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Integrating Ecological Surveillance and Habitat Analysis for Vector Control: A Case Study of Mosquito Populations in Post-Disaster Baluchistan

Shay Chirag[1] (Corresponding Author), **Parvez Jan[2]**, **Muhammad Askani[3]**, **Alishba Zahid[4]**, **Farid Asif Shaheen[5]**

[1], MSc Hons student, Department of Entomology, University of Agriculture Faisalabad, Pakistan, shay33chirag44@gmail.com

[2], MSc Hons student, Institute of Horticultural Sciences, University of Agriculture Faisalabad, Pakistan, parvezjan032@gmail.com

[3], MSc Hons student, Department of Horticulture, Sindh Agriculture University, Tando Jam, Pakistan, muhammadaskani402@gmail.com

[4], MSc Hons student, Department of Entomology, PMAS Arid Agriculture University, Rawalpindi, Pakistan, alishbazahid006@gmail.com

[5], Associate professor, Department of Entomology, PMAS Arid Agriculture University, Rawalpindi, Pakistan, shaheen@uaar.edu.pk

Abstract

Mosquitoes (Culicidae: Diptera) are major vectors causing diseases in humans and animals. This paper evaluated the mosquito diversity, breeding habitat and environmental drivers of five flood-prone districts in Balochistan, which include Quetta, Kech, Panjgur, Gwadar and Lasbella. Sampling was carried out in diverse habitats such as stagnant water, open drains, construction pits, vegetation, junkyards and residential places. The larvae and adults have been preserved in ethanol and distinguished with the help of morphological keys. The water quality parameters, such as pH, electrical conductivity (EC) and dissolved oxygen (DO) measured along with the temperature of each site. A total of 15,349 specimens representing four genera (Culex, Aedes, Anopheles and Armigeres) of mosquitoes were isolated. The indices of diversity showed moderate variation at the genus level with maximum values of Shannon-Wiener in Gwadar City, Paroom and Killi Ismail. Culex prevailed in most of the habitats, and Aedes had a close relation with urban ports full of containers. Significant differences were found among the Aedes and total mosquito populations in the various districts. The correlation analysis showed that EC and mosquito abundance had strong positive correlations, but the temperature had weak negative correlations. The findings show how the water chemistry and urbanization influence the mosquito populations after a flood. Integrated vector management (IVM) must include EC-informed larval control, reduction of containers in urban areas and the use of GIS-based hotspots mapping. The study offers an ecological base of specific interventions and disease prevention that is climate-resilient in Baluchistan.

Keywords: Diversity; Ecology; Floods; Habitats; Mosquitoes; Management and Vector

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Introduction

One of the most important insects in terms of a public health approach is mosquitoes (Culicidae: Diptera) (Zhang *et al*., 2024). They carry pathogens that cause malaria, dengue fever, chikungunya, Zika virus, yellow fever, filariasis and Japanese encephalitis (Poinsignon *et al*., 2025). These illnesses collectively account for millions of infections each year, and over one million people worldwide have died because of mosquito-borne diseases (Centers for Disease Control and Prevention, 2024). On top of human health, the mosquitoes impact livestock, disrupt the ecosystem and pose economic costs to the developing nations (Roiz *et al*., 2024). They present a long-term challenge to the health care systems around the world because they can accommodate different environments (Couper *et al*., 2021). Recent reports indicate that the changes in climate have enhanced these problems by changing the behaviour and physiology of the mosquitoes as well as their distribution, enhancing their effectiveness in transmitting diseases and their geographical spread (Abbasi, 2025).

Global Diversity and Ecological Adaptation

More than 3,600 species of mosquitoes have been reported worldwide, with the most important ones belonging to two major subfamilies, Anophelinae and Culicinae, including genera like Anopheles, Aedes and Culex (Datta Mudi *et al*., 2024). The species have an exceptional ecological adaptability and can live in natural water bodies as well as artificial containers, and this trait enables them to have a thriving survival in rural and urban environments (Wells *et al*., 2025). Climate change and extreme weather events have now spread further, allowing the mosquitoes to take over the areas that were not dominated by them in the past (Zhang *et al*., 2025). Such flexibility implies that ecological monitoring should be done continuously to forecast the species distribution and curb the risk of diseases (Sehi *et al*., 2025). The change in urbanization and land use is also important in the reorganization of the mosquito habitats as species such as *Aedes aegypti* flourish in containers and deforested areas, and species of Anopheles prevail in fields and farms (Fletcher *et al*., 2023).

