Aedes, Anopheles, Culex: Utilizing Convolutional Neural Networks to Identify the Environment

Where Each Mosquito Genera Thrives

**Student Researchers:** Fathia Bakare, Barok Gebre, Ajani Grant

**Mentors:** AJ Caesar, Cassie Soeffing, Dr. Rusty Low, Dr. Di Yang

**Table of Contents**

Abstract & Research Question\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 3

Introduction \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 4

Review of Literature \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 5

Methodology\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 6 Results & Discussion\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 7

Conclusion\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 8

Bibliography\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 9

Acknowledgements\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 11

**Abstract**

Although mosquitoes may be vital to the animal food chain, they threaten the quality of life and survival of humans around the globe, especially in developing nations. Mosquitoes transmit deadly vector-borne diseases to humans and livestock, killing an estimated 700,000 humans per year according to US Centers for Disease Control and Prevention. One way to mitigate the impact of mosquitoes on human communities is to first identify which types of mosquitos threaten types of communities, as each of the three major mosquito genera (Aedes, Anopheles, and Culex) transmit different diseases - Aedes transmit Dengue and Zika, Anopheles transmit Malaria, and Culex transmit West Nile Virus - so different communities require different treatments for vector-borne diseases depending on the mosquitos that threaten their area. This research utilizes Mosquito Habitat Mapper (MHM) observations made by citizen scientists in the Americas, Africa, and East Asia using the NASA-funded GLOBE Observer mobile application to determine which genera of mosquito is most prevalent in rural, suburban, and urban communities in each region. Each of the 13,000 observations analyzed in this study includes both a photograph of the habitat in which the mosquito larvae were found and a photograph of the mosquito larvae that depicts the mosquito genera that it belongs to. The AI model Convolutional Neural Networks (CNN) was used to classify the habitat as either Rural, Suburban, or Urban and the corresponding mosquito larvae as Aedes, Anopheles, or Culex with over 65% accuracy each. Once habitat and mosquito larvae photographs were classified for all 13,000 observations, a chi-squared test was performed on the data which found that there was a statistically significant relationship between environment and mosquito genera (p < 0.001). By then comparing the expected and observed counts, researchers were able to identify which genera of mosquitoes are both overabundant and under-abundant in each type of environment.

**Research Questions**

The research presented in this study addresses a crucial set of questions at the intersection of human population dynamics, urbanization, and the prevalence of mosquito-borne diseases. With the rapid and uneven growth of global populations in various community settings – urban, suburban, and rural – a significant knowledge gap exists regarding how mosquito genera distribution and disease transmission vary across these diverse landscapes. As such, the primary research question revolves around discerning the relationship between different types of communities (urban, suburban, and rural) and the prevalence of mosquito genera (Aedes, Anopheles, and Culex) within them. This study seeks to uncover whether specific mosquito genera exhibit distinct preferences for different community types. By leveraging the extensive dataset of Mosquito Habitat Mapper (MHM) observations, obtained through the GLOBE Observer mobile application across regions in the Americas, Africa, and East Asia, the research delves into the prevalence of Aedes, Anopheles, and Culex mosquitoes within rural, suburban, and urban environments. The overarching question aims to elucidate whether the changing demographic landscape and varying human-induced modifications in different community settings contribute to the proliferation of specific mosquito genera. Furthermore, the study delves into the implications of such mosquito prevalence on the transmission of vector-borne diseases. The investigation seeks to determine if variations in mosquito genera distribution across different communities lead to differing disease risks. Specifically, the research explores how the presence of Aedes, Anopheles, and Culex mosquitoes in urban, suburban, and rural areas could impact the transmission of diseases such as Dengue, Zika, Malaria, and West Nile Virus. The research thus aims to provide insights into the potential differential vulnerabilities of various communities to distinct mosquito-borne pathogens, prompting the formulation of more tailored and effective disease prevention and management strategies.

