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Appreciating the complexity of localized malaria risk in Ghana: Spatial data challenges and solutions

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ABSTRACT

Various factors have been associated with the ongoing high prevalence of malaria in Ghana. Among these are poor sanitation, low socioeconomic status (SES), building construction and other proximate micro environmental risks, and individual behaviors. What makes the curbing of malaria more challenging, is that for many of the most impacted areas there is little data for modeling or predictions, which are needed, as risk is not homogenous at the sub-neighborhood scale. In this study we use available local surveillance data combined with novel on-the-ground fine scale environmental data collection, to gain an initial understanding of malaria risk for the Teshie township of Accra, Ghana. Mapped environmental risk factors include open drains, stagnant water and trash. Overlaid onto these were clinical data of reported malaria cases collected between 2012 and 2016 at LEKMA hospital. We then enrich these maps with local context using a new method for malaria research, spatial video geonarratives (SVGs). These SVGs provide insights into the underlying spatial-social patterns of risks, to reveal where traditional data collection is lacking, and how and where to develop local intervention strategies.

1. Background

So what do you think is the most important contributing factor to malaria?

00:18:09 I think the first point is the environment. The environment is not clean. People do not take good care of their surroundings. *They leave everything just like that.*

00:18:21 And when they are sick, and they come to the hospital they don't take their drugs on time.

00:18:36 And sometimes people think when they come to the hospital they are coming to die. That is their perception. Because most of them come to the hospital late. So, some may die and some may live.

00:19:06 Another gutter.

00:19:08 You see the stagnant water here. The surface is clean so naturally mosquitos would breed inside and then come and bite them.

00:19:20 When you go in the evening you see that people are sleeping outside. They don't sleep inside their home, they sleep outside. Some of them build pavements around their buildings and then in the night they sleep there.

00:19:32 Because their rooms are so small, the ventilation, *you see the window there*, the ventilation is so poor.

00:19:46 Their children, everybody, their brothers, their sisters, their husband, their wife, all of them ….

00:20:34 So that when you see the mosquitos enter, they breed in the room there. Right in the room with them and they too continue biting them. So if one person has malaria you know all of them will have malaria.

00:20:48 …. not taking the drugs on time. I don't know if that is laziness or maybe they don't understand how it is.

00:21:04 And then when they … have bathrooms outside, they will bath and then leave the water behind the bathhouse and they will not collect it and throw it away.

00:21:32 So, we have a lot of problems in the area.

These opening comments come from a single spatial video geonarrative (SVG) (Curtis et al., 2015; Krystosik et al., 2017) collected in the Teshie township of Accra, Ghana. The purpose in using this novel spatial data collection approach was to help fill in a data gap for an area endemic with malaria. As often is the case for such places, there was little to no local spatial data (Shaffer et al., 2018). The SVG not only provides valuable insight into the social and spatial interconnections,

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but it can also be used as a source for mapping. The spatial references in the narrative (the italicized section), meaning places pointed out during data collection, as well as the environmental hazards digitized from the accompanying video (Curtis et al., 2019a; Curtis et al., 2017), can be turned into malaria risk maps (Ajayakumar et al., 2019), which for the purpose of this paper mean the environments or activities that increase localized exposure. In this paper we describe this process and the specific malaria findings for the multiple communities within Teshie.

Between 2015 and 2016, malaria in Africa increased by 20% with Ghana accounting for approximately 200,000 of these cases (WHO, 2017). While traditional vector control strategies such as the use of insecticide-treated nets and indoor spraying continue to be utilized, attention has shifted towards other complementary technological advances and innovative tools (World Health Organisation, 2017), such as malaria early warning systems (Awine et al., 2018; Darkoh et al., 2017). However, one challenge that remains for many locations is the lack of data required to fully understand local risk conditions and effectively target intervention (Chatterjee, 2018). While several novel approaches exist, for example utilizing participatory mapping or citizen science (Karanja, 2010), these are not ubiquitously applied, often requiring considerable logistical support, have limited ability for dynamic updating (Lundine et al., 2012; Panek and Sobotova, 2015), and provide little in terms of contextual insights. As a result, even variation between wet and dry seasons cannot be measured in terms of the change in local risk. Acquiring such a rich fine scale spatial data source, ideally for multiple time periods, could prove immeasurably valuable to local public health efforts.