Regional Context and Post-Disaster Challenges

The diversity of mosquito species is also high in Asia, as there are diverse climates in Asia (Popova *et al*., 2025). Hundreds of species are reported in countries like Thailand, Malaysia, Vietnam and over 350 species are recorded in India, including medically important vectors like *Anopheles culicifacies*, *Anopheles stephensi* and *Culex quinquefasciatus* (Laojun & Chaiphongpachara, 2024). In Pakistan, the faunistic surveys were mainly conducted in the north and central areas, with *Aedes aegypti*, *Aedes albopictus* and *Anopheles stephensi* being identified as the dominant vectors of disease (Afzal *et al*., 2023). Nevertheless, studies are few in regions with ecological differences like Balochistan, where frequent floods have formed non-homogeneous habitats which support the breeding of mosquitoes (Teillet *et al*., 2024). This post-disaster situation requires new information on species population and preference of habitats to make appropriate decisions on the proper control of vectors (Fletcher *et al*., 2023). Anthropization of landscapes, such as forest clearance and the spread of agricultural lands, has been demonstrated to benefit specific species of vectors that enhance risks of diseases in the disturbed habitats (Perrin *et al*., 2022).

Importance of Ecological Monitoring

Integrated vector management (IVM) requires the monitoring of mosquito populations, which will allow timely interventions depending on the presence, abundance and disease risks (Centers for Disease Control and Prevention, 2024). Through the measurement of species diversity, seasonal abundance and habitat features, scientists will be able to predict the risk of outbreaks and develop specific methods of control (Poinsignon *et al*., 2025). The landscapes of Balochistan that are impacted by flood are unique because there are temporary natural water bodies, irrigation canals and stagnant pools that offer breeding sites to various mosquito genera all year round (Teillet *et al*., 2024). The association of species composition with environmental factors like water quality, vegetation cover and temperature are critical in comprehending population changes and taking a proactive approach to control factors (Avramov *et al*., 2024). Integrated mosquito management (IMM) programs that combine mosquito habitats surveillance, reduction of breeding sites, controlling larval, adult and community education have been effective in reducing mosquito abundance and disease risks (Centers for Disease Control and Prevention, 2024)

Research Gap and Innovative Contribution

Despite the growing health risks posed by mosquito-borne diseases, there is a significant research gap in linking ecological monitoring with habitat investigation in flood-prone regions of Balochistan. Previous studies have largely overlooked these areas, leaving critical questions unanswered regarding species diversity, breeding site preferences and environmental drivers. With the frequency of extreme weather events increasing and altering vector ecology, this study addresses the urgent need for comprehensive data to guide sustainable mosquito management strategies by providing the first district-level ecological baseline of mosquito vectors in post-flood Balochistan. Through the integration of field surveillance and water quality analysis, it aims to inform targeted, habitat-specific vector control strategies in a region highly vulnerable to climate-driven disease outbreaks.

The study objectives are,

1. Determining the diversity and composition of the mosquito species in Balochistan flood-infected districts.
2. Determining key oviposition and breeding sites under different environmental conditions.
3. Exploring the effect of water quality, temperature and habitats on the mosquito abundance and distribution.
4. Ecological baseline to aid in habitat-based control of vectors and prevent disease risks in climate-sensitive regions of Pakistan.

Materials and Methods

Study Area

The study was carried out in five flood-prone districts of Balochistan, Such as Quetta, Kech, Panjgur, Gwadar and Lasbella. Balochistan is the biggest province in Pakistan with a total area of 341,190 km^2 and 35 districts and 7 divisions. The floods affected the chosen districts to a great extent, providing the perfect breeding places for mosquitoes.

Study Duration

Field sampling was conducted from July to August 2024, immediately after the monsoon floods, and laboratory analysis continued until after 2024.

Experimental Sites

The sampling was performed in each district with specific locations such as stagnant water, construction pits, open drainage canals, animal sheds, vegetation, junkyards and human dwellings.

Collection and Preservation

The larvae and adults of the mosquitoes were collected with the help of the longhandled dippers and the collection vials. The samples were placed in 70% ethanol vials to preserve them. The adult mosquitoes were euthanized by the use of ethyl acetate killing jars and by entomological pins (16 and 20). The specimens were stored in wooden boxes, which were lined with balls of naphthalene to avoid being spoiled by pests.