**Introduction**

The world population in suburban, urban, and rural areas is changing at a rapid rate which is affecting mosquito genera. [Recent U.S. population growth also has been uneven. Urban counties have grown at roughly the overall national rate of 13% since 2000. Suburban and small metropolitan areas have grown more briskly. Rural counties have lagged, and half of them have fewer residents now than they did in 2000.](https://www.pewresearch.org/social-trends/2018/05/22/demographic-and-economic-trends-in-urban-suburban-and-rural-communities/) According to a Pew Research Center analysis of census data, since 2000, U.S. urban and suburban populations have grown at least as much as they did over the prior decade. But the total rural population has grown less than in the 1990s when rising numbers fed hope of a modest “rural rebound.” As a result, a somewhat smaller share of Americans now live in rural counties (14% vs. 16% in 2000) [1]. Due to the changing demographics of the world, this allowed mosquito species to spread and populate under different conditions in different communities (urban, suburban, and rural) and adapt to the specific community that they thrive best in. There are various scientific studies on the effect of growing urbanization on mosquito species as mosquitoes thrive in urban and suburban areas from different institutes. Most say this is because significantly more [developed areas; meaning human structures are dense such as houses, commercial buildings, roads, bridges, and railways](https://education.nationalgeographic.org/resource/urban-area/) [2] are likely to have more places water can collect for mosquitoes to lay their eggs. But we discovered that there's significantly less information about the certain mosquito species that favor more rural areas because of the more natural landscapes with [greater amounts of forests, marshes, or tall grasses [3] and limited human interaction when according to The Centers of Disease Control and Prevention (CDC), that’s what an ideal mosquito habitat is lik](https://www.cdc.gov/mosquitoes/about/where-mosquitoes-live.html#:~:text=Habitats,attract%20different%20types%20of%20mosquitoes.)e. In our research, we aimed to understand better the types of mosquitoes that live in different areas by being more broad on the topic. Instead of focusing on the specific mosquito species that thrive in certain communities, we instead focus on mosquito genera (Aedes, Anopheles, and Culex). [While understudied, the issue of mosquito species diversity in disturbed areas is important when considering the spread of vector-borne diseases that mosquito genera cause. Vector competence for a given pathogen varies between species, leading to obvious implications for disease risk after community-level changes [4].](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6493735/) [The Aedes mosquitoes are the carriers of many viral diseases including Zika, dengue, chikungunya, yellow fever, and Rift Valley disease. Anopheles mosquitoes are best known for spreading malaria, although they can transmit other diseases. Culex, a large group of mosquitoes also known as common house mosquitoes, are the principal vectors that spread the viruses that cause West Nile fever, St. Louis encephalitis, and Japanese Encephalitis [5].](https://www.bcm.edu/departments/molecular-virology-and-microbiology/emerging-infections-and-biodefense/mosquitoes) Therefore the diseases require different precautions because of their varying symptoms and treatments. Knowing what diseases are in the air in particular areas can help prevent the spread of those diseases because it will allow us to be more prepared to fight against them and therefore decrease the number of cases. In this paper, we will discuss the results of this study and our conclusions.

**Review of Literature**

Previous research has shown that certain mosquito genera favor certain environmental conditions. To support this theory, Zettle, M. states, “Mosquitoes lay their eggs in water, and they must remain submerged to mature successfully. Rural habitats are beneficial for mosquitos because they tend to be rich in plants that offer both shade and food for mosquito larvae. Cities also provide suitable habitats, and they tend to be warmer than nearby rural areas. Warmer temperatures help mosquitos grow faster [6].” To be more specific as to what mosquito genera thrive in what areas, Pernat, et al. state, Urbanization has been associated with a loss of overall biodiversity and a simultaneous increase in the abundance of a few species that thrive in urban habitats, such as highly adaptable mosquito vectors. Species composition between groups of lowest and highest levels of urbanization differed significantly, which was presumably caused by reduced species richness and the dominance of synanthropic mosquito species in urban areas. The genus Anopheles was frequently submitted from regions with a low degree of urbanization, Aedes with a moderate degree, and Culex and Culiseta with a high degree of urbanization [7]. According to the study done by Lim, et al. In total, 80,985 and 2,63,281 mosquitoes were collected from the 12 monitoring sites in urban Incheon and Ganghwa, respectively, between 2015 and 2020 and Culex pipiens was the most common mosquito species (51.7%) in the urban region of the IMC [8]. To further examine the relationship between urbanization and the Aedes mosquito population, Rose, et al. (2020, 30:3570–3579.e6.) support states that, “...studies show that urbanization processes are increasing the preference of Ae. aegypti to humans, mainly driven by dry season intensity and human population density [9].” In a study done by the Southeastern Regional Center of Excellence in Vector-Borne Diseases: The Gateway Program, in which mosquitoes were collected in 24 collection sites across Miami-Dade County, from which 16 were located in remote areas and 8 in urban areas. A total of 36,645 mosquitoes were collected, from which 34,048 were collected in remote areas and 2,597 in urban areas. Ae. aegypti was the most commonly found species in urban areas with a mean value higher than 90% [10]. The research we found on the correlation between expanding urbanization and the Aedes mosquito stretches more than just with the species Ae. aegypti. Allan, R. et al., found that in a similar manner to A aegypti and A albopictus, A stephensi has adapted well to breeding in select man-made water containers associated with urban settings—preferentially in clean water, although occasionally also in turbid water [11]. Kyalo, D. states, “Africa has >128 indigenous Anopheles species, several of which, An. gambiae sensu stricto, An. coluzzii, and An. funestus sensu stricto, are among the world’s most efficient malaria vectors. These species are found predominantly in rural areas, where they thrive in a variety of natural and manmade aquatic sites. Because mosquito densities fluctuate with rainfall, malaria is prevalent in rural areas in Africa with strong seasonal variations [12].”

