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Assessing the effect of water storage practices on the relationship between mosquito exposure and fever in urban informal settlements in Makassar, Indonesia and Suva, Fiji

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By

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B.S.
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Assessing the effect of water storage practices on the relationship between mosquito exposure and fever in urban informal settlements in Makassar, Indonesia and Suva, Fiji

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Globally, over 1 billion people live in urban informal settlements that lack proper water infrastructure. Residents of these settlements may be more likely to store water, including in ways that could promote mosquito proliferation and the spread of vector-borne diseases. This study aimed to evaluate the association between exposure to mosquitoes and fever, stratified by water storage practices, in urban informal settlements in two countries. Survey data were collected through Revitalizing Informal Settlements and their Environments (RISE), a randomized control trial working in 24 urban informal settlements in Suva, Fiji and Makassar, Indonesia. The main survey items of interest were self-reported fever in the last week, self-reported frequency of exposure to mosquitoes in the last six weeks, and whether respondents stored drinking water. Multi-variate logistic regression models were used to analyze associations between fever and exposure to mosquitoes in the total sample and in a sub-sample of households that stored water. Models were adjusted for settlement-level clustering and relevant covariates, including wall materials, garbage disposal practices, water source, water access, and household wealth. We observed a positive association between daily mosquito exposure and having a fever in both Makassar [(adjusted OR 1.45, 95% CI: 0.24-8.67)] and Suva [(AOR 1.88, 95% CI: 1.18-3.02)]. A sub-analysis restricted only to respondents that stored water produced similar results for both Makassar (AOR 1.46, 95% CI: 0.27-7.78) models] and Suva (AOR 1.53, 95% CI: 0.99-2.34)]. Our study demonstrated that a higher self-reported frequency of mosquito encounters was associated with a higher odds of self-reported fever, including when stratified by water storage. Furthermore, our study provides impetus for including socio-environmental factors that increase people's vulnerability to mosquito exposure in studies of mosquito-borne infectious disease. With the rapid growth of urbanization and climate change, this relationship merits further attention.

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TABLE OF CONTENTS

Contents

Introduction

Water is an essential resource that all human beings need to survive and prosper. However, water insecurity remains a major burden experienced throughout the world with half a billion people experiencing severe water scarcity all year and 1.8 billion lacking a reliable source of drinking water (Adams, Stoler, & Adams, 2020). That burden is felt most prominently in the Global South, especially Sub-Saharan Africa and Southeast Asia (Adams et al., 2020; Gerlak & Wilder, 2012). Lack of water availability, accessibility, and/or quality directly contributes to the global burden of disease (Young et al., 2019). In some areas, even the municipal piped water is deemed unsafe due to factors such as pipes being inadequately maintained, low pressure in the water system, lack of chlorination, delivery of water being intermittent, and clandestine connections (Adams et al., 2020; Mintz, Reiff, & Tauxe, 1995). As result, many households in water insecure settings must store water to ensure availability when needed. However, household storage of water, along with other practices such as irrigation, can provide ideal stagnant water conditions for mosquitoes to lay their larva, especially during dry season conditions when natural water sources may be scarce (Rose et al., 2020).

In Southeast Asia and the Pacific, mosquito species such as those of the *Aedes* and *Culex* genus, are common vectors of emerging diseases and are abundant throughout this geographic expanse (Reuben, 1994). For example, a recent study in twelve settlements of Makassar, Indonesia captured a total of 44,012 mosquitoes from October 2018 to July 2019 and the vast majority were identified as *Culex quinquefasciatus* (95%) followed by *Aedes aegypti* (5%) and other genera such as *Anopheles* species. The female mosquitoes were captured in higher numbers than their male counterparts, which is of concern because the females are responsible for disease transfer (French et al., 2021). There are 42 species of *Culex* in Southeast Asia and *Culex* *quinquefasciatus* is an example of a mosquito species that is very anthropophilic (i.e., affinity for human blood) (Reuben, 1994). One study in Malaysia demonstrated that stagnant water throughout residential areas were prime environments for the proliferation of *Culex* (Van Lun et al., 2012). There are mosquitoes that breed in stagnant water in sources found around the home such as bird baths, discarded tires, buckets, artificial containers that hold water, and clogged gutters (Haroona, 2020). Another study demonstrated the correlation between high mosquito prevalence (again, *Aedes* and *Culex* genera) and open containers, suggesting that the environment was facilitating the prevalence of these arthropods, specifically in urban settings (LaDeau, Leisnham, Biehler, & Bodner, 2013).

There is evidence that "climate change, rapid urbanization and changing land-use patterns will increase the risk of disease emergence in the coming decades" (Baker et al., 2021). This risk will also likely involve a disease shift with the reduction of malaria and increase of arboviruses. Malaria is a disease transmitted by mosquitoes of the genus Anopheles, which are more acclimated to rural settings and are more sensitive to increased temperatures (Baker et al., 2021; Mordecai, Ryan, Caldwell, Shah, & LaBeaud, 2020). Meanwhile, arboviruses are mainly transmitted by species of the genera *Aedes* and *Culex* (Pierson & Diamond, 2020), which are highly adapted to urban environments and can withstand increasing temperatures (Baker et al., 2021; Mordecai et al., 2020). Arboviruses are a family of viruses that can be divided into different genera, one of the most prominent being flaviviruses such as Dengue Fever, Japanese Encephalitis, and West Nile Virus. (Go, Balasuriya, & Lee, 2013; Kardena et al., 2021; Pierson & Diamond, 2020). Most flavivirus infections (~50-80%) are asymptomatic and therefore cause little to no illness (Pierson & Diamond, 2020). Febrile symptoms (i.e., fever) are common for all flaviviruses, as well as myalgia (muscle pain) and arthralgia (joint pain) (Pierson & Diamond, 2020).

The complex interactions between human beings and wildlife have been impacted by urbanization and affect the emergence of zoonoses or diseases (Hassell, Begon, Ward, & Fèvre, 2017). Over the last few years, the prevalence of flaviviruses have increased throughout Southeast Asia and the Pacific. For example, the number of Dengue cases in Indonesia rose from approximately 68,000 cases in 2017 to nearly 138,000 in 2019 (Nurhayati-Wolff, 2019). Vector borne diseases like Chikungunya, Dengue, West Nile Virus, and Zika are also becoming increasingly common throughout Pakistan (Haroona, 2020). In 2012, Fiji's Ministry of Health detected only 708 positive cases of Dengue; however by 2014 the country saw over 15,000 cases confirmed (Services, 2017). Fiji is also experiencing the emergence and propagation of unfamiliar viruses, such as Chikungunya virus, which has been circulating throughout neighboring Pacific Island countries. There is concern of an eventual outbreak of this disease within Fiji (Hassan, 2015).

There are approximately 1 billion people who live in informal settlements globally (Satterthwaite et al., 2020). These city sites can often occupy dangerous zones such as proximity to railways, waste dumps, low lying coastal areas, etc. (Satterthwaite et al., 2020). One recent evaluation performed a comparative analysis of urban informal settlements in North Jakarta, Indonesia (Alzamil, 2018). The study found that flooding was a major issue given that these settlements (also referred to locally as *kampungs*) are vulnerable to rising sea levels and that there is a lack of proper sewage and rainwater drainage (Alzamil, 2018). Water supply was considered a major utility issue due to there being no piped water and residents having difficulty accessing water sources or sanitary water tanks in each house (Alzamil, 2018). A Settlement Situation Analysis was carried out in Fiji and evaluated 171 of the 250 informal settlements in this country (Hay, 2016). Water accessibility did not appear to be as severe an issue, with about 75% of dwellings having a formal connection (albeit in some cases shared), however some settlements had PVC piping prone to breakage or leakage (Hay, 2016). For example, one settlement had exposed piped network prone to damage and with the costly installation households would often collect water near a creek already polluted by a nearby municipal rubbish dump (Hay, 2016). The dump along with other unsanitary conditions (e.g. pit latrines) exacerbated issues with mosquitoes that were associated with vector-borne viruses (Hay, 2016).