1.1. *Malaria transmission and control in Ghana*

Malaria in Ghana, as with several other neighboring West African countries remains a considerable public health concern (UNDP, 2015), leading to an estimated 32.5% of all clinic outpatient attendance, with children under five and pregnant women being the most vulnerable (Ankomah et al., 2003; Dadzie et al., 2018). Biomedical research (Ademolue et al., 2017; Ahouidi et al., 2016; Mensah-Brown et al., 2017), social interventions (Irs, 2015) and legislature (Evered and Evered, 2011) are all being used to tackle malaria control. In addition, improving urban environments (Frank et al., 2016), educating local behavior (Febir et al., 2016), appropriate urban and regional planning, and good governance to improve socioeconomic conditions (Owusu et al., 2008) are also utilized. The construction materials used in building a house, whether a family can afford a mosquito net, or their improper use (Nyarko and Cobblah, 2014), and more generally the level of education and occupation of residents (Diallo et al., 2017) have all been found to be contributory factors leading to malaria in Ghana.

Malaria transmission can also be thought of as a multi-scalar geographic problem; regionally, it varies with temperature (Darkoh et al., 2017) and humidity (Adu-Prah and Kofi Tetteh, 2015). At a more local level, satellite imagery along with census and survey data found in demographic and health surveys (DHSs) can be used to map neighborhoods by urban type and environmental risks (Appiah et al., 2011; Verutes et al., 2012). The hardest scale to map, are the granular risks, the sub-neighborhood spaces around a home or daily activity locations such as play spaces. When mapping at these fine scales, it is also important to capture context, not being content to know why a hotspot exists but understanding why it occurs. Though challenging to acquire, this type of contextualized spatial data mirrors current research objectives in the geospatial sciences, (Curtis et al., 2016b; Kwan, 2012). For example, if a community is considered as endemic for malaria, that risk is not homogenously distributed within sub neighborhood sections, with some micro spaces posing a higher disease threat (Appiah et al., 2011; Haque et al., 2010). Sanitary conditions in and around a drainage channel (Jankowska et al., 2011) site-specific features such as poorly drained soil around a water point, even the conditions in and around a home can lead to variable risk in the same "neighborhood" (Kreuels et al., 2008). Micro elevation and proximity to mosquito breeding sites such as tires, containers, stagnant water in canals, pools, marshlands, and any other spaces that can hold water (Messina et al., 2011; Townes et al., 2013) are all risks for malaria. Conceptually, mapping out these breeding sites (standing water, vegetation, trash), adding on a social layer including the locations of homes, infrastructure (for example schools) and even community gathering points could be vital in reducing disease. In reality, the data challenges to allow such mapping are unsurmountable. In this paper we consider the social and spatial complexity of malaria in one Ghanaian town, and show how such contextualized mapping might indeed be possible.

1.2. *Study area*

Teshie, a suburb of Accra, Ghana (Fig. 1) was chosen as the focal point for this study due to its socio-economic and health challenges (Verutes et al., 2012). Almost 50% of households report a monthly income of between 100 and 500 new Ghana Cedis (approximately U.S. $25 - $125) (The International Bank for Reconstruction and Development, 2010). About 91% of houses are built of cement blocks or concrete, and roofs are predominantly iron/zinc sheets (56%) or asbestos (36%). There is limited access to toilets and proper sanitary conditions, with the local area drainage channels being clogged with illegal refuse dumping (The International Bank for Reconstruction and Development, 2010). The local belief is that malaria incidence is linked to solid waste collection (Amoatey et al., 2008), house construction and the domicile's immediate environment, and behavioral factors such as the use of insecticide-treated nets (ITNs) (Amoatey et al., 2008).