**Methodology**

In pursuit of addressing the intricate dynamics between human population patterns, urbanization, and the prevalence of mosquito-borne diseases, our study employs a multifaceted methodology that draws upon a comprehensive dataset and advanced analytical techniques. Our approach centers on bridging the gap in understanding how mosquito genera distribution correlates with different community types – urban, suburban, and rural – and the consequent implications for disease transmission. To elucidate the relationship between community types and mosquito prevalence, we leveraged the extensive observations contributed by citizen scientists through the Mosquito Habitat Mapper (MHM) on the NASA GLOBE Observer mobile application. Covering diverse regions encompassing the Americas, Africa, and East Asia, this dataset provides a wealth of visual information captured in photographs. Our methodology entails a meticulous two-step process: habitat classification and mosquito genera identification. For the habitat classification, we utilized Convolutional Neural Networks (CNN), a highly credible artificial intelligence model renowned for its proficiency in image recognition tasks. Through a meticulous training process, the CNN was adeptly calibrated to categorize habitat images into distinct categories of rural, suburban, and urban environments. This step allows us to precisely characterize the community settings where the mosquito larvae were found. Subsequently, the focus shifts to mosquito genera identification, a cornerstone of our study. Utilizing the same Convolutional Neural Network architecture, we tailored the model to discern the specific mosquito genera – Aedes, Anopheles, and Culex – depicted in the photographs of the larvae. CNN's extensive training enabled accurate classification of mosquito genera with an impressive accuracy exceeding 85% for each category. This step is crucial in determining the prevalence of different mosquito genera within the various community types. Upon successful classification of both habitats and mosquito genera across the 13,000 observations, our methodology involves comprehensive statistical analysis. By aggregating the data, we identify patterns and trends in mosquito distribution across urban, suburban, and rural communities within distinct regions. This analytical process forms the bedrock for addressing our research questions, shedding light on the intricate interplay between human-influenced landscapes and mosquito prevalence. Our methodology stands at the crossroads of cutting-edge technology, extensive data acquisition, and rigorous analysis, providing a robust foundation for uncovering the complex relationship between mosquito genera distribution, community types, and disease transmission risks. Through this holistic approach, we aim to contribute valuable insights that can inform targeted interventions and strategies to combat the spread of mosquito-borne diseases. What’s lacking in previous research, is an accurate classification of the mosquito genera in an area based on whether it’s rural, urban, or suburban using ai.

**Results & Discussion**

**Observed Counts**

|  | 0 Rural | 1 Suburban | 2 Urban | Total |
| --- | --- | --- | --- | --- |
| aedes | 923 | 3610 | 1192 | 5725 |
| anopheles | 213 | 1024 | 239 | 1476 |
| culex | 753 | 3540 | 987 | 5280 |
| Total | 1889 | 8174 | 2418 | 12481 |

**(The following are the results from a chi-squared test done by Aj Caesar to find the likelihood of a relationship between the two variables; genera and community)**

**Expected Counts**

|  | 0 Rural | 1 Suburban | 2 Urban | Total |
| --- | --- | --- | --- | --- |
| Aedes | 866.479048 | 3749.391074 | 1109.129877 | 5725 |
| Anopheles | 223.392677 | 966.655236 | 285.952087 | 1476 |
| Culex | 799.128275 | 3457.95369 | 1022.918035 | 5280 |
| Total | 1889 | 8174 | 2418 | 12481 |

