IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Seasonal Variation In Water Temperature And Ph Regulating *Anopheles* Larval Ecology In Urban Bikaner (Western Rajasthan)

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Abstract :

The ecological success of malaria vectors in arid urban landscapes is intricately linked to water quality parameters, particularly temperature and pH. This study investigates the seasonal influence of these variables on the larval ecology of *Anopheles stephensi*, *Anopheles subpictus*, *Anopheles culicifacies*, and *Anopheles annularis* across three urban habitats in Bikaner, Rajasthan, from January 2022 to December 2023. Results indicate that larval development peaked during spring and monsoon seasons, when water temperatures ranged between 18–28 °C and pH levels remained neutral to slightly alkaline (7.0–7.6). In contrast, the during peak summer season brought thermal extremes and acidic conditions (pH 6.4–6.6), significantly reducing larval abundance. Species-specific trends emerged: *An. stephensi* exhibited year-round adaptability, particularly in anthropogenic containers; *An. subpictus* and *An. annularis* favoured shaded, vegetated pools during monsoon months; while *An. culicifacies* was more abundant in peri-urban seepage zones and semi-natural habitats ,these species preferred buffered habitats during monsoon and post-monsoon. Among the three study sites, Central Public Park maintained the most stable larval habitats due to consistent irrigation and canopy coverage. These findings emphasize the species-specific physicochemical thresholds that regulate mosquito breeding and underscore the need for climate-adaptive, habitat-specific vector surveillance in urban malaria control strategies.

Keywords: urban mosquito breeding, water temperature, pH, seasonal variation, vector control, climate adaptation.

1. Introduction

Vector-borne diseases, particularly malaria, remain a major public health challenge worldwide, especially in tropical and subtropical regions. Malaria is caused by protozoan *Plasmodium* parasites and transmitted exclusively through the bite of infected female *Anopheles* mosquitoes. Of the approximately 465 known *Anopheles* species, only around 30 are regarded as competent malaria vectors (Sinka *et. al.,* 2012). In 2022 alone, over 249 million cases and 600,000 deaths were reported globally (WHO, 2022). India contributes nearly 70% of Southeast Asia's malaria burden, underlining the importance of local ecological monitoring and region-specific interventions.

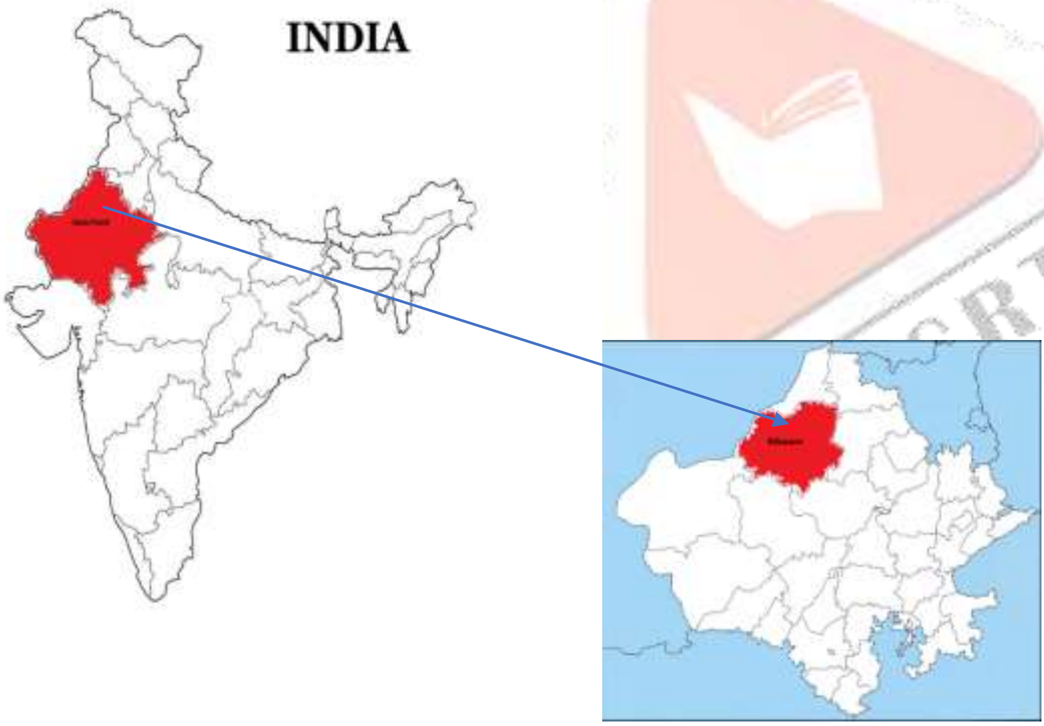
The ecological success of *Anopheles* mosquitoes is strongly influenced by climatic and environmental factors such as temperature, humidity, rainfall, salinity, and pH. Among these, water temperature and pH are critical determinants of larval development and survival. Temperature regulates metabolic activity, larval moulting, and developmental timing; whereas pH influences ion exchange, enzymatic function, and physiological balance. *Anopheles* larvae typically perform best within 20–30 °C and a pH range of 6.8 to 8.0, with deviations beyond these ranges such as summer heatwaves or acidic stormwater causing developmental delays or increased larval mortality (Beck-Johnson *et. al.,* 2013).