Specimen Identification

Identification was done in the Dengue Vector Research Laboratory (DVRL), Department of Entomology of the University of Agriculture in Faisalabad. The morphological identification was done using standard taxonomic keys and literature. The diagnostic characteristics of the antennae, proboscis, wing scales and genitalia were observed under a Nikon SMZ-745T trinocular microscope, which was fitted with a 13 MP digital camera. In the case of genitalia preparation, the specimens were subjected to the treatment of 10% potassium hydroxide (KOH) solution, neutralized using glacial acetic acid and dehydrated using graded ethanol solutions.

Water Quality Analysis

The Agriculture and Soil Fertility Department, Quetta, measured the properties of physicochemical breeding water, such as pH, electrical conductivity (EC) and dissolved oxygen (DO) using laboratory equipment (pH meter, EC meter, DO meter).

Table 1. Mean Water Quality Parameters of Mosquito Breeding Habitats in Five Flood-Affected Districts of Baluchistan.

Districts	PH	EC_uS_cm	DO_mg_L	Temp_C
Gwadar	7.77	2882.66	5.71	26.78
Kech	7.68	694.64	5.65	26.81
Lasbella	7.74	1865.56	6.99	26.78
Panjgur	7.26	973.44	6.2	26.47
Quetta	7.7	781.84	5.87	27.59

Keys: 1.EC_uS_cm: Electrical Conductivity (µS/cm), DO_mg_L : Dissolved Oxygen (mg/L),emp_C : Temperature (°C)

Data Analysis

The Shannon Wiener Diversity Index (H) and species evenness (E) were calculated for the species diversity. To evaluate the relationships between environmental variables and mosquito abundance, statistical procedures were conducted to evaluate the relationships between the two factors: one-way ANOVA and Pearson correlation. The data processing was done with the help of SPSS and Microsoft Excel.

Results

The abundance and diversity of mosquitoes differed significantly amongst the five districts of Baluchistan affected by floods, and there was a high level of spatial heterogeneity of the ecological conditions and human activity. A total of 15,349 specimens of four genera of Culicidae, Culex, Aedes, Anopheles and Armigeres were obtained in surveyed localities. Total diversity indices revealed moderately high levels of species richness at the regional level of between 0.268 in Kech and 0.553 in Gwadar, whereas the evenness of species varied between 0.194 and 0.399, which implied a pattern of uneven distribution of species across the sites. Culex was also the most common genus among all the districts, especially in highly contaminated or stagnant water bodies and Aedes with a strong association to highly populated urban settlements and containerized environments. Anopheles was relatively few but was a uniform occurrence in several districts, casting doubt upon its flexibility in an urbanized environment. Armigeres was uncommon and was only found in very low proportions in scattered localities. Mixed habitats, with higher environmental heterogeneity, were observed in the diversity hotspots like Gwadar City (H′ = 1.025) and Paroom (H′ = 0.810), whereas zero diversity, meaning one dominant genus, was observed in the locations of Jinnah Road and Singanisar. These results indicate the role of habitat complexity, sanitation and human action on the structure of mosquito communities and offer a reference point to specific approaches to the control of the vectors in flood-prone areas.

Figure 1 shows that the abundance and diversity of mosquitoes differed among the surveyed Quetta localities. There were 2,288 specimens of four genera of the Culicidae in Total. The overall Shannon-Wiener index (H′ = 0.483) indicated an average species diversity, but species evenness (E =0.349) was used to indicate a fairly balanced distribution of genera. Killi Ismail had the greatest diversity (H′ = 0.722), followed by Boosa Mandi (H′ = 0.652) and Sirki Road (H′ = 0.628). Jinnah Road had inconsequential diversity (H′ = 0). The most common species were the Culex species, which were common in most areas, especially the Macher Colony (501 specimens) and Pashtonabad (385 specimens). The Aedes was greater in human settlements (Macher Colony, 26 and Barwary Road, 24), and Anopheles were less, with the highest number in Pashtonabad (46). The Armigeres were very sparingly met with in five localities. ***(Annexure A)***