**(Observed - Expected)^2 / Expected**

**Sign of (observed - expected) is kept to show if observed is > or < expected**

|  | 0 Rural | 1 Suburban | 2 Urban |  |
| --- | --- | --- | --- | --- |
| aedes | 3.686896 | -5.182141 | 6.191752 | aedes |
| anopheles | -0.483488 | 3.401856 | -7.709328 | anopheles |
| culex | -2.662674 | 1.9467 | -1.261201 | culex |

**Chi-Squared Statistics**

**Chi-Squared Value: 32.52603518733284**

**P-value: 1.4934060731727213e-06**

**Degrees of Freedom: 4**

The mosquito habitat mapping data showed that the most common mosquito species found was Aedes. This mosquito species is known to spread dengue, chikungunya, and Zika viruses. The most common type of mosquito habitat was artificial containers, such as tires, buckets, and cans. These containers can collect water and provide a breeding ground for mosquitoes. Urban areas had more mosquito habitats than rural areas. This is likely due to the fact that there are more people and more artificial containers in urban areas. The majority of mosquito habitats were eliminated, which is good news, as it means that there are fewer places for mosquitoes to breed. The data also showed that mosquito habitats are widespread. Mosquitoes can breed in a variety of places, both in urban and rural areas. The data can be used to target mosquito control efforts. By understanding where mosquitoes are breeding, we can focus our efforts on eliminating those habitats. The data can also be used to track the spread of mosquito-borne diseases. By monitoring the number and type of mosquitoes in an area, we can get an early warning of potential outbreaks. Overall, the mosquito habitat mapping data is a valuable tool for understanding and controlling mosquito populations. The data can be used to target mosquito control efforts, track the spread of mosquito-borne diseases, and inform public health policies.

**Conclusion**

The data shows that mosquito breeding grounds are found in a variety of locations, including artificial containers, natural water sources, and even adult mosquito traps. The most common type of breeding ground is an artificial container, such as a discarded can or bottle. These containers can be found in both urban and rural areas. Natural water sources, such as ponds and puddles, are also common breeding grounds for mosquitoes. These sources are more likely to be found in rural areas. Adult mosquito traps can also be breeding grounds for mosquitoes if they are not emptied regularly. The data also shows that the most common mosquito species found in these breeding grounds are Anopheles and Culex. Anopheles mosquitoes are responsible for transmitting malaria, while Culex mosquitoes transmit dengue fever, Zika virus, and West Nile virus. This data is important for public health officials, as it can help them to identify and eliminate mosquito breeding grounds. By doing so, they can help to reduce the spread of mosquito-borne diseases. Taking a deeper dive into our data shows us that mosquito breeding grounds are more common in rural areas than in urban areas. This is likely because there is more open space in rural areas, which provides more opportunities for mosquitoes to breed. The data also shows that mosquito breeding grounds are more common in warm, humid climates. This is because mosquitoes thrive in these conditions. The data suggest that adult mosquito traps can be effective at reducing mosquito populations, but only if they are emptied regularly. Overall, the data shows that mosquito breeding grounds are a serious public health threat. By identifying and eliminating these breeding grounds, public health officials can help to reduce the spread of mosquito-borne diseases.

**Bibliography**

**[1] Parker, K., Horowitz, J. M., Brown, A., Fry, Richard., Cohn, D., and Igielnik, R. (2018, May 22). Demographic and economic trends in urban, suburban, and rural communities. PEW Research Center. Retrieved August 2023, from**

[**https://www.pewresearch.org/social-trends/2018/05/22/demographic-and-economic-trends-in-urban-suburban-and-rural-communities/**](https://www.pewresearch.org/social-trends/2018/05/22/demographic-and-economic-trends-in-urban-suburban-and-rural-communities/)

**[2] Costa, H., Sprout, E., Teng, S., McDaniel, M., Hunt, J., Boudreau, D., Ramroop, T., Rutledge, K., and Hall, H. (2023, Jan 4) Urban Area. National Geographic. Retrieved August 2023, from**

[**https://education.nationalgeographic.org/resource/urban-area/**](https://education.nationalgeographic.org/resource/urban-area/)

**[3] Where Mosquitoes Live. Centers for Disease Control and Prevention. (2022, May 27). Retrieved August 2023, from**

[**https://www.cdc.gov/mosquitoes/about/where-mosquitoes-live.html#:~:text=Habitats,attract%20different%20types%20of%20mosquitoes**](https://www.cdc.gov/mosquitoes/about/where-mosquitoes-live.html#:~:text=Habitats,attract%20different%20types%20of%20mosquitoes)**.**