Some local malaria data with a spatial reference exist for Teshie from the West African Center for Cell Biology of Infectious Pathogens (WACCBIP), at the University of Ghana, Legon. The work at WACCBIP focuses on the immune response to malaria infections and identifying essential parasite proteins that could serve as vaccine candidates. Unfortunately, the reported malaria cases at the Ledzekuku-Krowor Municipal Assembly (LEKMA) hospital from 2012 to 2016 provided by WACCBIP only include a named community of Teshie, but no specific address. Adding a further challenge is that there was no commonly available boundary map for Teshie. In effect these data can only be assigned to a best guess location for a "fuzzy" community. While limiting, this is a situation the authors have found with their work in other countries and it is not unusual.

Overlaid onto these cases are spatial video (SV) environmental surveys which have previously been used to map out potential mosquito breeding sites in other locations (Curtis et al., 2016a; Curtis et al., 2017; Krystosik et al., 2017; Smiley et al., 2017). We will then advance this previous work by adding spatially specific context through the use of SVGs (Ajayakumar et al., 2019; Curtis et al., 2015).

2. Methods

The purpose of this study is to determine the spatial heterogeneity in malaria risk across the Teshie town of Accra. Environmental data are digitized from SV surveys collected in 2016 and 2017, positive malaria cases for 2012 to 2016 are supplied by the LEKMA hospital, and contextual insights are mapped from SVGs conducted in 2017 and 2018. While the time period for each of the data layers varies slightly, the opinion of collaborators is that these spatial outputs are still comparable.

Fig. 1. The study area, Teshie, a suburb of the Greater Accra region. The map shows communities within Teshie where data was collected. Boundaries are as a result of a combined buffer/Thiessen Polygon apportioning of space.

Fig. 2. Examples of environmental health risks digitized from the SVs. a) multiple tires – ranked 5 b) a privacy shield built over an open drain to be used as a urinal for workers in that environ – mostly taxi drivers and food vendors. Close to it is a pile of trash and a lot of overgrowth. The trash and overgrowth were ranked 3 each. c) a stagnant open drain which has a resident disposing (probably grey) water into it. This water risk was ranked 5. d) stagnant and contaminated open drain, with food vendors conducting business nearby. The water in the drain was ranked 5 and the trash, 2. e) a larger contaminated open canal that stretches along the breadth of a community. The stagnant water was ranked 4, the trash ranked 5 and the overgrowth on the edges of the drain ranked 3. f) a stagnant pool of water by an open drain and overgrowth close to a residential setting. The stagnant water was ranked 4. Risks were ranked a scale of 1(least) - 5 (most) depending on the volume and depth of risk identified throughout the study area.

Fig. 3. Different structures digitized from the SVs. Included informal wooden structures referred to locally as "kiosks", houses with scavenged roofing, bathrooms connected to open drains and well-designed houses with good roofing and painting. D is an example of a structure ranked as 1 whilst F is ranked as 5.

2.1. Spatial video (SV)

Field researchers from WACCBIP at the University of Ghana, Legon, Ghana, collected visual environmental data from Teshie using Contour +2 SV cameras between October 2016 and February 2017. A camera was mounted on either side of the research vehicle and angled slightly downward to capture both building quality and ground conditions. All main roads in the study area were driven by the field team. After data collection, videos were transferred to the GIS Health and Hazards Lab at Kent State University where data was retrieved using CameraPlayer (Fig. 4a), a bespoke spatial software developed by the project team (Ajayakumar et al., 2019; Curtis et al., 2018). CameraPlayer displays a simultaneous image and map which are used as a digitizing source to create environmental map layers. Risk features mapped included the physical conditions of buildings, which had relevance not only to gauge local economic status but also in terms of allowing mosquitoes access to living and sleeping areas, open drains, stagnant water, and trash[1] (see Figs. 2 and 3 for examples). The risk maps included a digitized point which was weighted by the value of its risk. For example, in the top left corner of Fig. 2, multiple tires are weighted at this location as "5" on a 1 (least) to 5 (most) scale.[2] The digitized map layers were downloaded from CameraPlayer as shapefiles for enhanced cartographic display in a GIS.