Figure 2 demonstrates the geographical distribution of mosquito abundance and diversity in the localities of Kech. The number of specimens of four genera of the Culicidae collected amounted to 3,038. The overall Shannon-Wiener index (H′ = 0.268) indicated the presence of low to moderate species diversity, and the species evenness (E = 0.194) demonstrated that species distribution was rather uneven. The diversity was greatest in Oversease (H′ = 0.66), then Chasar (H′ = 0.401) and Satelite Town (H′ = 0.389), whereas Singanisar did not have any diversity (H′ = 0). Culex dominated in most locations, with Aedes dominating the human habitation areas of Turbat City and Chasar, with Anopheles and Armigeres being present in relatively few numbers. **(Annexure B)**

Figure 3 shows the distribution of abundance and diversity of mosquitoes in different localities in Panjgur. A total of 3,047 specimens of four genera of the Culicidae were collected. The overall Shannon-Wiener index (H′ = 0.336) represented low to moderate diversity, whereas the species evenness (E = 0.242) was an indication of uneven distribution of species. Paroom was found to have the most diversity (H′ = 0.810) and then by Naag (H′ = 0.680) and Soordo (H′ = 0.477), with Washbood having the least. Culex species took dominance in all the surveyed locations, but Aedes were more prevalent in peri-urban and human habitation, like Tasp and Kallag. Anopheles and Armigeres were of relatively low abundance.
(Annexure C)

Figure 4 illustrates the spatial distribution of the abundance and diversity of mosquitoes in different localities in Gwadar. A total of 3,340 specimens of four genera of the Culicidae were obtained. The overall Shannon-Wiener index was moderate (H′ = 0.553), and the evenness of species (E = 0.399) was indicative of a relatively even distribution of species. Gwadar City had the greatest diversity (H′ = 1.025), with the next level of diversity being Dhorgai (H′ = 0.742) and Jiwani (H′ = 0.596). Surbandar had the least diversity (H′ = 0.291). Culex species were prevalent in most regions, whereas the Aedes species were mainly related to the coastal as well as urban regions like Gwadar City and Jiwani. Anopheles and Armigeres were found in lesser percentages. **(Annexure D)**

Figure 5. shows the mosquito abundance and diversity variation across various localities in Lasbella. In total, 3,636 specimens of four genera of the Culicidae were collected. The total Shannon-Wiener index (H′ = 0.504) indicated moderate diversity, while species evenness (E = 0.364) suggested a relatively balanced distribution of species. Akram Colony Hub exhibited the highest diversity (H′ = 0.863), followed by Winder (H′ = 0.742) and Lassi Road (H′ = 0.614), whereas Lohrhi Parha Hub had the lowest diversity (H′ = 0.291). Culex species dominated most sites, while Aedes were strongly associated with urban settlements such as Jam Colony Hub and Akram Colony Hub. Anopheles were comparatively less abundant, and Armigeres occurred rarely. **(Annexure E)**

The One-Way ANOVA results (Table 2) revealed significant variation in Aedes and total mosquito populations among the five districts ($p < 0.05$). In contrast, populations of Culex, Anopheles and Armigeres did not differ significantly across districts ($p > 0.05$). These findings suggest that environmental or ecological differences among districts may specifically influence Aedes abundance and overall mosquito density.

Table 2. One-Way ANOVA results for mosquito genera among districts.

Mosquito Genus / Variable	Sum of Squares	df	Mean Square	F-value	Sig. (p-value)
Aedes	274.35	4	68.59	3.42	0.049*
Culex	6540.27	4	1635.07	1.58	0.258
Anopheles	134.23	4	33.56	2.97	0.068
Armigera	1.78	4	0.45	1.09	0.417
Total Mosquitoes	8252.21	4	2063.05	4.22	0.034*

*Significant at $p < 0.05$

The Pearson correlation analysis (Table 3) indicated a strong positive and significant association of Aedes, Anopheles and total mosquito populations with electrical conductivity (EC) and among themselves ($r > 0.85$, $p < 0.01$). Armigeres exhibited a moderate positive correlation ($r = 0.75$, $p < 0.05$) with Aedes and total mosquitoes. Temperature showed a weak negative correlation with mosquito abundance, whereas dissolved oxygen (DO) displayed weak positive but non-significant correlations with all genera.

Table 3. Pearson correlation matrix among mosquito genera and water quality parameters.