People who live in informal settlements are already made vulnerable by inadequate infrastructure and resources, and this is further compounded by human and mosquito interactions. Unreliable water supplies cause people to revert to storing water, whether for drinking or household purpose, and mosquitos that are vectors for viral diseases are prone to these stagnant water habitats, which can include storage containers (Adams et al., 2020; Carvalho, Magalhães, & Medronho, 2017; Ruiz, Walker, Foster, Haramis, & Kitron, 2007). If the storage containers are not properly protected or cleaned, such as with cap covers or flap covers then they can inadvertently amplify the mosquito population, especially disease carrying mosquitoes like *Aedes* (Adams et al., 2020; Kittayapong & Strickman, 1993).

There is an abundance of research about certain mosquito species being vectors that transmit various viral infectious diseases to humans and cause illnesses. There are also several studies that demonstrate how mosquitoes utilize environments with stagnant water, both within the household or in the outside environment (Haroona, 2020; Kittayapong & Strickman, 1993), as part of their life cycle. However, there are few studies that provide evidence for the pathway from stagnant water to mosquitoes and finally to fever as a proxy for viral infections. This study examines the association between self-reported mosquito exposure and self-reported fever among residents who live in informal settlements and hypothesizes that there will be a positive relationship. We also examine how that association is related to household water storage practices, and hypothesize that households that store water will have an even stronger positive association between self-reported mosquito exposure and self-reported fever. The evaluation of this relationship will use data from informal settlements enrolled in the RISE (Revitalizing Informal Settlements and their Environments) trial.

Methods

Setting

The RISE trial is a cluster randomized controlled trial that is addressing water and sanitation issues within urban informal settlements in Fiji and Indonesia, which are further challenged by growing populations and climate change (Leder et al., 2021; RISE). RISE purposively chose Indonesia and Fiji as countries to carry out this trial due to a range of characteristics these countries represent across the Asia-Pacific, such as: water security, tidal inundations, population densities, etc. Both countries also have large portions of the population that experience inadequate water and sanitation infrastructure. Candidate sites for each country were selected in tandem with stakeholders, such as: local government authorities, research partners, intervention funders, etc. The selection criteria for informal settlements to be able to participate in the study included: 1) having 30-100 houses, 2) physically separated from other settlements, 3) no conditions that would require imminent relocation (i.e., landslide risk), 4) representing the most vulnerable populations, 5) in areas presumably at high-risk of exposure to water-borne diseases, 6) at least 5-10 children under 5 years of age, 7) secure tenure of home by occupants, 8) existence of water stressors like flooding or poor drainage, 9) possibility of scaling and replicating the design of the intervention, 10) both settlement leaders and inhabitants providing consent to the infrastructure modifications as well as both environmental and health assessments carried out by the program. Selected settlements were then randomly assigned to either control (6 total) or intervention (6 total) groups for each country/city (Leder et al., 2021). Since this study is a baseline analysis, it did not include a comparison between the intervention and control groups.

Data Collection and Data Management

In Indonesia, baseline data were collected from November – December 2018. There were two surveys, both of which were standardized and administered on handheld tablets. The first survey gathered information related to the house (i.e., environmental risks, housing quality, water and sanitation services, household assets, and solid/hard waste disposal practices). The second survey captured information about the health and wellbeing of the respondent and of children in the household. These surveys also included questions related to psychological, social, and economic wellbeing (French et al., 2021).

A standard operational procedure was employed for both survey questionnaires as a guideline for how data were collected. Confirmed consent was prioritized before any survey collection was done. In the case of desired respondents not being present for initial survey visits, a maximum of three attempts were made to complete the questionnaires with said respondents. The household survey required the respondent to be the *female head of household* or a caretaker to complete this questionnaire; if no such individual was available then arrangements were made to return to the household. Survey forms were administered by trained enumerators using SurveyCTO. For the sites in Indonesia, the tool provided surveys in both English and Bahasa Indonesia. Additional local languages (such as Makassarese) were only utilized by interviewers if there was confusion over survey questions that were not made clear from the Bahasa Indonesia translation. In Fiji, the interviews were administered in the local language of I-Taukei. The same data collection procedures and steps were carried out in Suva, Fiji from June-July 2019.

Variables

The outcome variable of interest was self-reported fever in the past seven days, measured through a survey question that asked, “In the last week, have you had a fever?”. For this study this variable was utilized as a proxy for infectious diseases, since fever is a common symptom for mosquito-borne illnesses. The main independent variable represented the frequency of the respondent’s exposure to mosquitoes in the past six weeks, measured through a survey question that asked, “In the past 6 weeks, how often have you encountered mosquitoes trying to bite you inside your house?”. Response options were very often, every day; often, several times a week; occasionally, once a week; never. An additional independent variable of interest was related to water storage and came from a survey question that asked, “Do you ever store water from this source [i.e., one of the previously mentioned water sources], for example, in a container or a jug, in your house?”.

Additional covariates related to housing materials were included, based on evidence from the literature that the built environment (i.e.; roof, waste disposal, etc.) contributed to the prevalence of mosquito exposure (LaDeau et al., 2013; Lindsay, Wilson, Golding, Scott, & Takken, 2017; Tusting et al., 2015). The survey collected data on the main materials used for flooring, outer walls, and roofing. Responses to these questions were categorized based on Tusting et al. (2015), which provided a definition of traditional materials vs. modern materials, with regards to the roof, floors, and walls. In line with this definition, traditional materials were categorized as earth materials like mud or thatching while modern materials were fabricated materials such as ‘corrugated tin’ or ‘tiles’(Tusting et al., 2015).This guided transformation of related variables from the house survey.

The question related to flooring asked, “What is the main flooring type used in this house?”. Possible choices were: Ceramic/tiles/terrazzo, Laminate (plastic), Concrete, Granite/Stone, Bricks, Wood/Boards, Bamboo, and Soil/dirt. The *floor variable* was transformed as a binary response to ‘Traditional/Unimproved’ vs. ‘Modern/Improved’; all original responses were categorized as ‘Modern’ except for ‘Soil/dirt’. The question related to walls asked, “Main material used in the outer wall of this house”. Possible responses were: Masonry, Wood/Plywood, Bamboo (woven or mat), Tin or Corrugated Iron, Ceramic Tiles, and Tent/Taupulin. The *wall variable* was transformed as a binary response to ‘Traditional/Unimproved’ vs. ‘Modern/Improved’; all original responses were categorized as ‘Traditional except for ‘Masonry’. The question related to roofs asked, “Main roofing type of this house”. Possible responses were: Foliage/ palm leaf/ thatch/ grass, Bamboo, Wood/plywood, Corrugated tin/ iron/ aluminum/ zinc, Tent/ Tarpaulin, Roof tiles/Shingles, Asbestos, and Metal Plates. The *roof variable* was transformed as a binary response to ‘Traditional/Unimproved’ vs. ‘Modern/Improved’; all original responses were categorized as ‘Traditional except for ‘Corrugated tin/ iron/ aluminum/ zinc’ ‘Roof tiles/Shingles’.

Waste disposal was considered part of the built environment because improper waste management (i.e., open plastic containers) provides environments for mosquitoes to thrive (LaDeau et al., 2013; Lindsay et al., 2017). Thus, the variable for where garbage was disposed was utilized and transformed accordingly. The question related to garbage asked: “What other ways do you dispose of your garbage?”. Possible responses were: Neighborhood collection point (non-government collection), Dumped in yard/garden//vacant land within the settlement and left to decompose, Dumped in yard/garden/vacant land outside the settlement and left to decompose, Dumped in waterway/drain within the settlement and left to get washed away, Dumped in waterway/drain outside the settlement and left to get washed away, Burned, or Buried. The *garbage variable* was transformed into ‘Dumped within settlement’, ‘Dumped outside settlement’ or ‘Properly managed’.