As climate variability intensifies, altered rainfall patterns and extreme weather events are reshaping the seasonal activity and geographic distribution of mosquito vectors. While warmer conditions may shorten the parasite's extrinsic incubation period (EIP), environmental extremes such as high evaporation and acidic runoff may reduce habitat stability and suppress vector populations, particularly in arid urban landscapes.

Bikaner, located in Rajasthan's Thar Desert, exemplifies such conditions, with harsh summers exceeding 48 °C, erratic monsoons, and limited natural freshwater systems. However, the spread of anthropogenic water containers, seepage zones from irrigation canals, and shaded urban ponds create temporary but critical larval habitats. Past entomological surveys have shown that *Anopheles stephensi* breeds year-round in domestic containers, while *An. subpictus* appears seasonally during monsoon, especially in vegetated urban pools. *An. culicifacies* India's most efficient malaria vector in rural and peri-urban zones is increasingly recorded in canal seepage and agricultural drainages near city margins, demonstrating ecological plasticity. Similarly, *An. annularis*, typically found in fields and organically enriched habitats, has adapted to slow-flowing irrigation channels in Bikaner's periphery. These vectors exhibit distinct seasonal patterns, habitat preferences, and responses to water chemistry, making them vital indicators of ecological change. Despite extensive national studies, few investigations have integrated climate-sensitive water chemistry profiles with vector population dynamics in arid urban ecosystems like Bikaner. This study addresses that gap by examining the seasonal influence of water temperature and pH on larval development and abundance of *An. stephensi*, *An. subpictus*, *An. culicifacies*, and *An. annularis* over a two-year period (January 2022–December 2023) across three ecologically distinct urban habitats.

2. Study Area:-

The study was conducted in Bikaner district (28.02°N, 73.31°E) in northwestern Rajasthan, a semi-arid region characterized by extremely hot summers reaching up to 50°C, short-lived monsoons, and limited freshwater availability. To capture the urban ecological variability, three distinct sites were selected within the city. JNV Colony represents a densely populated residential zone with widespread use of overhead tanks, rooftop containers, and cemented open drains, all of which serve as potential anthropogenic mosquito breeding habitats. Bichhwal Area lies on the peri-urban fringe and is typified by wastewater ponds, canal seepage zones, and irrigation-fed pools associated with nearby agricultural activity, offering semi-natural aquatic habitats. In contrast, the Central Public Park functions as a managed green space maintained by the municipal corporation, featuring seasonal ornamental fountains, shallow water basins, and shaded vegetation that provide intermittent yet suitable conditions for mosquito proliferation. These three sites collectively offer a spectrum of aquatic habitat conditions essential for understanding species-specific mosquito breeding patterns across urban gradients.



3. Materials and Methods :

Water sampling and mosquito larval surveillance were conducted monthly from January 2022 to December 2023 at three study sites in Bikaner. Field visits were carried out between 8:00 AM and 10:00 AM to reduce the effect of temperature variations. Various aquatic habitats including overhead tanks, buckets, cattle troughs, ponds, construction site puddles, and pipe leakages were sampled based on the presence of stagnant water, visible mosquito breeding activity, and ease of access. At each site, water temperature and pH were measured using standard field instruments. Larval species composition and habitat preference of *Anopheles* mosquito in selected area in Bikaner All data were recorded monthly and categorized seasonally as winter (November–February), summer (March–June), monsoon (July–October) to examine changes in larval habitats and water conditions over time.