Variables	Aedes	Culex	Anopheles	Armigera	Total	pH	EC (µS/cm)	DO (mg/L)	Temp (°C)
Aedes	1	0.621	0.911**	0.748*	0.954**	0.532	0.889**	0.414	-0.217
Culex	0.621	1	0.690	0.532	0.715	0.488	0.663	0.301	-0.193
Anopheles	0.911**	0.690	1	0.769*	0.933**	0.517	0.852**	0.391	-0.248
Armigera	0.748*	0.532	0.769*	1	0.801*	0.471	0.720	0.355	-0.211
Total	0.954**	0.715	0.933**	0.801*	1	0.569	0.904**	0.432	-0.233
pH	0.532	0.488	0.517	0.471	0.569	1	0.576	0.395	-0.182
EC (µS/cm)	0.889**	0.663	0.852**	0.720	0.904**	0.576	1	0.421	-0.237

DO (mg/L)	0.414	0.301	0.391	0.355	0.432	0.395	0.421	1	-0.408
Temp (°C)	-0.217	-0.193	-0.248	-0.211	-0.233	-0.182	-0.237	-0.408	1

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

Discussion

The study presents the initial description of the diversity and distribution of the mosquitoes throughout the flood-affected districts of Balochistan, showing apparent spatial heterogeneity due to ecological and anthropogenic determinants. Culex predominance in most locations can be explained by some studies indicating resistance to stagnated, organically contaminated water, such as during urban sewer conditions and floodwaters with sewage (Noori *et al*., 2015; Bermond, 2023). This is proposed by the positive association of Culex abundance with electrical conductivity (EC), used to measure ionic and organic concentrations in water, which also supports Culex larval development (Avramov *et al*., 2023). Other flood-prone areas have reported similar phenomena as water containing higher concentrations of nutrients promotes rapid population growth by increasing the rate of larval development and shortening the time to hatch (Sivabalakrishnan *et al*., 2024). Also, higher EC values being associated with elevated concentrations of dissolved salts and organic matter provide microhabitats which promote Culex oviposition and survival of larvae (Kengne *et al*., 2019). Such conditions not only provide additional resources for larvae but also increase population persistence by reducing the predation pressure of aquatic predators (Smith *et al*., 2025). This situation illustrates the importance of water interaction, especially during post-flood conditions, when stagnant pools acting as breeding sites for mosquitoes become highly nutrient-loaded.

Aedes mosquitoes tend to increase in population in Macher Colony and Jam Colony Hub, aided by artificial habitats comprising tires, water storage tanks and coolers. Past research in Pakistan, which studied *Aedes aegypti* mosquitoes, noted the preference of urban container habitats (Mukhtar *et al*., 2018; Khan *et al*., 2019). A positive statistical correlation between Aedes and EC suggests the possible use of salty, saline or mineralized water in coastal regions, particularly Gwadar. Aedes mosquitoes can endure salty water (Idris *et al*., 2013). Larval mosquitoes adapt to survive in saline environments through osmoregulation and advanced physiological mechanisms (Kengne *et al*., 2019). These unique adaptability traits are believed to provide competitive dominance to Aedes in urban coastal environments as they tap into diverse water sources and brackish storage tanks, and discarded containers (Surendran *et al*., 2020). This ability or plasticity has been scientifically noted. However, this adaptation of the Aedes mosquitoes is mainly caused by human activity, especially human activities like the storage of water during droughts or after floods. The effect of such acts is usually the creation of artificial containers and tanks, as well as stagnant pools, which are most suitable and permanent breeding sites. The problem is further worsened by the presence of damaged infrastructure in the post-disaster environment, poor waste management and the presence of debris, which provide many sites where water can be held (Singh *et al*., 2020).

Local level variabilities such as high Shannon-Wiener indices recorded for Gwadar City and Paroom and zero diversity for Jinnah Road and Singanisar indicate differences in the diversity and heterogeneity of the water sources, vegetation and human activities which have the potential to support the coexistence of multiple genera. In contrast, areas where the same genus most often dominates likely have poor sanitation and fewer types of habitats. For example, the diversity and abundance seen in Macher Colony can be explained by the combination of stagnant drains and high container density, while the low diversity in Hazara Town can be explained by the fact that a large proportion of the waste is managed, and thus, fewer breeding sites are available. As seen in previous studies of urban ecosystems, mosquito community structures depend largely on infrastructure and waste management (Becker *et al*., 2020). Also, greater habitat heterogeneity tends to encourage resource partitioning and diminish interspecific competition, allowing several different genera to coexist (Shittu *et al*. 2024). On the other hand, ecological simplifications through inadequate sanitation and uniform water bodies could lead to the dominance of highly resilient and opportunistic Culex species, which flourish in degraded environments (MacDonald *et al*. 2025). These patterns underscore the importance of urban planning and environmental management in shaping mosquito assemblages and mitigating vector proliferation.