Socio-economic factors have been found in other studies to be an important factor in the interaction between health outcomes and exposure to mosquitoes (Adams et al., 2020). The survey questions related to socioeconomics asked, “Look at SHOWCARD 5 and tell me if anyone in the household owns any of the following”. Response options ranged from up to 20 different assets, such as, but not limited to: a computer/laptop, mobile/smartphone, bank account, washing machine, and so on. This survey question and responses were transformed (i.e., condensed) by RISE into a *wealth index* variable with categories for ‘Poorest’, ‘Poor’, ‘Middle’, ‘Rich’ and ‘Richest.

The literature also provided information as to which sources of water facilitate the prevalence of mosquitoes, which tended to be stagnant and open sources (Haroona, 2020; Ruiz et al., 2007). The survey question related to water source asked, “Tell me all the different water sources you use for any purpose. (Select all that apply)”. Response options were: Mains water [reticulated supply from water company], Borewell [deeper well], Shallow well [hung dug], Rainwater harvest/collection, Tanker truck/drum/bucket, Cart with small tank/drum/bucket, Bottled water, Moving surface water [river, creek, etc.], Standing water [marshes, rawa-rawa], Other. The *Water Source Variable* was transformed into a binary variable with options being stagnant and open sources of water or not.

Water access has been found to be an important factor in regard to mosquitos and general health (Adams et al., 2020). The survey question related to water access asked, “Is your access to water source…”, (water source variable and options described in the previous variable).

Response options were: ‘Available everyday through the whole year’, ‘Available through the whole year, but not all the time’, ‘Available in the dry season only’, and ‘Available in the wet season only’. The variable was transformed to be binary into to represent the dichotomy between access to water all year and access to water intermittently.

Study Design and Statistical Method

The data for this study originated from the RISE trial. This study involved a cross-sectional study design, given that data related to water storage were only collected at baseline. The variables for fever and water storage were binary and all other variables of interest are ordinal. A multivariate logistic regression analysis was utilized to analyze the data and assess the magnitude of association between the exposure variable and outcome. The variable for *water storage* was used for a sub-group analysis to examine the association between the main variables of interest among only those who store drinking water. The covariates related to socioeconomics, built environment, water source, and water access were incorporated into the analysis models based upon previous studies that suggest these variables have an association with mosquitoes (LaDeau et al., 2013; Ruiz et al., 2007; Whiteman et al., 2020) and infectious disease, which are represented by the proxy variable fever (Adams et al., 2020; Troyo, Fuller, Calderón-Arguedas, Solano, & Beier, 2009). The models were also adjusted for clustering to account for the study design in each country. All covariates were analyzed for correlation so as not to over-compensate for confounding in case an association is found between covariates. All models were first analyzed disaggregated by country (i.e., Indonesia and Fiji) and then also aggregated for a pooled sample analysis. All models were also stratified by the covariate related to water storage for an analysis of a sub-sample of the population who store water in their homes. All analyses were carried in STATA 16.

Informed consent and institutional review

Prior to informed consent all involved study settlement, households, as well as individual respondents/caregivers were provided with explanatory statements about the nature of participation in the study and that they could withdraw at from any or all components of the study at any point in time. Prior to proceeding with any surveys or sample collections verbal consent was documented and affirmed. Study protocols were approved by the ethics boards at Fiji National University (Fiji), Hasanuddin University (Indonesia), and Monash University (Australia). Data was shared with Emory under a data transfer agreement. Emory's Institutional Review Board confirmed that the study did not require Emory IRB approval.

Results

Surveys Completed

In Suva, Fiji, 773 surveys were completed, of which 12 were removed due to missing data for at least one of the main variables of interest (mosquito exposure, water storage, and fever prevalence) or any pertinent demographic variables. In total, the analytic sample consists of 761 households. In Makassar, Indonesia, 599 surveys were completed, of which 34 were removed for a total analytic sample of 565 cleaned households. All the data were centrally managed by Monash University, and required access through a secured browser (i.e., https://serp-gateway.erc.monash.edu). Thus, all data processing steps (i.e., compiling, cleaning, analyzing, etc.) occurred in this secured browser.

Frequencies of Main Variables

Main variables of interest, disaggregated by country and aggregated as a pooled sample, are shown in Table 1. In Fiji most respondents (53%) reported that they encountered mosquitoes trying to bite them on a daily basis, with the remaining frequencies showing that 23% reported encountering mosquitoes often (multiple times in a week) and the remaining 24% had little to no mosquito exposure. A large majority of respondents (91%) reported not having had a fever in the last week. Most respondents (73%) reported that they stored water within their homes. In Indonesia most respondents (85%) reported that they encountered mosquitoes trying to bite them on a daily basis, with the remaining frequencies being 9% for being exposed often to mosquitos and 6% of respondents having little to no mosquito exposure. A large majority of respondents (89%) reported not having had a fever in the last week. Most respondents (66%) reported that they stored water within their homes.

To ensure that the models that included covariates were not over-adjusting for confounding variables, a bivariate analysis among the pertinent covariates was carried out. In Fiji the adjusted model included the following covariates: garbage disposal, unimproved water source, wealth index, and water access. All variables demonstrated weak correlations to one another: r = 0.4 between garbage and water source, r = 0.11 between garbage and wealth, r = 0.11 between water source and wealth, r = 0.07 between water access and garbage disposal, r = 0.22 between water access and water source, and r = -0.01 between water access and wealth. In Indonesia the adjusted model included the following covariates: garbage disposal, wall materials, unimproved water source, and wealth index. All variables demonstrated weak correlations to one another: r = 0.008 between garbage and wall material, r = -0.002 between garbage and water source, r = -0.06 between garbage and wealth, r = 0.07 between wall material and water source, r = -0.24 between wall materials and wealth, r = -0.10 between water source and wealth, r = 0.18 between water access and garbage disposal, r = 0.13 between water access and wall materials , r = 0.06 between water access and water source, and r = -0.02 between water access and wealth.

Table 1: Main Variables of Interest for Makassar, Indonesia and Suva, Fiji

	Indonesia *(n=565)*	Fiji *(n = 761)*	Total *(n = 1326)*
Mosquito Frequency			
Very Often	480 (84.96)	404 (53.09)	884 (66.67)
Often	53 (9.38)	172 (22.60)	225 (16.97)
Occasionally/Never	32 (5.66)	185 (24.31)	217 (16.37)
Fever			
Yes	63 (11.15)	69 (9.07)	132 (9.95)
No	502 (88.85)	692 (90.93)	1194 (90.05)
Water Storage			
Yes	374 (66.19)	556 (73.06)	930 (70.14)
No	191 (33.81)	205 (26.94)	396 (29.86)

Participant Characteristics

Sociodemographic characteristics of the study population, stratified by country and by water storage practices, are shown in Table 2. In Makassar, there were a total of 565 households represented with 191 (34%) households stating they do not store water in the home and the remaining 374 (66%) households do store water in the home. In Suva, there were a total of 761 households represented with 205 (27%) households that don't store water while the remaining 556 (73%) do. Most participants were female in both Indonesia (90%) and Fiji (69%). In Indonesia, most respondents reported their ethnicity was Makassarese (73%) and that they were Muslim (96%). In Fiji, participants were mostly ethnic I-Taukei (76%) and Christian (82%). The plurality of households in both countries had been in their communities for more than 10 years (but not whole life) (Indonesia – 43% and Fiji – 39%). Also, most respondents' highest level of completed education was secondary in both Indonesia (45%) and Fiji (63%).