4. Result :

During the observation period from January 2022 to December 2023, larval surveillance across three selected urban sites in Bikaner JNV Colony, Bichhwal Area, and Central Public Park revealed the presence of four *Anopheles* species: *Anopheles subpictus*, *An. stephensi*, *An. culicifacies*, and *An. annularis*. Among these, *An. subpictus* exhibited the highest overall larval density (34.7%), followed closely by *An. stephensi* (33.3%), *An. culicifacies* (18.0%), and *An. annularis* (12.1%).

Table:1 Larval species composition and habitat preference of *Anopheles* in selected area in Bikaner

Species Name	Abundance (%)	Seasonal Presence	Habitat Preference
Anopheles subpictus	34.7%	Monsoon	Ponds, cattle troughs, vegetated pools
Anopheles stephensi	33.3%	Year-round (peak in summer)	Urban tanks, overhead containers, drains
Anopheles culicifacies	18.0%	Spring to late monsoon	Construction sites, pipe leaks, puddles
Anopheles annularis	12.1%	Monsoon	Algae-rich ponds

Table 2: Monthly average data of Water Temperature and pH (During 2022–2023) of JNV Colony Bikaner

Month	Temp (°C, 2022)	pH (2022)	Temp (°C, 2023)	pH (2023)
January	8.9	7.4	7.9	7.3
February	10.4	7.5	8.9	7.4
March	14.8	6.9	13.4	6.9
April	18.6	7.1	18.4	7.1
May	27.8	7.2	26.8	7.2
June	30.1	6.7	29.4	6.7
July	22.1	6.4	23.6	6.4
August	19.4	6.6	19.4	6.6
September	20.3	6.4	19.8	6.4
October	18.3	7.4	18.6	7.4
November	16.4	7.8	16.2	7.8

December	11.2	7.7	9.8	7.7

Interpretation: In JNV Colony, larval development was most favourable in April and May, when temperatures ranged from 18.4°C to 26.8°C and pH remained stable at 7.1–7.2. During monsoon (July–October), acidic pH (6.4–6.6) combined with high temperatures (>29°C) likely suppressed larval growth. monsoon months showed recovery in both parameters, supporting renewed larval activity. Winter temperatures remained low (<11°C), which may have slowed development despite alkaline pH.

Table:3 Monthly average data of Water Temperature and pH (During 2022–2023) of Bichhwal Area Bikaner

Month	Temp (°C, 2022)	pH (2022)	Temp (°C, 2023)	pH (2023)
January	8.1	7.2	7.5	7.3
February	9.6	7.5	8.4	7.4
March	15.4	6.9	12.9	6.9
April	19.3	7.1	21.6	7.1
May	28.1	7.2	29.8	7.2
June	21.1	6.7	31.2	6.7
July	28.4	6.4	28.9	6.4
August	25.3	6.6	26.2	6.6
September	21.6	6.4	22.1	6.4
October	18.9	7.2	18.5	7.2
November	16.1	7.5	15.9	7.5
December	12.3	7.8	9.2	7.8

Interpretation: Bichhwal area showed ideal larval conditions in May, with temperature near 29.8°C and pH at 7.2. Summer months (March–August) brought thermal stress and acidic pH (6.4–6.6), likely reducing suitability. Monsoon recovery was evident with moderate temperature (15.9–18.5°C) and pH up to 7.5. Winter conditions were chemically stable, but low temperatures likely limited larval activity.

