habitats, likely disrupt mosquito biodiversity and altered vector distribution patterns. Such ecological shifts often favor generalist species while displacing those with niche environmental requirements [28,29]. Furthermore, methodological differences may account for this variation; while previous investigations utilized a broader geographical scope and employed additional trapping methods for both larval and adult stages, the present study was restricted to specific rural localities using adult collection techniques, including mosquito nets, aspirators, light traps, and spray catches [26, 27].

Several studies have documented the mosquito fauna of different regions of Pakistan. For instance, 29 species were documented in both the Changa Manga Forest [30] and Lahore [31]. Within Khyber Pakhtunkhwa, Swat recorded 21 species [11], and Peshawar documented up to 31 species [32]. Conversely, more localized studies in Upper Dir [33] and the Palosai stream in Peshawar [9] reported only 9 species each. These variations highlight how localized ecological niches and the degree of environmental modification dictate vector biodiversity across the province. The presence of *Anopheles culicifacies* and *Aedes aegypti* in the current study, despite their absence in high-altitude surveys likes those in Upper Dir [33], suggests that the specific environmental profile of Kohat remains a permissive niche for those medically important vectors.

Climatic factors such as rainfall, humidity and temperature play a crucial role in shaping mosquito population dynamics by influencing breeding, larval development, survival, and dispersal patterns [34-36]. The results of present study revealed a strong positive correlation between temperature and mosquito abundance (ρ_s=0.93, *P<0.001*), indicating that temperature is the master regulator of mosquito density in the region. This exceptionally strong correlation suggests that the thermal profile of District Kohat is currently optimized for the physiological acceleration of mosquito life cycle. As demonstrated by Ciota et al. [37], elevated temperatures reduce the duration of the gonotrophic cycle and accelerated larval development, leading to rapid population turnover. Furthermore, heat significantly shortens the extrinsic incubation period of pathogens within the vector, thereby increasing the risk of transmission [37].

In contrast, the relationship between mosquito abundance and other climatic factors was found to be statistically weak. Rainfall exhibited a marginal positive correlation (ρ_s=0.29, P=0.34), reflecting its dual role in regulating mosquito populations. While moderate precipitation can increase breeding by creating temporary larval habitats, excessive rainfall may reduce populations by flushing larvae from breeding sites [38]. The weak correlation observed in this study suggested that mosquitoes in these rural localities may rely more on permanent, anthropogenic water sources than on transient rainfall. Furthermore, relative humidity demonstrated a weak negative correlation (ρ_s=-0.097, P=0.76), indicating a limited influence on population density during the sampling period. These results highlight the complexity of mosquito climate interactions, which vary significantly across different geographical contexts. For example, research in the Eastern Province of Saudi Arabia reported a positive association between mosquito abundance and both humidity and rainfall, but a negative relationship with temperature [39]. Similarly, studies in Central Iran documented a significant negative correlative between humidity and mosquito abundance [40], while findings from Nigeria indicated that population densities were strongly influenced by both temperature and rainfall [38]. Conversely, investigations in Northern Malaysia reported no correlation between rainfall and *Anopheles* populations [41]. These complex species-specific and non-linear interactions between climatic variables and mosquito population emphasize the importance of localized ecological studies for the development of effective vector control strategies [42].

The predominance of *Culex* and *Anopheles* observed in this study suggests that control efforts should focus on the elimination of stagnant water sources, the improvement of drainage systems, and community-based sanitation initiatives to reduce mosquito breeding habitats. These findings necessitate a transition toward climate informed Integrated Vector Management in District Kohat. The high predictive value of temperature data allows health authorities to move beyond reactive measures toward a proactive surveillance model. Integrating climatic data into public health surveillance can facilitate the development of early warning systems that trigger larval control and community awareness campaigns approximately two weeks prior to fore-casted thermal peaks [39]. Since rainfall was not the primary driver in these rural localities, resources allocation should prioritize sources reduction in permanent water storage and drainage infrastructure rather than focusing solely on post monsoon interventions.

5. Conclusion

The present study provided the diversity and abundance of mosquito species and their seasonal variations in rural settings of District Kohat, Pakistan. Mosquito abundance with seven different identified species showed clear seasonal variation and was positively associated with temperature. The current study findings highlighted the importance of implementing mosquito control measures from early spring to autumn, when mosquito populations increase. Such measures may help reduce the risk of mosquito-borne disease such as malaria and dengue in the region. Future research should utilize molecular techniques for pathogen screening and insecticide resistance profiling to enhance vector control precision. Additionally, high-resolution GIS modeling is needed to map spatial risk zones based on localized climatic variables.

Author contributions

Zainab Bano: Conceptualization, Methodology, Investigation, Writing-original draft. Noor ul Akbar: Data curation, Formal analysis, Writing-review & editing. Mubbashir Hussain: Investigation, Sampling, Species identification. Muzamil Shah: Investigation, Sampling, Species identification. Muhammad Yaser Khan: Formal analysis, Validation, Writing-review & editing. Shahid Niaz Khan: Supervision, Project administration, Validation. All authors have read and approved the final manuscript for publication.

Ethical approval

This study protocol was approved by the Ethical Committee of Kohat University of Science and Technology, Kohat, following the research ethics guidelines and protocols vide approval letter No. 627.

Conflicts of Interest

The authors report no conflicts of interest.

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Data availability statement

The data presented in this study are available on request from the corresponding author.

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