Built Environment

Built environment characteristics of the study population, stratified by country and by water storage practices, are shown in Table 2. In Indonesia, 75% of households used one or more sources of water known to attract and help mosquitoes proliferate, and of those households 76% stored water. In Fiji, only 7% of households used one or more sources of water that mosquitoes are known to frequent; the remaining 93% of households stated that they only used mains water as their water source. There was limited variability among variables related to the built environment in either country. In Indonesia 99% of households had a modern roof (i.e., tin or tiles) and 97% of households had modern flooring (i.e., tiles, plastic, concrete, stone, bricks, wood, and/or bamboo). However, there was variability in housing structure related to walls with 51% of households using traditional materials (i.e., wood, bamboo, tent, ceramic tiles, and/or iron) and the remaining 49% using modern wall materials (i.e., masonry). In Fiji 97% of households had modern roofs and 99% had modern floors; in contrast, 97% households used traditional wall materials. Regarding waste management, only 12% of households in Indonesia safely disposed of garbage in a manner that does not attract mosquitoes (i.e., at a neighborhood collection point, or by burning or burying the trash). Households mainly (83%) dumped garbage in the settlement or in waterways within the settlement. Similarly in Fiji only 16% of households safely disposed of garbage. Households also mainly (81%) dumped garbage directly within the settlement or waterways. Both countries had mostly consistent water access all year (Indonesia - 88%, Fiji – 85%).

Table 2: Demographic and Built Environment information for Makassar, Indonesia and Suva, Fiji by water storage practice

Demographic Variable	Indonesia *(n=565)*			Fiji *(n = 761)*		
	Water Storage (n=374)	No Water Storage (n=191)	*Total* *(n=565)*	Water Storage (n=556)	No Water Storage (n=205)	*Total* *(n=761)*
Demographic Characteristics						
Mosquito Frequency						
Very Often	323 (86.36)	157 (82.20)	480 (84.96)	296 (53.24)	108 (52.68)	404 (53.09)
Often	32 (8.56)	21 (10.99)	53 (9.38)	130 (23.38)	42 (20.49)	172 (22.60)
Occasionally/Never	19 (5.08)	13 (6.81)	32 (5.66)	130 (23.38)	55 (26.83)	185 (24.31)
Age (mean, SD)	41.72 (12.15)	40.20 (13.07)	41.21 (12.48)	43.02 (14.23)	40.69 (13.94)	42.39 (14,18)
Gender (n, %)						
Female	340 (90.91)	168, (87.96)	508, (89.91)	392 (70.50)	133 (64.88)	525, (68.99)
Male	34 (9.09)	23, (12.04)	57, (10.09)	164 (29.50	72 (35.12)	236, (31.01)
Ethnicity (n, %)						
Makassar / Itaukei	275, (73.53)	140, (73.30)	415, (73.45)	424, (76.26)	155, (76.61)	579, (76.08)
Bugis/ Indo-Fijian	66, (17. 65)	37, (19.37)	103, (18,23)	111, (19.96)	40, (19.51)	151, (19.84)
Other	33, (8.82)	14, (7.33)	47, (8.32)	21, (3.78)	10, (4.88)	31, (4.07)
Religion (n, %)						
Islam/ Christian	362, (96.79)	183, (95.81)	545, (96.46)	455, (81.83)	169, (82.44)	624, (82)
Other	12, (3.21)	8, (4.19)	20, (3.54)	101, (18.17)	36, (17.56)	137, (18)

Years lived in the settlement at baseline (n, %)						
Unknown/Other	0, (0)	0, (0)	0, (0)	0, (0)	1, (0.49)	1, (0.13)
Less than 2 years	30, (8.02)	14, (7.33)	44, (7.79)	46, (8.27)	16, (7.80)	62, (8.15)
2-5 years	39, (10.43)	24, (12.57)	63, (11.15)	57, (10.25)	16, (7.80)	73, (9.59)
5-10 years	47, (12.57)	19, (9.95)	66, (11.68)	76, (13.67)	28, (13.66)	104, (13.67)
More than 10 years	160, (42.78)	83, (43.46)	243, (43.01)	226, (40.65)	70, (34.15)	296, (38.90)
Whole life	98, (26.20)	51, (26.70)	149, (26.37)	151, (27.16)	74, (36.10)	225, (29.57)
Literacy (n, %)						
Both	326, (87.17)	168, (87.96)	494, (87.43)	545, (98.02)	205, (100)	750, (98.55)
Only Read	5, (1.34)	1, (0.52)	6, (1.06)	1, (0.18)	0, (0)	1, (0.13)
Only Write	3, (0.80)	1, (0.52)	4, (0.71)	1, (0.18)	0, (0)	1, (0.13)
Neither	38, (10.16)	18, (9.42)	56, (9.91)	9, (1.62)	0, (0)	9, (1.18)
Unknown	2, (0.53)	3, (1.57)	5, (0.88)	0, (0)	0, (0)	0, (0)
Highest level of education (n, %)						
No school	27, (7.22)	11, (5.76)	38, (88.14)	9, (1.62)	1, (0.49)	10, 1.31
Primary	179, (47.86)	72, (37.70)	251, (44.42)	105, (18.88)	38, (18.54)	143, 18.79
Secondary	158, (42.25)	96, (50.26)	254, (44.96)	360, (64.75)	123, (60)	483, 63.47
Above secondary	10, (2.67)	12, (6.28)	22, (3.29)	81, (14.57)	41, (20)	122, 16.03
Other	0, (0)	0, (0)	0, (0)	1, (0.18)	2, (0.98)	3, 0.39
Built Environment Characteristics						
Unimproved Water Source (n, %)						
Yes	283, (75.67)	140, (73.30)	423, (74.87)	41, (7.37)	10, (4.88)	51, (6.70)
No	91, (24.33)	51, (26.70)	142, (25.13)	515, (92.63)	195, (95.12)	710, (93.30)
Water Access						
Available all year	325 (86.90)	173 (90.58)	498 (88.14)	471 (84.71)	175 (85.37)	646 (84.89)
Intermittent availability	49 (13.10)	18 (9.42)	67 (11.86)	85 (15.29)	30 (14.63)	115 (15.11)
Flooring material (n, %)						
Traditional	12, (3.21)	7, (3.66)	19, (3.36)	10, (1.80)	0, (0)	10, (1.31)
Modern/Improved	362, (96.79)	184, (96.34)	546, (96.64)	546, (98.20)	205, (100)	751, (98.69)
Wall material (n, %)						
Traditional/Unimproved	194, (51.87)	94, (49.21)	288, (50.97)	542, (97.48)	199, (97.07)	741, (97.37)
Modern/Improved	180, (48.13)	97, (50.97)	277, (49.03)	14, (2.52)	6, (2.93)	20, (2.63)
Garbage (n, %)						
Dumping in settlement	316, (84.49)	153, (80.10)	469, (83.01)	450, (80.94)	169, (82.44)	619, (81.34)
Dumping outside settlement	19, (5.08)	11, (5.76)	30, (5.31)	15, (2.70)	4, (1.45)	19, (2.50)
Safe Disposal	39, (10.43)	27, (14.14)	66, (11.68)	91, (16.37)	32, (15.61)	123, (16.16)