Table : 4 Monthly average data of Water Temperature and pH (During 2022–2023) of Central Public Park Bikaner

Month	Temp (°C, 2022)	pH (2022)	Temp (°C, 2023)	pH (2023)
January	8.5	7.4	7.4	7.3
February	10.1	7.4	8.3	7.5
March	13.5	7.6	12.9	7.7
April	18.2	6.8	17.9	7.6
May	27.3	6.9	25.8	6.8

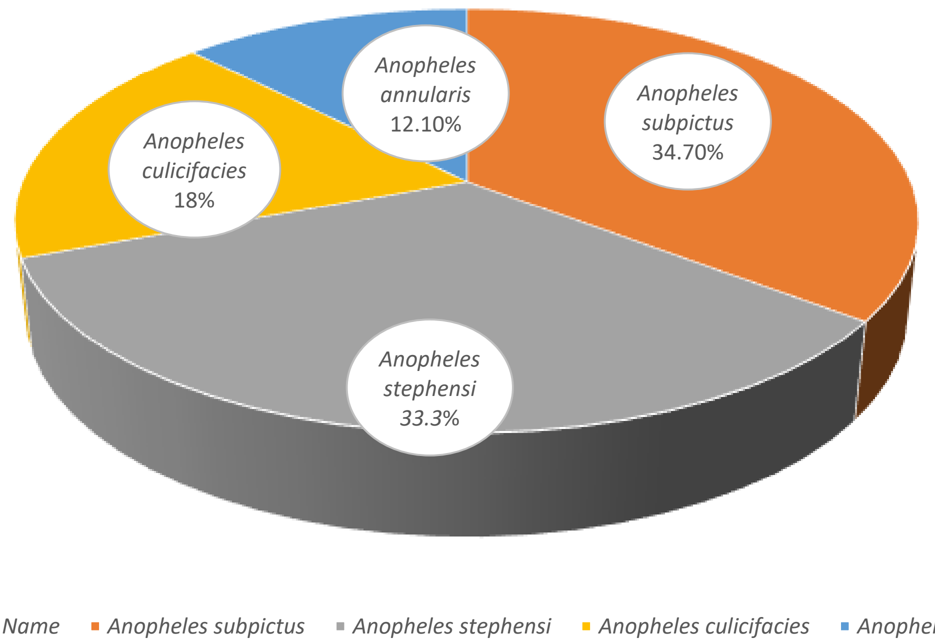
June	29.8	6.7	28.6	6.6
July	30.4	7.1	22.5	6.5
August	28.7	7.2	19.3	6.7
September	26.1	6.8	19.7	6.8
October	19.2	7.4	18.8	7.2
November	16.3	7.6	15.5	7.2
December	10.4	7.7	8.6	7.4

Interpretation: Central Park maintained the most stable habitat, likely due to irrigation and vegetation. In months March to May had optimal temperature (17.9–25.8°C) and pH (6.8–7.6). Even during monsoon, buffered conditions supported some larval survival and the is pH (7.2–7.6) and temperature (15.5–18.8°C) again favoured development, making it the most consistent breeding site.

Table 5: Optimal Conditions of larval development all *Anopheles* species

Parameter	Optimal Range	Observed Range (Bikaner)	Suitability Impact
Temperature (°C)	18–28	7.4–31.2	Optimal in monsoon
Ph	7.0–7.8	6.4–7.8	Acidic pH (<6.6) reduces survival
Combined Effect	Temp + pH synergy	Variable by season	Moderate in monsoon, High in Apr–May