Flooding can boost mosquito populations by creating temporary pools and providing organic materials and spreading containers that grow Aedes mosquitoes. These results are consistent with findings on the spike in mosquito-borne illness after floods in Pakistan (Vohra *et al*., 2023; World Weather Attribution, 2022). Furthermore, natural predators and competitor larvae being removed by flood waters increases the rate of mosquito survival (Coalson *et al*., 2021). While the number of Anopheles mosquitoes recorded was low, their presence in certain districts, especially in light of the urbanization of Anopheles stephensi in South Asia, is concerning (WHO, 2022). The ability of the species to exploit urban malaria control artifacts, such as artificially stored and controlled water, is a growing challenge. Within the flood cycle, the conditions created by water stagnation and nutrient enrichment lead to rapid post-disturbance population recovery (Wu *et al*., 2024). These, compounded by human displacement and water storage during post-flood recovery, increase the likelihood of an outbreak of diseases spread by vectors (Kengne *et al*., 2019). These dynamics highlight the need for integrated vector management strategies that address both environmental and behavioural drivers in flood-prone regions.

Culex dominance is notable due to the spread of the West Nile Virus reported in Pakistan (Khan *et al*., 2018), but due to the presence of Aedes in urban centers, the possibility of dengue must also be considered. For this reason, the control strategies should be flexible to the local context, container control and urban settlements larviciding for Aedes and drainage enhancement in peri-urban areas for Culex. Including EC monitoring in routine surveillance will be useful in identifying potential high-risk breeding sites. Future research for water quality profiling should also include species-level identifications. This addition will enhance the ecological and interpretive framework for appropriate action. For instance, remotely sensed GIS-based habitat mapping might improve predictive modelling of mosquito hotspot areas, especially in the context of climate change-induced floods (Otieno *et al*., 2025). These climate change scenarios will increase. Real-time meteorological data and socio-environmental indicators integration with remote sensing GIS will allow pre-emptive vector control to mitigate potential outbreaks (Soghigian *et al*., 2023). This is a globally accepted approach to climate-resilient vector surveillance systems and underlines the need for inter-sectoral cooperation and flexibility in high-risk areas.

Conclusion and Recommendations

The present study shows some peculiar ecological scenarios in mosquito abundance and diversity in five flood-influenced districts of Baluchistan, where Culex thrives in polluted water with organic matter, Aedes tends to occur in urban container habitats, and Anopheles is low in abundance. The positive association between the abundance of mosquitoes and electrical conductivity (EC) clearly displays that water chemistry is one of the main conditions that determine the suitability of the habitat for larvae in post-flood settings. To apply these findings in practice, the vector control programs need to be based on district-specific approaches. City centers need to target Aedes suppression through container management and citizen outreach, whereas the peri-urban and flood-prone areas need to be enhanced with drainage and EC-based larviciding to mitigate the spread of Culex. Water quality monitoring and GIS-based risk mapping should be incorporated into the surveillance systems to inform specific interventions. To policymakers, one of the recommendations of this study is the incorporation of water chemistry measures and habitat profiling in the normal planning of the surveillance and control of vectors. To the researchers, the next area of work is the identification of the species-level, seasonal and climate resilient control models that consider land use change and urban growth. The ability to predict the diseases caused by mosquitoes and the enhancement of the local entomological capacity will be crucial in reducing the danger of mosquito-borne diseases in Balochistan and other flood-prone areas.

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(Annexure A)