Associations between self-reported mosquito exposure and self-reported fever

Results of statistical analyses are displayed in Tables 3-6. Among settlements in Makassar, Indonesia self-reported frequency of exposure to mosquitos was not significantly associated with fever. In the unadjusted model, the odds of being exposed to mosquitos on a *daily basis* and having a fever within the last week was 1.25 (CI: 0.37, 4.24) times the odds of being exposed to mosquitoes only *occasionally or not at all* and having a fever. When the model was adjusted for covariates related to water source, water access, built environment, and socioeconomics the odds increased to 1.45 (CI: 0.42, 5.06) when compared between *daily* and *occasional/no exposure* to mosquito and an outcome of fever. The cluster-adjusted model was also 1.45 (CI: 0.24, 8.67) in the odds ratio comparison. A sub-sample model was carried out to evaluate the association between mosquitoes and fever among households that stored their water in the home. In the unadjusted model among households that stored water, the odds of being exposed to mosquitos on a *daily basis* and having a fever within the last week was 1.31 (CI:0.29, 5.85) the odds of being exposed to mosquitoes only *occasionally or not at all* and having a fever. When the model was adjusted for covariates, the odds increased to 1.46 (CI: 0.31, 6.81) when compared between *daily* and *occasional/no exposure* to mosquito and an outcome of fever. The cluster-adjusted model also had an odds ratio comparison of 1.46 (CI: 0.27, 7.78)

Within a few of the adjusted models, statistically significant associations were observed between certain covariates and fever. Statistical significance was ascribed to a p-value of 0.05 or less. In terms of built environment, households with traditional wall materials had 1.86 (CI: 1.05, 3.31, p=0.04) odds of an outcome of fever compared to homes that used modern wall materials. Households ascribed as poor on the wealth index had 2.60 (CI*:* 1.10, 3.31, p=0.04) the odds having had a fever in the last week compared to households with the poorest level on the wealth index. When the model was further adjusted for clustering only the association between wall materials and fever remained significant with an adjusted odds ratio of 1.86 (CI: 1.05, 3.28, p – 0.03). The adjusted sub-sample model also found a significant association between wall materials and fever, including when the model further adjusted for settlement clustering. Specifically, the odds of homes made of traditional wall materials and report of having a fever in the last week was 2.01 (CI: 1.02, 3.94, p=0.04) the odds of reports of a fever from homes made with modern wall materials

Among settlements in Suva, Fiji self-reported frequency of exposure to mosquitos was not significantly associated with fever in the unadjusted or adjusted models. In the unadjusted model, the odds of being exposed to mosquitos on a *daily basis* and having a fever within the last week was 1.70 (CI: 0.89, 3.23) the odds of being exposed to mosquitoes only *occasionally or not at all* and having a fever. When the model was adjusted for covariates related to built environment and socioeconomics the odds increased to 1.88 (CI: 0.98, 3.64) when compared between *daily* and *occasional/no exposure* to mosquito and an outcome of fever. This odds ratio (1.88) was the same for the cluster adjusted model (CI: 1.18, 3.02, p=0.01) and was found to be significant. Sub-sample models of only the population that stored their water were also evaluated for an association between mosquito exposure and report of fever. In the unadjusted model among households that stored water, the odds of being exposed to mosquitos on a *daily basis* and having a fever within the last week was 1.40 (CI: 0.71, 2.79) the odds of being exposed to mosquitoes only *occasionally or not at all* and having a fever. When the model was adjusted for covariates, the odds increased to 1.53 (CI: 0.75, 3.11) when compared between *daily* and *occasional/no exposure* to mosquito and an outcome of fever. The cluster-adjusted model also had an odds ratio comparison of 1.53 (CI: 0.99, 2.34).

Within a few of the adjusted models, statistically significant associations were observed between certain covariates and fever. In terms of water access, respondents in the adjusted full model who had access to water all year had 1.99 (CI: 1.07, 3.73, p=0.03) odds of reporting having a fever in the last week compared to respondents who had intermittent access to water (i.e. seasonal, inconsistent, etc.). In the sub-sample cluster-adjusted model access to water also had a significant relationship with fever (OR: 1.58; CI: 1.09, 2.28; p=0.02).

The final analysis was done of a pooled sample that concatenated all the data from both countries, resulting in a larger sample size (n=1326). The unadjusted model did not have a significant association and resulted in 1.62 odds (CI: 0.94, 2.81) of reporting fever for respondents who were exposed to mosquitoes *daily* compared to *occasionally or not at all*. However, this relationship became statistically significant for both the adjusted model (OR: 1.76; CI: 1.00, 3.12; p=0.05) and cluster adjusted model (OR: 1.76; CI: 0.99, 3.14; p=0.05). At the sub-sample level, no significance was found for any of the models for the pooled sample. In the unadjusted model, the odds of reporting fever among respondents who were exposed to mosquitoes *daily* was 1.43 (CI: 0.79, 2.60) the odds of those who were exposed to mosquitoes *occasionally or not at all*. This odds ratio increased to 1.56 (CI: 0.81, 2.81) for the adjusted model and to 1.51 for the cluster adjusted model (0.81, 2.81).

Also, within the pooled sample, there were few other significant relationships between covariates and fever. In the full model, statistically significant associations were observed between water accessibility and fever (OR: 1.77; CI: 1.11, 2.84; p=0.02) in the adjusted model and in the cluster-adjusted model (OR: 1.77; CI: 1.16, 2.71; p=0.01). This was also the case between traditional wall materials and fever both in the adjusted model (OR: 1.68; CI: 1.07, 2.64; p=0.02) and the cluster adjusted model (OR: 1.68; CI: 1.07, 2.65; p=0.02).

Indonesia

Table 3: Logistic regression model of odds ratios associated with self-reported fever in the previous seven days among respondents in the RISE baseline survey in Makassar, Indonesia

		Indonesia (n= 565)		
Variable		OR estimate	95% CI	P-value
Unadjusted				
Mosquito	Daily	1.25	(0.37, 4.24)	0.72
	Often	0.80	(0.24, 2.71)	0.72
Adjusted				
Mosquito	Daily	1.45	(0.42, 5.06)	0.56
	Often	1.21	(0.26, 5.60)	0.81
Water Source	Stagnant water sources	1.41	(0.72, 2.78)	0.32
Water Access	Availability of water	1.74	(0.85, 3.59)	0.13
Built Environment 1	*Wall Materials*	*1.86*	*(1.05, 3.31)*	*0.04***
Built Environment 2	Garbage (outside settlement)	1.75	(0.62, 4.95)	0.29
	Garbage (proper disposal)	0.96	(0.40, 2.29)	0.93
Socioeconomics	*Wealth (Poor)*	*2.60*	*(1.10, 3.31)*	*0.04***
	Wealth (Middle)	2.19	(0.88, 5.45)	0.09
	Wealth (Rich)	1.06	(0.38, 2.92)	0.91

	Wealth (Richest)	1.88	(0.73, 4.88)	0.20
Cluster Adjusted (12 Settlements)				
Mosquito	Daily	1.45	(0.24, 8.67)	0.68
	Often	1.21	(0.19, 7.77)	0.84
Water Source	Stagnant water sources	1.41	(0.72, 2.78)	0.32
Water Access	Availability of water	1.74	(0.89, 3.43)	0.11
Built Environment 1	*Wall Materials*	*1.86*	*(1.05, 3.28)*	*0.03***
Built Environment 2	Garbage (outside settlement)	1.75	(0.35, 8.64)	0.50
	Garbage (proper disposal)	0.96	(0.47, 1.96)	0.91
Socioeconomics	Wealth (Poor)	2.60	(0.86, 7.88)	0.09
	Wealth (Middle)	2.19	(0.91, 5.30)	0.08
	Wealth (Rich)	1.06	(0.41, 2.77)	0.90
	Wealth (Richest)	1.88	(0.68, 5.18)	0.22

Table 4: Logistic regression model of odds ratios associated with self-reported fever in the previous seven days among respondents in the RISE baseline survey in Makassar, Indonesia *among households that store water*