Fig:1 Larval species composition of *Anopheles* in Bikaner



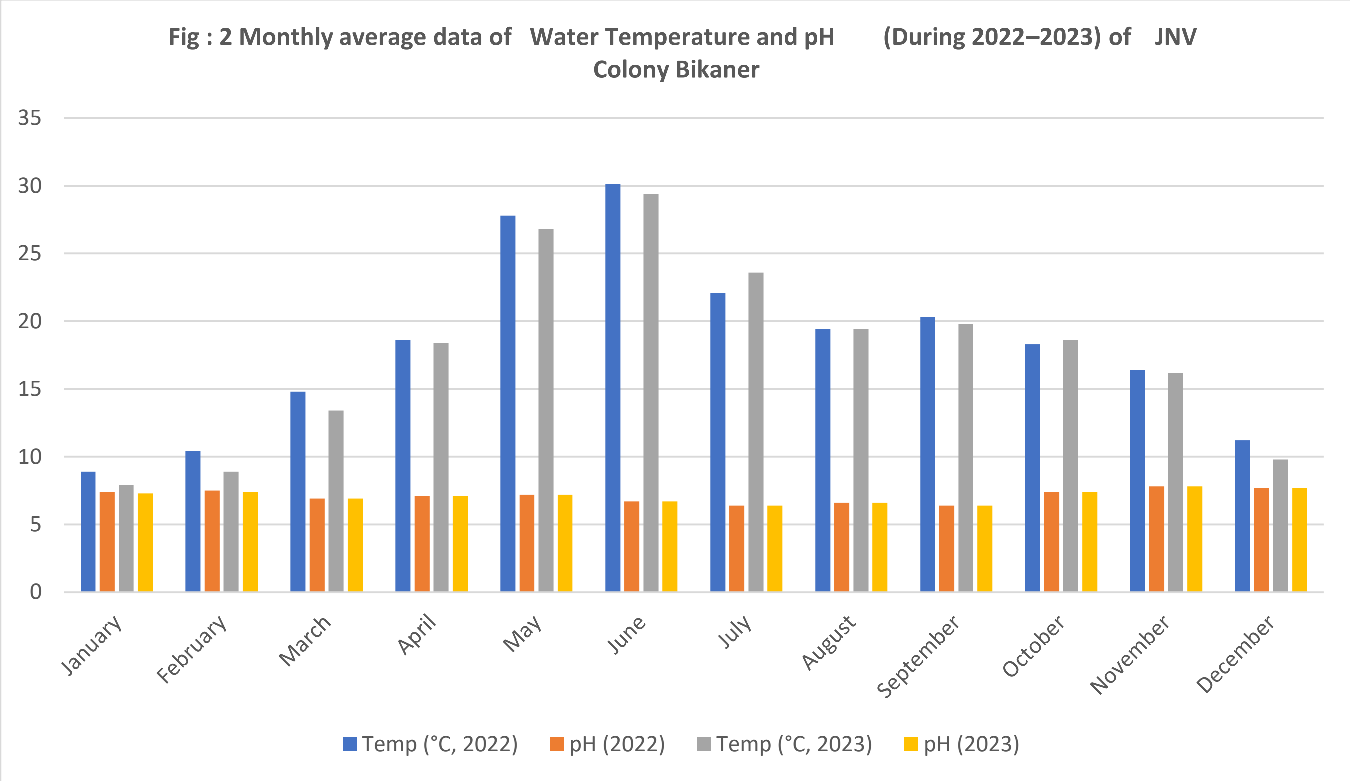


Fig : 2 Monthly average data of Water Temperature and pH (During 2022–2023) of JNV Colony Bikaner
35
30
25
20
15
10
5
0
January
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March
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November
December
Temp (°C, 2022)
pH (2022)
Temp (°C, 2023)
pH (2023)