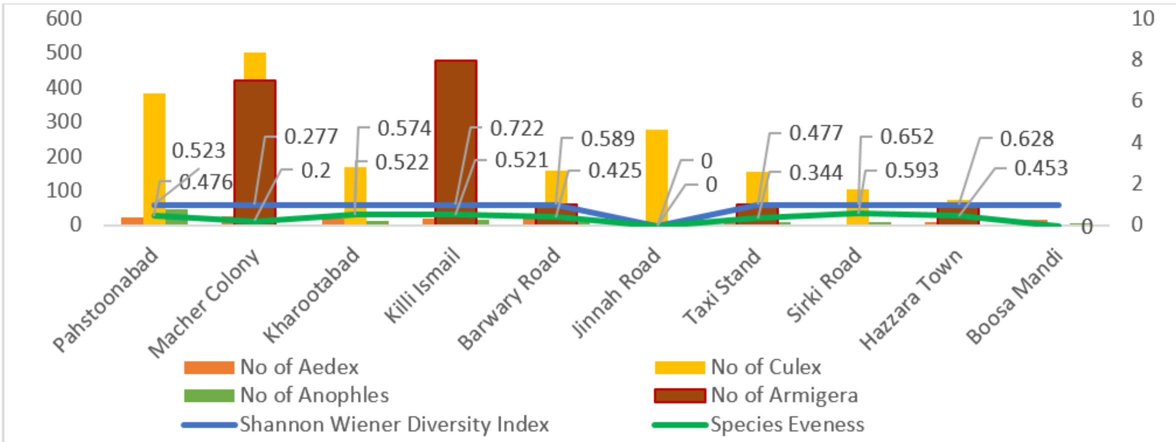

Figure 1. Diversity of mosquito species and their population in the district of Quetta, Balochistan.

(Annexure B)

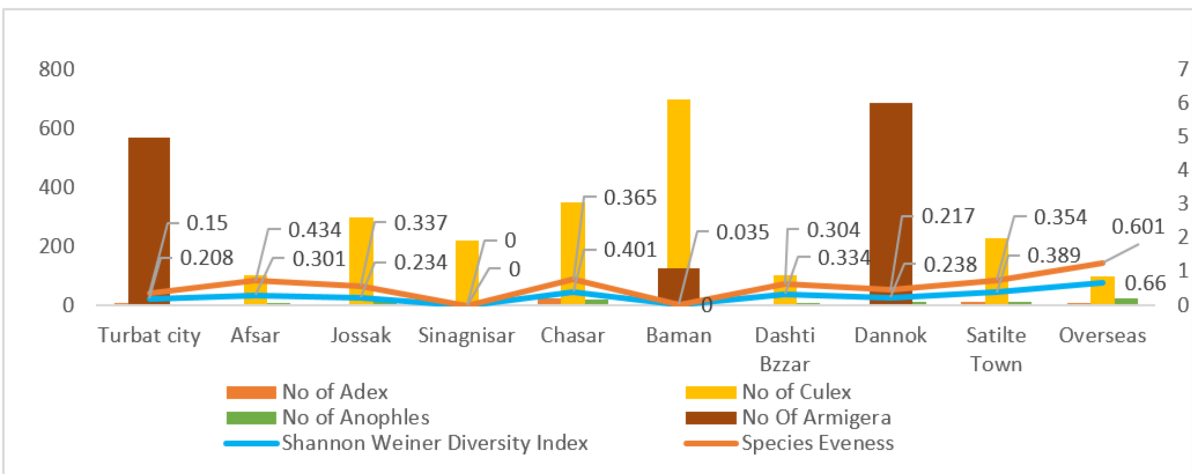

Figure 2. Diversity of mosquito species and their population in District Kech, Balochistan.

(Annexure C)

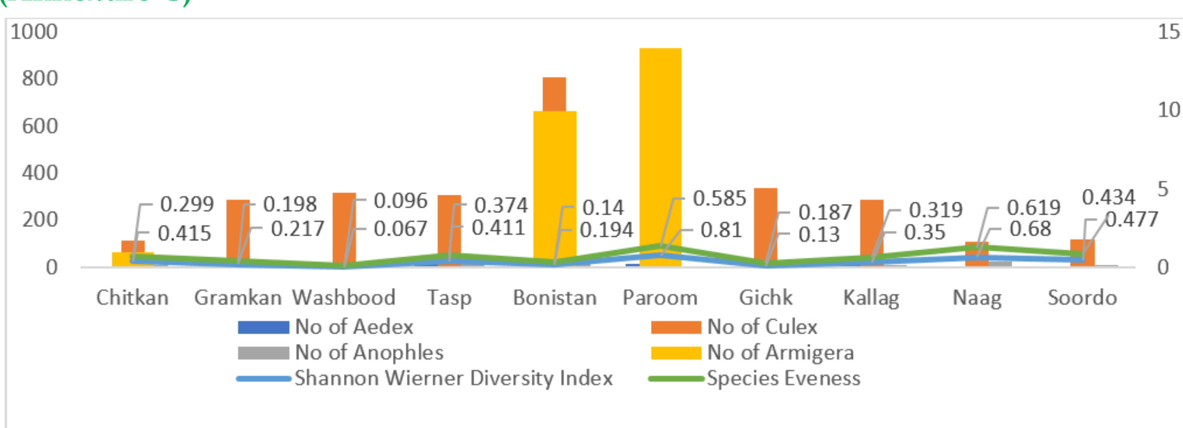

Figure 3. Diversity of mosquito species and their population in the district of Panjgur, Balochistan.