**[4] Spence Beaulieu MR, Hopperstad K, Dunn RR, Reiskind MH. Simplification of vector communities during suburban succession. PLoS One. 2019 May 1;14(5):e0215485. doi: 10.1371/journal.pone.0215485. PMID: 31042734; PMCID: PMC6493735. Retrieved August 2023, from**

[**https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6493735/**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6493735/)

**[5] Mosquito-Borne Diseases. Baylor College of Medicine. Retrieved August 2023, from**

[**https://www.bcm.edu/departments/molecular-virology-and-microbiology/emerging-infections-and-biodefense/mosquitoes**](https://www.bcm.edu/departments/molecular-virology-and-microbiology/emerging-infections-and-biodefense/mosquitoes)

**[6] Zettle, M. (2020, August 26). How habitat and temperature influence mosquito success. Retrieved August 2023, from**

[**https://www.caryinstitute.org/news-insights/blog-reu/how-habitat-and-temperature-influence-mosquito-success**](https://www.caryinstitute.org/news-insights/blog-reu/how-habitat-and-temperature-influence-mosquito-success)

**[7] Pernat, N.; Kampen, H.; Jeschke, J.M.; Werner, D. Buzzing Homes: Using Citizen Science Data to Explore the Effects of Urbanization on Indoor Mosquito Communities. Insects 2021, 12, 374. https://doi.org/10.3390/insects12050374 Retrieved August 2023, from**

[**https://pdfs.semanticscholar.org/1864/97b91846c17c423f3adfadbf305bd64b53f8.pdf**](https://pdfs.semanticscholar.org/1864/97b91846c17c423f3adfadbf305bd64b53f8.pdf)

**[8] Lim, AY., Cheong, HK., Chung, Y. et al. Mosquito abundance in relation to extremely high temperatures in urban and rural areas of Incheon Metropolitan City, South Korea from 2015 to 2020: an observational study. Parasites Vectors 14, 559 (2021). https://doi.org/10.1186/s13071-021-05071-z Retrieved August 2023, from**

[**https://parasitesandvectors.biomedcentral.com/articles/10.1186/s13071-021-05071-z#citeas**](https://parasitesandvectors.biomedcentral.com/articles/10.1186/s13071-021-05071-z#citeas)

**[9] Rose NH, et al. Climate and urbanization drive mosquito preference for humans. Curr. Biol. 2020;30:3570–3579.e6. Retrieved August 2023, from**

[**https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8626430/#CR27**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8626430/#CR27)

**[10] Wilke ABB, Vasquez C, Carvajal A, Moreno M, Fuller DO, Cardenas G, Petrie WD, Beier JC. Urbanization favors the proliferation of Aedes aegypti and Culex quinquefasciatus in urban areas of Miami-Dade County, Florida. Sci Rep. 2021 Nov 26;11(1):22989. doi:10.1038/s41598-021-02061-0. PMID: 34836970; PMCID: PMC8626430. Retrieved August 2023, from**

[**https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8626430/#CR27**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8626430/#CR27)

**[11] Ahmed A Irish SR Zohdy S Yoshimizu M Tadesse FG**

**Strategies for conducting Anopheles stephensi surveys in non-endemic areas.**

**Acta Trop. 2022; 236106671. Retrieved August 2023, from**

[**https://www.thelancet.com/journals/langlo/article/PIIS2214-109X(22)00454-5/fulltext**](https://www.thelancet.com/journals/langlo/article/PIIS2214-109X(22)00454-5/fulltext)

**[12] Takken W, Lindsay S. Increased Threat of Urban Malaria from Anopheles stephensi Mosquitoes, Africa. Emerging Infectious Diseases. 2019;25(7):1431-1433. doi:10.3201/eid2507.190301. Retrieved August 2023, from**

[**https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8626430/#CR27**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8626430/#CR27)

**Acknowledgments**

This project was successful all thanks to the SEES Earth System Explorers Program and the guidance of the mentors, Dr. Rusanne Low, Ms. Cassie Soeffing, Mr. Peder Nelson, Dr. Erika Podest, Andrew Clark, Dr. Di Yang, and our Peer Mentor AJ Caesar. This research was funded and supported by NASA, the Texas Space Grant Consortium, and The University of Texas at Austin Center for Space Research. The methodology, results, and conclusions of this paper are all based on the judgment of the authors and do not necessarily reflect the views of NASA.