All digitized risks were imported into ArcMap 10.5.1 (ArcMap, 2017) where they were spatially explored for patterns of risk in the neighborhoods. For example, though not reported in this paper, the combined location and intensity of these risks were visualized using a kernel density analysis (KDA) a technique which had been used in similar settings for these type of SV data (Curtis et al., 2016, 2017).

2.2. Clinical data

Clinical data used for this study included patient information collected between 2012 and 2016 for the Erythrocyte Invasion Mechanisms (EIM) study at WACCBIP. The initial aim of EIM was to understand the mechanism of ligand binding by the *Plasmodium falciparum* parasite and malaria severity within patients aged between 2 and 14 years in urban areas of Ghana (Ademolue et al., 2017; Mensah-Brown et al., 2017). These data contained demographic information, clinical diagnosis and malaria microscopy results (positive and negative) for each patient enrolled. However, clinical data contained only given community names and there were no community boundary maps available, this meant only a spatially "fuzzy" understanding of disease could be established. To maximize the spatial utility of these data a series of community centroids were identified in collaboration with local expertise by marking the location (anchor point) that most typified that community. A Thiessen polygon surface was created in ArcMap 10.5.1. which in effect divided Teshie into polygons by assigning the rest of the map to its closest anchor point. Boundaries were drawn at the 50:50 distance point between two anchor points (See Fig. 1). This surface was clipped at a distance of 0.5 km from the anchor point in order to provide a conservative estimate of how far a community was likely to extend outwards.[3] Each factor of interest (clinical cases, environmental health risk factors and built environment measures) were spatially joined to these new areas for comparative mapping and analysis.

2.3. Spatial video geonarratives (SVGs)

While the first two data inputs mimicked more traditional epidemiological mapping, the goal of this work was to enhance these layers with additional contextual insight. To do this, "go-along" interviews (Curtis et al., 2016b; Curtis et al., 2015) were conducted in 2017 and 2018 using a variant of the SV called a SVG. This is an interactive and innovative approach to qualitative and quantitative fine scale mapping that adds context to locations (Ajayakumar et al., 2019; Curtis et al., 2015; Krystosik et al., 2017). SVGs record the reflections and insights of an individual as he/she moves through his/her neighborhood. Memories and informed interpretation of events are triggered by the sights, sounds, and smell of the surrounding environment. For example, a subject might identify where mosquitoes are considered to be a nuisance and even offer suggestions as to why. These comments are captured along with a spatially encoded video recording and then mapped and analyzed using Wordmapper software (Ajayakumar et al., 2019; Curtis et al., 2019c) which had been developed by the project team (Fig. 4b). Subjects included residents and local health workers who were familiar with the communities involved in the study. SVG can be collected using a vehicle, which increases the area that can be covered while also making the subject feel more comfortable because he/she is not in the sun, and therefore more willing to divulge greater detail. However, for some environments which either require a more granular consideration or are inaccessible by vehicle, then a walking SVG is collected. The SVG captured both spatial mentions (pointing to specific features and describing them, an example being the italicized text in the quote opening this paper), as well as associated imagery (the video frame of what is being described) and the GPS coordinate stream, all of which are merged together. Wordmapper combines the text of the narrative (which have time stamps preceding each comment as seen in the opening quote) and the GPS path extracted from the SVG using CameraPlayer (Fig. 4a). The text and GPS are merged together so that every comment, and every word, is assigned a location. An initial reading of the narrative is used to identify malaria related themes, and these then inform the selection of keywords in Wordmapper. For example, adding in drain would identify all mapped comments referencing that feature. A word cloud is also generated from the words in the selected comments; these co-occurring words can further guide additional term selection. The combination of spatial queries, visual support, and thematic mining of the text allow for a deeper understanding of social-spatial topics (Ajayakumar et al., 2019; Curtis et al., 2019c). For our study, the purpose was to understand different perspectives on malaria, where it (and mosquitoes) occurred, identifying the causative factors and implications of these locations and then what could be done as intervention.