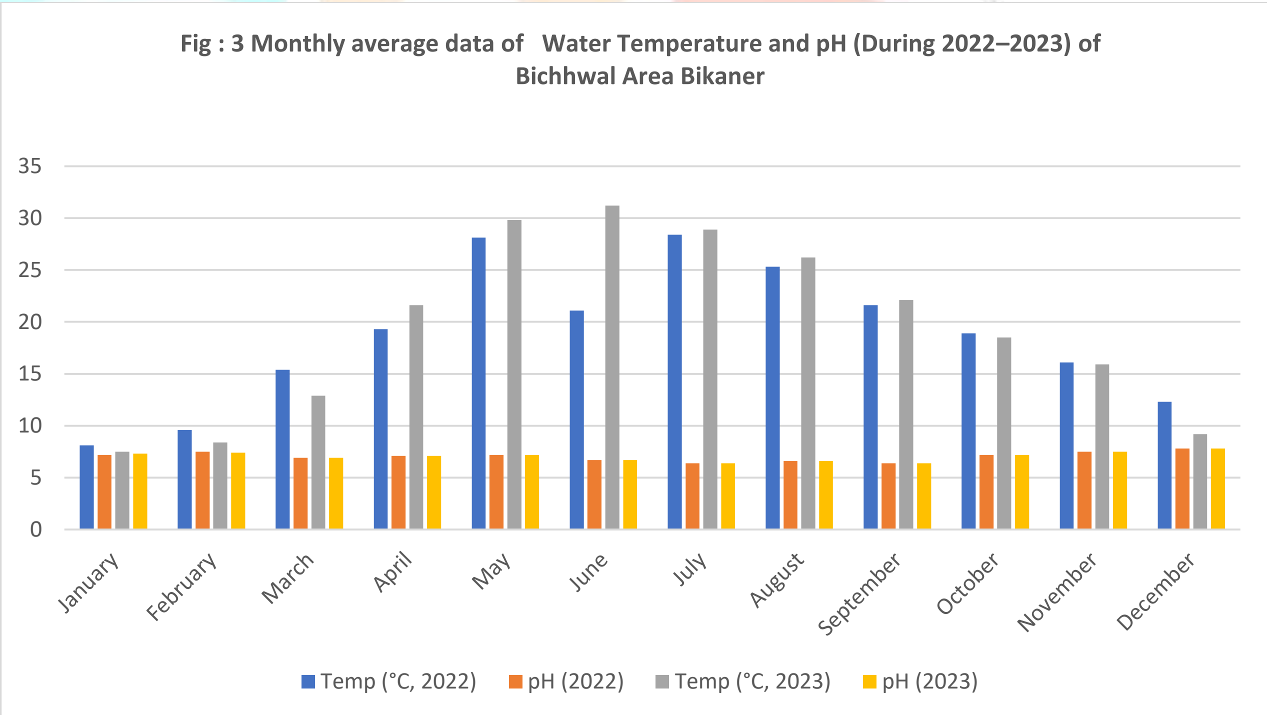
Fig : 3 Monthly average data of Water Temperature and pH (During 2022–2023) of Bichhwal Area Bikaner
35
30
25
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0
January
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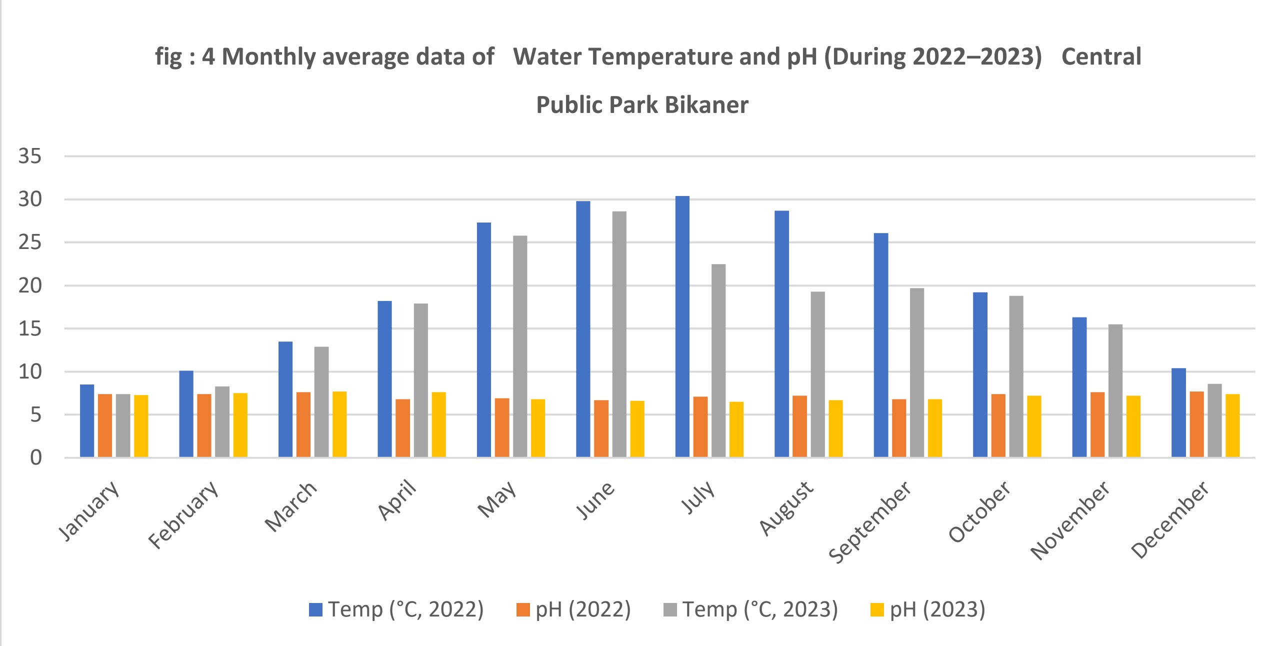
Temp (°C, 2022)
pH (2022)
Temp (°C, 2023)
pH (2023)