		Indonesia (n= 374)		
Variable		OR estimate	95% CI	P-value
Unadjusted				
Mosquito	Daily	1.31	(0.29, 5.85)	0.73
	Often	1.21	(0.20, 7.35)	0.83
Adjusted				
Mosquito	Daily	1.46	(0.31, 6.81)	0.63
	Often	1.35	(0.21, 8.59)	0.75
Water Source	Stagnant water sources	1.49	(0.68, 3.27)	0.32

Water Access	Availability of water	1.32	(0.57, 3.08)	0.51
Built Environment 1	*Wall Materials*	*2.01*	*(1.02, 3.94)*	*0.04***
Built Environment 2	Garbage (outside settlement)	1.85	(0.56, 6.15)	0.32
	Garbage (proper disposal)	1.29	(0.48, 3.43)	0.61
Socioeconomics	Wealth (Poor)	2.06	(0.78, 5.41)	0.14
	Wealth (Middle)	1.52	(0.54, 4.28)	0.43
	Wealth (Rich)	0.92	(0.29, 2.89)	0.89
	Wealth (Richest)	1.94	(0.70, 5.42)	0.21
Cluster Adjusted (12 Settlements)				
Mosquito	Daily	1.46	(0.27, 7.78)	0.66
	Often	1.35	(0.29, 6.27)	0.70
Water Source	Stagnant water sources	1.49	(0.52, 4.27)	0.46
Water Access	Availability of water	1.32	(0.59, 2.99)	0.50
Built Environment 1	Wall Materials	2.01	(0.94, 4.30)	0.07
Built Environment 2	Garbage (outside settlement)	1.85	(0.33, 10.46)	0.49
	Garbage (proper disposal)	1.29	(0.56, 2.95)	0.55
Socioeconomics	Wealth (Poor)	2.06	(0.70, 6.06)	0.19
	Wealth (Middle)	1.52	(0.60, 3.84)	0.38
	Wealth (Rich)	0.92	(0.31, 2.78)	0.89
	Wealth (Richest)	1.94	(0.68, 5.56)	0.22

Fiji

Table 5: Logistic regression model of odds ratios associated with self-reported fever in the previous seven days among respondents in the RISE baseline survey in Suva, Fiji

		Fiji (n=761)		
Variable		OR estimate	95% CI	P-value
Unadjusted				
Mosquito	Daily	1.70	(0.89, 3.23)	0.11
	Often	0.82	(0.35, 1.91)	0.64
Adjusted				
Mosquito	Daily	1.88	(0.98, 3.64)	0.06
	Often	0.79	(0.33, 1.87)	0.59
Water Access	Availability of water	*1.99*	*(1.07, 3.73)*	*0.03***
Built Environment	Garbage (Outside Settlement)	2.24	(0.60, 8.32)	0.23
	Garbage (Proper Disposal)	1.58	(0.85, 2.95)	0.15
Socioeconomics	Wealth (Poor)	1.35	(0.62, 2.94)	0.45
	Wealth (Middle)	0.76	(0.32, 1.77)	0.52
	Wealth (Rich)	1.31	(0.59, 2.89)	0.50
	Wealth (Richest)	1.04	(0.46, 2.33)	0.92
Cluster Adjusted (12 Settlements)				
Mosquito	*Daily*	*1.88*	*(1.18, 3.02)*	*0.01***
	Often	0.80	(0.27, 2.33)	0.67
Water Access	Availability of water	*2.00*	*(1.20, 3.33)*	*0.01***
Built Environment	Garbage (Outside Settlement)	2.23	(0.66, 7.67)	0.20
	Garbage (Proper Disposal)	1.57	(0.83, 3.02)	0.16
Socioeconomics	Wealth (Poor)	1.35	(0.58, 3.14)	0.48
	Wealth (Middle)	0.76	(0.32, 1.78)	0.52
	Wealth (Rich)	1.31	(0.55, 3.11)	0.54
	Wealth (Richest)	1.04	(0.33, 3,23)	0.95

Table 6: Logistic regression model of odds ratios associated with self-reported fever in the previous seven days among respondents in the RISE baseline survey in Suva, Fiji *among households that store water*

		Fiji (n= 556)		
Variable		OR estimate	95% CI	P-value
Unadjusted				
Mosquito	Daily	1.40	(0.71, 2.79)	0.33
	Often	0.73	(0.30, 1.80)	0.50
Adjusted				
Mosquito	Daily	1.53	(0.75, 3.11)	0.25
	Often	0.73	(0.29, 1.83)	0.51
Built Environment	Garbage (Outside Settlement)	2.62	(0.67, 10.35)	0.17
	Garbage (Proper Disposal)	1.71	(0.87, 3.36)	0.12
Water Access	Availability of water	1.56	(0.77, 3.23)	0.21
Socioeconomics	Wealth (Poor)	1.22	(0.53, 2.83)	0.64
	Wealth (Middle)	0.77	(0.31, 1.87)	0.56
	Wealth (Rich)	1.29	(0.55, 3.00)	0.56
	Wealth (Richest)	0.97	(0.39, 2.39)	0.95
Cluster Adjusted (12 Settlements)				
Mosquito	Daily	1.53	(0.99, 2.34)	0.06
	Often	0.73	(0.25, 2.12)	0.57
Water Access	*Availability of water*	*1.58*	*(1.09, 2.28)*	*0.02***
Built Environment	Garbage (Outside Settlement)	2.63	(0.73, 9.4)	0.14
	Garbage (Proper Disposal)	1.71	(0.70, 4.15)	0.24
Socioeconomics	Wealth (Poor)	1.22	(0.39, 3.77)	0.73
	Wealth (Middle)	0.77	(0.27, 2.18)	0.62
	Wealth (Rich)	1.29	(0.42, 3.98)	0.66
	Wealth (Richest)	0.97	(0.23, 4.07)	0.97

Indonesia and Fiji Combined

Table 7: Logistic regression model of odds ratios associated with self-reported fever in the previous seven days among respondents in the RISE baseline survey in Makassar, Indonesia and Suva, Fiji

		Total *(n=1326)*		
Variable		OR estimate	95% CI	P-value
Unadjusted				
Mosquito	Daily	1.62	(0.94, 2.81)	0.09
	Often	0.90	(0.43, 1.86)	0.77
Adjusted				
Mosquito	*Daily*	*1.76*	*(1.00, 3.12)*	*0.05***
	Often	0.94	(0.45, 1.96)	0.87
Water Source	Stagnant water sources	1.36	(0.91, 2.02)	0.14
Water Access	*Availability of water*	*1.77*	*(1.11, 2.84)*	*0.02***
Built Environment 1	*Wall Material*	*1.68*	*(1.07, 2.64)*	*0.02***
Built Environment 2	Garbage (Outside Settlement)	1.84	(0.82, 4.10)	0.14
	Garbage (Proper Disposal)	1.28	(0.78, 2.10)	0.33
Socioeconomics	Wealth (Poor)	1.87	(1.06, 3.32)	0.03
	Wealth (Middle)	1.30	(0.71, 2.38)	0.40
	Wealth (Rich)	1.22	(0.65, 2.27)	0.53
	Wealth (Richest)	1.37	(0.74, 2.52)	0.31
Cluster Adjusted (12 Settlements)				
Mosquito	*Daily*	*1.76*	*(0.99, 3.14)*	*0.05***
	Often	0.94	(0.39, 2.25)	0.89
Water Source	Stagnant water sources	1.35	(0.93, 1.98)	0.11
Water Access	*Availability of water*	*1.77*	*(1.16, 2.71)*	*0.01***
Built Environment 1	*Wall Material*	*1.68*	*(1.07, 2.65)*	*0.02***
Built Environment 2	Garbage (Outside Settlement)	1.84	(0.64, 5.28)	0.26
	Garbage (Proper Disposal)	1.28	(0.74, 2.19)	0.37
Socioeconomics	Wealth (Poor)	1.87	(0.89, 3.92)	0.10
	Wealth	1.30	(0.68, 2.50)	0.43