3. Results

A total of 2288 structures were digitized from the SVs (Table 1). The majority of the structures were wooden, many having visual structural problems which could have disease implications, broken windows, open doors and poor roofing (Fig. 3). There was some variation in building

[1] The same risks had previously been digitized for similar environments in Colombia, Haiti and Nicaragua (Krystosik et al., 2017; Curtis et al., 2016, 2017).

[2] While this map appear subjective, previous research has shown that if a single researcher codes the risks then there is consistency across the maps, especially for values at the high (4 and 5), and low (1 and 2) end. Ranking values are site specific and should not be quantitatively compared between study sites, though the visual mapped output (where higher concentrations are found) is comparable for purposes of discussion.

[3] The authors understand the potential spatial error involved in this method (some neighborhoods will be bigger than others), though without any other boundary maps for guidance, we were confident this method provided a working solution. The resulting maps were shared with our collaborators working in Teshie who agreed they were a fair representation of the neighborhood extent.

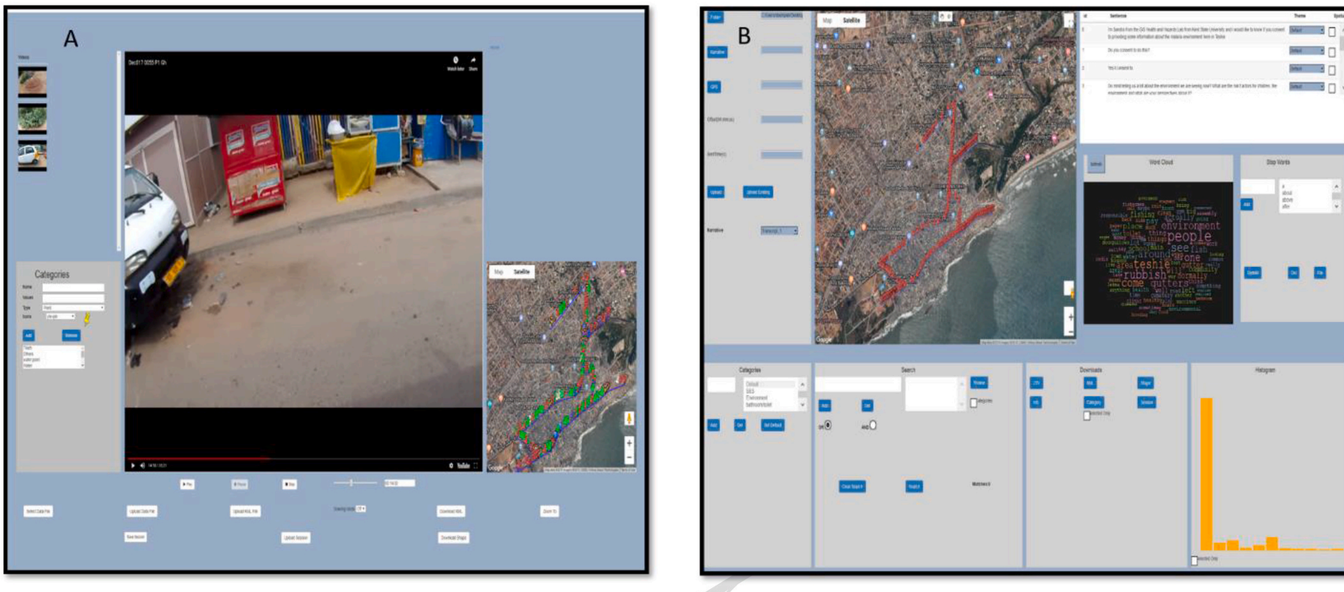

Fig. 4. These images show the bespoke software used in the analysis of SVs and SVGs. CameraPlayer (A) is used to simultaneously view the video and the location of each video frame. This software also allows for the GPS path to be extracted. Risks such as trash, stagnant water, food vendors, can be digitized and saved as either GIS or Google Earth layers. Wordmapper (B) takes the GPS output, and the transcribed narrative as a text file, and then uses a media offset (the difference between the time stamps of both files) to automatically map out the narrative. The resulting map, and the text, can be queried to find out what was said at one location, or where all comments mentioning a certain risk feature were made.