Water temperature and pH showed distinct seasonal variation across the study sites, directly influencing larval development. During the winter months (November to February), water temperatures remained low (7.4°C to 10.5°C), and pH levels were neutral to slightly alkaline (7.2–7.7) (Table 2-4) (fig 2-4). While these conditions supported limited larval presence, low temperatures restricted developmental rates. As summer (March to June) progressed, water temperatures rose steadily from around 13°C to nearly 30°C, and pH values stayed within the optimal range (6.9–7.2). These months especially April and May offered the most favourable conditions for larval development, with high larval presence and stable water chemistry recorded across all three sites. In summer to monsoon season (June to august) brought high temperatures, sometimes exceeding 30°C, and pH levels declined to acidic ranges (6.4–6.6). These harsher conditions led to a visible reduction in larval presence particularly in sun-exposed, ephemeral water bodies. However, in shaded and vegetated habitats such as Central Public Park, larval development continued under buffered pH conditions and moderated temperatures due to canopy coverage and irrigation, making it most ecological stable breeding zone. *An. stephensi* was observed throughout the year, showing strong adaptability to urban containers such as overhead tanks and domestic storage vessels. *An. subpictus* showed highest densities during the monsoon season, preferring semi-natural, vegetated water bodies. *An. culicifacies* was recorded from spring through monsoon, breeding in temporary puddles, leaking pipelines, and construction site water collections highlighting its opportunistic nature. *An. annularis*, though less frequent, was recorded only during the monsoon in algae-rich, stagnant ponds, indicating its preference for stable, vegetated aquatic habitats.

Site-wise observations confirmed these patterns. JNV Colony supported year-round breeding of *An. stephensi*, particularly in man-made containers with relatively consistent pH and temperature. *An. culicifacies* was most common in Bichhwal Area, where irrigation overflow, canal seepage, and semi-natural pools provided ideal habitats during the warmer months. Central Public Park, with its shaded fountains, algae-rich basins, and tree cover, supported high densities of *An. subpictus* and *An.*

annularis during the monsoon season. These findings emphasize how species-specific habitat preferences, combined with seasonal water quality variation, play a critical role in shaping the local distribution and abundance of malaria vectors in urban Bikaner.

5. Discussion

The present study underscores the ecological significance of water temperature and pH in regulating the seasonal dynamics of *Anopheles* larval development in the arid urban landscape of Bikaner, Rajasthan. Across all three study sites JNV Colony, Bichhwal Area, and Central Public Park larval suitability was highest during April–May and October–November, when water temperatures ranged between 18–28°C and pH remained within the neutral to slightly alkaline range (7.0–7.6). These findings are consistent with the laboratory observations of Kaur and Kocher (2015), who reported 100% larval mortality of *Anopheles* at pH 3.0 and significantly delayed development at pH 4.0–5.0.

During the monsoon period (July–September), despite increased water availability, larval abundance declined sharply. This reduction coincided with acidic pH values (6.4–6.6) and elevated temperatures (29°C), which are known to impair larval physiology. Vishwas (2021) demonstrated that larval emergence of *An. stephensi* and *An. subpictus* was optimal at pH 7.0–7.5 and temperatures between 24–28°C, with significant suppression at pH <6.6 or temperatures >32°C. Similar findings were reported by Akeju *et. al.,* (2022), who observed that acidic pH and high conductivity negatively impacted *Anopheles* larval abundance in urban Nigeria.

Species-specific responses observed in this study further reinforce the role of physicochemical thresholds in shaping vector ecology. *An. stephensi*, a known urban vector, was present year-round and tolerated moderate fluctuations in pH and temperature, consistent with its adaptability to artificial containers (Tyagi *et. al.,* 2010). In contrast, *An. subpictus* showed peak abundance in monsoon months, favouring vegetated pools with buffered pH and moderate temperatures, as also noted by Surendran *et. al.,* (2011) in Sri Lanka. *Anopheles culicifacies,* typically a rural species, was found in Bichhwal Area, particularly during spring and early monsoon, when canal seepage, irrigation overflow, and puddled construction sites offered warm, semi stable conditions. Water bodies with pH between 6.8–7.2 and temperatures around 27–30°C supported its development. Similar pattern was recorded in Rajasthan by Kumawat and Yadav (2017) and in semi-urban Gujarat by Singh *et. al.,* (2013). *Anopheles annularis* was the least frequently observed, restricted to late monsoon (August–October) in Central Public Park, where algae-rich, shaded ponds held pH close to 7.4 and temperature between 22–24°C. Its narrow niche aligns with ecological findings by Das *et. al.,* (2008) in eastern India and Kocher and Tyagi (2010), who identified *An. annularis* as a species favouring clean, vegetated, and thermally buffered habitats.