(Annexure D)

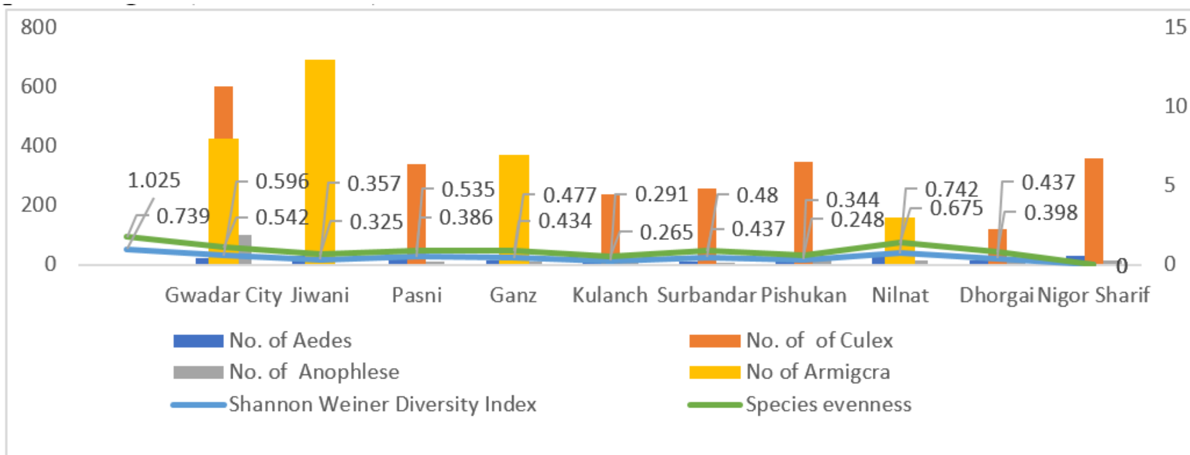

Figure 4. Diversity of mosquito species and their population in District Gwadar, Balochistan.

(Annexure E)

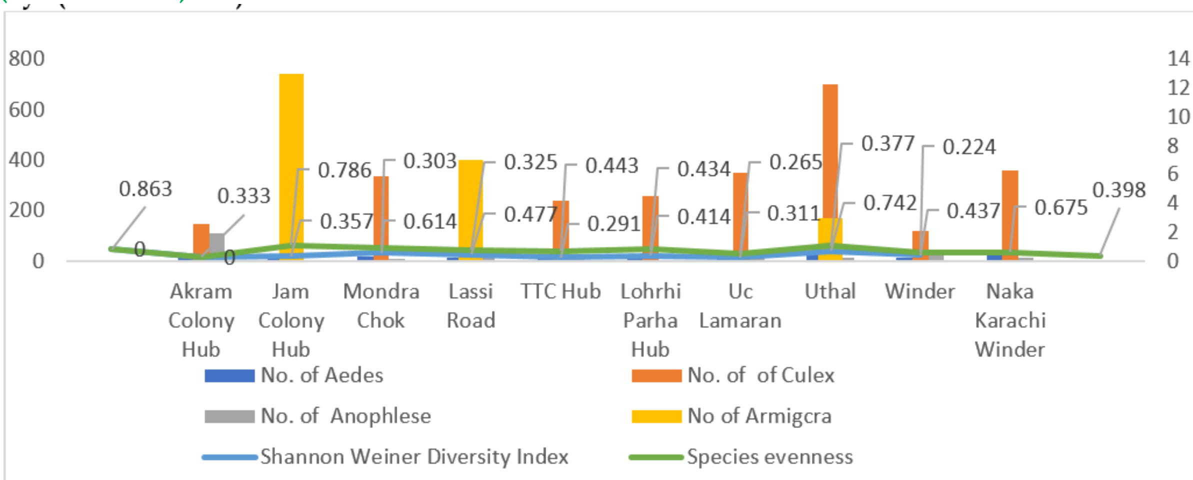

Figure 5. Diversity of mosquito species and their population in the district of Lasbella, Balochistan