	(Middle)			
	Wealth (Rich)	1.22	(0.66, 2.26)	0.53
	Wealth (Richest)	1.37	(0.62, 3.04)	0.44

Table 8: Logistic regression model of odds ratios associated with self-reported fever in the previous seven days among respondents in the RISE baseline survey in Makassar, Indonesia and Suva, Fiji *among households that store water*

		Total *(n = 930)*		
Variable		OR estimate	95% CI	P-value
Unadjusted				
Mosquito	Daily	1.43	(0.79, 2.60)	0.24
	Often	0.84	(0.38, 1.85)	0.67
Adjusted				
Mosquito	Daily	1.56	(0.81, 2.81)	0.20
	Often	0.86	(0.38, 1.90)	0.70
Water Source	Stagnant water sources	1.41	(0.89, 2.21)	0.14
Water Access	Availability of water	1.41	(0.82, 2.42)	0.21
Built Environment 1	Wall Materials	1.71	(0.95, 3.08)	0.07
Built Environment 2	Garbage (Outside Settlement)	2.18	(0.90, 5.30)	0.09
	Garbage (Proper Disposal)	1.50	(0.87, 2.59)	0.15
Socioeconomics	Wealth (Poor)	1.58	(0.84, 2.96)	0.15
	Wealth (Middle)	1.05	(0.54, 2.04)	0.89
	Wealth (Rich)	1.14	(0.58, 2.24)	0.71
	Wealth	1.30	(0.67, 2.54)	0.44

	(Richest)			
Cluster Adjusted (12 Settlements)				
Mosquito	Daily	1.51	(0.81, 2.81)	0.20
	Often	0.86	(0.38, 1.90)	0.70
Water Source	Stagnant water sources	1.41	(0.89, 2.21)	0.14
Water Access	*Availability of water*	1.41	(0.82, 2.42)	0.21
Built Environment 1	Wall Material	1.71	(0.95, 3.08)	0.07
Built Environment 2	Garbage (Outside Settlement)	2.18	(0.90, 5.30)	0.09
	Garbage (Proper Disposal)	1.50	(0.87, 2.60)	0.15
Socioeconomics	Wealth (Poor)	1.58	(0.84, 2.96)	0.15
	Wealth (Middle)	1.05	(0.54, 2.04)	0.89
	Wealth (Rich)	1.14	(0.58, 2.24)	0.71
	Wealth (Richest)	1.30	(0.67, 2.54)	0.44

Discussion

The results of the analysis for both study sites in Indonesia and Fiji demonstrated that an association existed between residents reporting having a fever in the last week and reporting that they encountered mosquitoes trying to bite them on a daily basis. This association grew in strength as the models were adjusted for additional pertinent socio-ecological factors, specifically: whether someone had only intermittent access to water (i.e., seasonal) as opposed to all year and if certain housing materials (i.e.; walls) were traditional and therefore more vulnerable to mosquitos entering a home. These findings were consistent with other studies that also demonstrated how socio-ecological factors can amplify the association of fever, representative as a symptomatic viral infection, and mosquito exposure (Baker et al., 2021; Tusting et al., 2015). Between the two study countries, Fiji demonstrated the strongest association at all model levels when compared to the models in Indonesia. All models were further stratified by water storage practice categorized as whether a respondent did or did not store water in the household. In this stratification only the sub-group that *did* store water were selected and presented. Similar to the full models there was a consistent positive trend in both countries between the association of an outcome of fever and daily exposure to mosquitoes, which also increased in strength when models were adjusted.

When both countries were pooled as a single model there was a greater sample size (n=1326), which provided a stronger power to the analysis and resulted in more precise and significant correlations between mosquito exposure and fever, when adjusted for other covariates. The sub-sample analysis, which only analyzed the respondents that stored their water in the home, resulted in positive associations between daily mosquito exposure and report of fever; however, no sub-sample models reached statistical significance and the association decreased in strength. This was the opposite of what was hypothesized, since stagnant water, including water storage containers, has been found to be an instigator of mosquito proliferation (Haroona, 2020) such as with *Culex* genera, which are known to carry viral diseases (Van Lun et al., 2012). The original question regarding water storage practices did not further elicit information as to whether residents left their household water containers exposed or covered. Thus, there is a chance that some residents were utilizing safe water storage practices, such as covering a container with appropriate lids (Mintz et al., 1995) and that would cause a barrier against mosquitos. Overall, these results were consistent with the literature and foment other studies that argue for the integration of components, such as social determinants of health, when evaluating the association between vectors (e.g. mosquitoes) and infectious diseases (Adams et al., 2020; Carvalho et al., 2017).

For several millennia certain mosquitoes have specialized to develop an affinity for human beings as well as adapt to the changes that humans incur on their surrounding environment (Stensmyr, 2020). For example, one article discusses how these mosquitoes may have been induced to utilize water storage containers as breeding grounds, after humans started using these containers to have access to water during times of drought (Stensmyr, 2020). When there is both a stressor that induces water storage behavior and a concentrated abundance of humans in an area, this amplifies interactions with vector-mosquitoes and contributes to the argument that urbanization may increase the rate of certain mosquito species (Stensmyr, 2020). In this study, water storage behavior is common among both countries (over 66% of people store water in Indonesia and over 73% in Fiji), and this commonality enables the risk of exposure to mosquitoes. Species such as *Aedes aegypti* are known for carrying diseases like yellow fever or Dengue fever, which both tend to manifest in urban environments (Mundi, 2021). Both of these diseases are often associated with symptoms such as fever and severe headache (Mundi, 2021). The main carriers of the flaviviruses, such as what causes Japanese Encephalitis or West Nile virus, are the Culex mosquito species (Go et al., 2013). These viral infections and their related vectors are widespread given that “up to 70% of adults in tropical regions of Asia have JEV antibodies" (Go et al., 2013). In both study countries there has been concerning growth in several of these viral diseases.

Around 2016 the Ministry of Health in Indonesia launched a campaign to screen the re-emergence of the Chikungunya virus. They found that there was a massive and fast replacement of species genotypes, with the Asian-Pacific genotype asserting dominance, which raises concerns over the invasive capacity in Indonesia and other parts of the world (Anggraeni et al., 2021). There is also concern over the Chikungunya virus in Fiji and the Ministry of Health worries about the encroaching prospects of an “explosive outbreak” on this island nation (Hassan, 2015). Dengue is highly endemic in Indonesia, occurring from January to June, and is prone to cause cyclical epidemics in urban areas, making it one of the leading causes of hospitalization and death among children (WHO, 2006). The number of Dengue cases have also been increasing in Indonesia jumping from 68,410 cases in 2017 to 1,377,600 cases in 2019 (Nurhayati-Wolff, 2019). In Fiji, Dengue cases are particularly high during summer months and cases have also been amplifying over the last few years, from 708 positive cases in 2012 to over 15,000 confirmed cases in 2014 (Services, 2017).

Inaccessibility to clean, reliable, and protected water both increases the population of mosquitoes, especially the disease-carrying species that are prone to humans, and heightens the interactions that humans have with these vectors. Storing water is a way that people respond to unreliable water supplies to meet various needs such as body hygiene, household purposes, and consumption (Adams et al., 2020; Carvalho et al., 2017). However, sometimes people may be led "to store water in unfavorable or inappropriate containers, such as barrels, which cannot be fully sealed and facilitates the reproduction of the vector" (Carvalho et al., 2017) thereby amplifying mosquito populations, such as *Aedes* genera (Adams et al., 2020). Urban poverty magnifies these issues even more since some communities will often have several water storage containers to buffer against seasonal scarcity along with other shortfalls (Adams et al., 2020). In both country study sites most respondents had access all year to a source of water. Nevertheless, there were ~12% in Indonesia and 15% in Fiji who had water intermittently or seasonally throughout the year, and therefore suffered multiple health stressors related to water inaccessibility.