Among the three sites, Central Public Park consistently maintained more stable physicochemical conditions, likely due to regular irrigation and vegetative shading. This buffering effect reduced thermal and pH extremes, supporting larval development even during marginal seasons. Similar site-specific buffering effects have been documented by Dery *et. al.,* (2010) in Ghana and Joshi *et. al.,* (2005) in the Thar Desert.

The findings of this study align with a broad body of literature emphasizing the importance of water quality not just water presence in determining mosquito breeding success. Muturi *et. al.,* (2021) and Multini *et. al.,* (2021) reported that acidic pH, high salinity, and elevated temperatures significantly reduced larval emergence in African and Brazilian habitats. In India, Singh *et. al.,* (2013) and Bansal *et. al.,* (1994) observed similar trends in Rajasthan and Gujarat, where physicochemical stressors suppressed larval development despite water availability.

From a climate change perspective, rising temperatures and erratic rainfall patterns may further compress the seasonal windows of larval suitability. Afrane *et. al.,* (2012) and Omumbo *et. al.,* (2010) reported that warming trends in East Africa shifted *Anopheles* distributions into higher altitudes and altered breeding cycles. Yamana and Eltahir (2013) showed similar outcomes in the Sahel, predicting shorter but more intense breeding bursts under warming scenarios. In Bikaner, increasing summer heat and declining water quality may reduce larval survival windows but also accelerate development cycles, potentially increasing vector density in shorter intervals.

The ecological thresholds *identified* in this study pH 7.0–7.6 and temperature 18–28°C are consistent with global reviews by Leather (2010), Abiodun *et. al.,* (2016), and Kondrachine (1992), reinforcing their relevance across diverse geographies. These thresholds also align with WHO guidelines for larval source management, which emphasize the importance of targeting physiochemically favourable habitats (WHO, 2005). The observed patterns have direct implications for vector control planning. Kocher *et. al.,* (2010) and Das *et. al.,* (2008) emphasized that integrating environmental monitoring with larval surveillance enhances the precision of malaria control strategies. In arid urban settings like Bikaner, where water quality fluctuates sharply, incorporating pH and temperature monitoring into routine surveillance can help identify high-risk periods and optimize larvicidal interventions.

6. Conclusion :

This study demonstrates that water temperature and pH are critical ecological factors shaping the seasonal breeding patterns of *Anopheles stephensi*, *An. subpictus*, *An. culicifacies*, and *An. annularis* in the arid urban environment of Bikaner. The highest larval suitability was recorded in April–May and October–November, when water temperatures remained within 18–28°C and pH levels ranged from 7.0 to 7.6, providing favourable conditions for larval development across all species. larval abundance declined markedly during the monsoon months (July–September) due to increased water temperatures and lower pH values (6.4–6.6), highlighting the physiological vulnerability of mosquito larvae to acidic and thermally stressed aquatic environments. *An. stephensi* was present throughout the year, thriving in urban containers with stable water conditions. *An. subpictus* was most abundant in

September–November, preferring shaded, vegetated habitats with chemically buffered water. *An. culicifacies* appeared primarily in March–July, especially in seepage zones, puddles, and temporary habitats linked to irrigation. *An. annularis* was recorded only during August–October, favouring stagnant, algae-rich ponds under shaded conditions. Site-wise, Central Public Park offered the most stable larval habitat due to regular irrigation and canopy cover, while JNV Colony and Bichhwal Area experienced greater seasonal and physicochemical fluctuations. The study reveals that water quality particularly temperature and pH plays a more decisive role than water quantity in determining Anopheles breeding success. Incorporating simple environmental monitoring of these parameters into routine mosquito control programs can greatly improve timing, targeting, and overall effectiveness of vector management. In cities like Bikaner, where vector ecology is tightly linked to seasonal water chemistry, such evidence-based strategies are essential for advancing malaria prevention and elimination goals.

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