Without the added factor of mosquito exposure leading to viral infection, water inaccessibility alone is a severe stressor on health, especially for marginalized communities (Hanrahan, Sarkar, & Hudson, 2015). When there is a lack of stable water infrastructure or access there is a direct impediment on human health. Historically, industrialized nations that have invested in improved water and sanitation, have also witnessed great improvement in public health (Rural Community Assistance Partnership, 2004). Water source is also of great importance because it can either inhibit or increase a threatening mosquito population. For example, one study in Malaysia discussed that "Culex mosquitoes are most likely to lay eggs in stagnant polluted water and their breeding sites are normally near adult feeding areas" (Van Lun et al., 2012). Stagnant water builds up in proximity to the home in materials such as bird baths, discarded tires, buckets, artificial containers that hold water, and clogged gutters (Haroona, 2020; LaDeau et al., 2013). Over 74% of respondents from the Indonesian RISE settlements stated that they obtained their water from a stagnant source. Since mosquitoes proliferate in such zones, these respondents were very likely coming in direct contact with mosquitos. Sometimes communities, especially informal settlements, have limited options for trash removal, so waste is often dumped outside near or in proximity to a homestead and after a rainfall, this trash can collect with water, which also encourages mosquito growth (Adams et al., 2020). In this study, 83% of respondents from Indonesia and 81% of respondents from Fiji stated that that they dump their garbage directly within the settlement or in waterways within the settlement. Given the described evidence this increases the possibility of stagnant water areas after a rainfall, thus creating ideal environments for mosquitoes to thrive.

Another study asserted that viral diseases, such as West Nile Virus, are associated with the urban landscape, stating that “the age of housing, land use, and the concomitant social and natural features" contribute to the transmission of this disease (Ruiz et al., 2007). In the Troyo et al. 2009 study, “significant correlations [were found] between Dengue incidence and urban structural variables (tree cover and building density) suggest[ing] that properties of urban structure may be associated with Dengue incidence in tropical urban settings” (Troyo et al., 2009). In general, the built environment has the capacity to either protect people against mosquito exposure or encourage encounters with these vectors. This can be as fine-tuned to the very materials that a house is constructed with, as evidenced by Tusting et al. (Tusting et al., 2015). This article was systematic review of 90 different studies related to modern housing being associated with lower risk of mosquito transmitted disease (i.e., Malaria) (Tusting et al., 2015). The results were such that modern wall materials were associated with about a one-quarter reduction in malaria infection and modern roof materials were associated with reduced incidences of clinical malaria (Tusting et al., 2015). The review demonstrated that modern houses are protective against malaria vectors (i.e., mosquitoes) by blocking the entry routes providing fewer gaps that mosquitoes may find attractive, such as mud and thatch material (Tusting et al., 2015). In general, urban areas are particularly vulnerable to viral epidemics, such as Dengue, because the built environment can provide ideal conditions for mosquitoes to proliferate and eventually make contact with humans, and there few widely available vaccines for such diseases (Lindsay et al., 2017). Given that modern housing materials are protective against mosquitoes, the fact that over 50% of study respondents in Indonesia and over 97% of respondents in Fiji use traditional wall materials (ex: mud) is of concern.

Between the years 1975 and 2010 the global urban population tripled and the majority of the growth concentrated in Sub-Saharan Africa and Asia where water insecurity was already prominent (Adams et al., 2020). Methods for controlling mosquito populations have included pesticide spray and most recently introducing genetically modified mosquitoes to help eliminate the spread of diseases (Lindsay et al., 2017). However, these strategies are resource intensive and there is a looming threat to insecticide resistance (Lindsay et al., 2017). People who are lower-income tend to be at higher risk of disease burden from mosquitoes due to having worse living conditions that may facilitate mosquito proliferation (Franklinos, Jones, Redding, & Abubakar, 2019). Research from Brazil has demonstrated that informal settlements make people who are already socio-economically insecure to be even more vulnerable to mosquito-borne illnesses

(Carvalho et al., 2017). Carvalho et al. write, "The inclusion of social inequalities as risk markers for Dengue indicates the transformation of space and social dynamics as fundamental factors in the development of spaces conducive to the maintenance of dDengue" (Carvalho et al., 2017). All these factors – water, built environment, wealth – compound together and cause an already unprotected and resource-stretched population to be increasingly threatened by the viral diseases brought by common mosquitoes that thrive in urban settings. The global population is increasing, and more people are flooding into urban areas that are not infrastructurally prepared to support this influx of people. As a result, there is increased concern that outbreaks of Dengue, Chikungunya, Zika, etc. are going to be widespread, especially throughout the Asian Global South where urban expansion is rapid.

Climate change is predicted to increase risks such as water scarcity, natural disasters, heat stress, etc., which will have a negative impact on people, especially those who live in informal settlements and lack the adequate infrastructure and resources to adapt (Satterthwaite et al., 2020). Furthermore, climate change is contributing to rising global temperatures, which will impede the growth of some mosquito species; however, it will increase the growth of other species, including those species referenced in this study (Baker et al., 2021). Therefore, it is predicted that there is going to be a major shift in disease transmission, with fewer malaria cases and more viral cases like Zika (Baker et al., 2021). Since there still is a prevalent issue of global inequity in access to healthcare, especially in low-to-middle income countries, the emergence/re-emergence of infectious disease agitated by climate change and urbanization is highly concerning (Baker et al., 2021).

There are a variety of cost-effective and sustainable strategies to help mitigate and reduce the mosquito population, such as proper coverage of water storage containers (Kittayapong & Strickman, 1993) and the adequate development of urban infrastructures (Lindsay et al., 2017). Built environment targeted strategies to reduce human contact with Ae. aegypti include reducing small plastic containers around the home, improving solid waste management, and designing houses to be better sealed and screened to prevent mosquito entry (Lindsay et al., 2017). Also, "provision of constant piped water will reduce the need to store water in container in and around homes, since water-filled containers are known to be favored habitats" for mosquito vectors (Lindsay et al., 2017). Proper development of water infrastructures would not only help control mosquito population growth but is also key "to eliminating persistent poverty in these areas [with] improved water services" (Rural Community Assistance Partnership, 2004).

There were several limitations to this study. Firstly, there is likely measurement error in the data, such as with questions that ask - "In the past 6 weeks, how often have you encountered mosquitoes trying to bite you inside your house" – which could cause recall bias. There was likely self-report bias due to the design of the survey. In addition, water storage was a main variable of interest, but the survey did not include questions asking whether people who store their water also cover their water containers. Thus, it was difficult to accurately assess the relationship between water storage practices and mosquito exposure. Additionally, the outcome of interest, fever, was a proxy and no evidence was provided to conclusively assess and demonstrate that a fever was caused by a mosquito-borne illness and not another ailment (i.e., diarrhea).

Overall, our study generated evidence that supports the hypothesis that increased rates of mosquito exposure also increase the risk for fever, which is being used as a proxy for viral infectious diseases. People become more vulnerable to these risks due to inadequate built environment structures, inaccessibility to water and/or use of a stagnant water source, and a low socio-economic wealth status. There is a need to employ further studies that measure the direct pathway from mosquitoes to a stagnant (ideally household based) water source to an infectious disease, as well as take into consideration the previously mentioned socio-environmental factors (i.e., water access, built environment, etc.) that impact this relationship. Furthermore, as urbanization and climate spur a shift in disease transmission, it is imperative to respond and address the issues that put the health already vulnerable people more at risk.

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