Table 1
Ranking of health risks and the corresponding number of structures and clinical cases reported per community.

#	Community	Total risk locations	All structures	Risks/ Structures*100	# cases
1.	**Ayorkor Wuor**	251	211	119	1
2.	**Tsui Bleoo**	170	176	97	14
3.	**Yoomo Specs**	143	180	79	2
4.	**LEKMA**	128	95	135	1
5.	**Block Factory**	98	197	50	1
6.	**Gonno School**	83	170	49	7
7.	**Teshie Camp 2**	68	149	46	12
8.	**Anomantu**	66	128	52	4
9.	**Bukueshie**	60	252	24	4
10.	**Teshie Mobil**	58	115	50	4
11	**Old Manna**	56	82	68	2
12	**Rapture**	55	52	106	1
13	**Manna**	40	13	308	1
14	**Tebibiano**	36	109	33	7
15	**Cold Store**	34	109	31	3
16	**Teshie NDC**	32	88	36	1
17	**Point 5**	12	55	22	1
18	**Alloway**	11	10	110	1
19	**Krobo 1**	11	39	28	2
20	**Lascala**	9	35	26	5
21	**Aboma**	5	18	28	2
22	**Adoemli**	4	5	80	1
23	**Agblezaa**	–	–		5
24	**Malik**	–	–		1
25	**Manet**	–	–		1
26	**Penney**	–	–		5
27	**Sea lady**	–	–		3
28	**Teshie market**	–	–		3
	Total	1430	2288		95

type and quality across the study area. Some sections had more robust better quality housing, while others had the typical "organic" pattern of densely packed homes, dusty unfinished roads, and open drains that tends to be associated with informal settlements. The drains, irrespective of community, were often filled with water and trash (Fig. 2c, 2d, 2e), and urinals, easily recognized in the videos by their tall thin privacy shields, were often proximate, sometimes even overhanging the drainage channel (Fig. 2b). As has been found in other studies (King et al., 2000; Nurudeen et al., 2014), vendors, including food sellers were often located next to these drains due to the constant traffic of passersby (Fig. 2d).

A total of 1430 risk locations, not including the open drains, were mapped from the SV source. Risk features mapped included trash (because of the potential for mosquito breeding, and vermin attraction), overgrowth and stagnant water (because of the risks posed for mosquito breeding and enteric disease spread). An example map for these features can be seen in Fig. 5, which was a SVG walk along one of the most frequently mentioned drains in the SVGs.

Table 1 provides a summary for the total number of structures appearing on the SV route for each community, and the total number of risks digitized. Ayorkor Wuor had the highest number of risk factors followed by Tsui Bleoo, Yoomo Specs, and LEKMA area. Ayorkor Wuor, Block factory, Yoomo Specs, Bukueshie and Tsui Bleoo also had the poorest quality housing (Fig. 6), with densely packed poorly constructed structures. Bukueshie, for example, had densely packed buildings and poor connectivity (interior roads and paths), yet interestingly the number of visually identified health risks was relatively low. While there were some variation in the risk total based on the amount of SV video time, which varied across communities due to factors such as road access, comparing risks to total structures can be used as a proxy for the overall condition of that neighborhood, especially if a minimum of 50 structures is used as a cut off. Fig. 6 provides a summary of the risk totals assigned to the Thiessen polygon neighborhood map.

Onto these risk maps were overlaid the clinical cases of malaria. Of the 215 clinical cases reported, 95 fell within the communities in Teshie. The remainder were either outside the Teshie township (53) or did not specifically list the community in which the patient resided (67). The

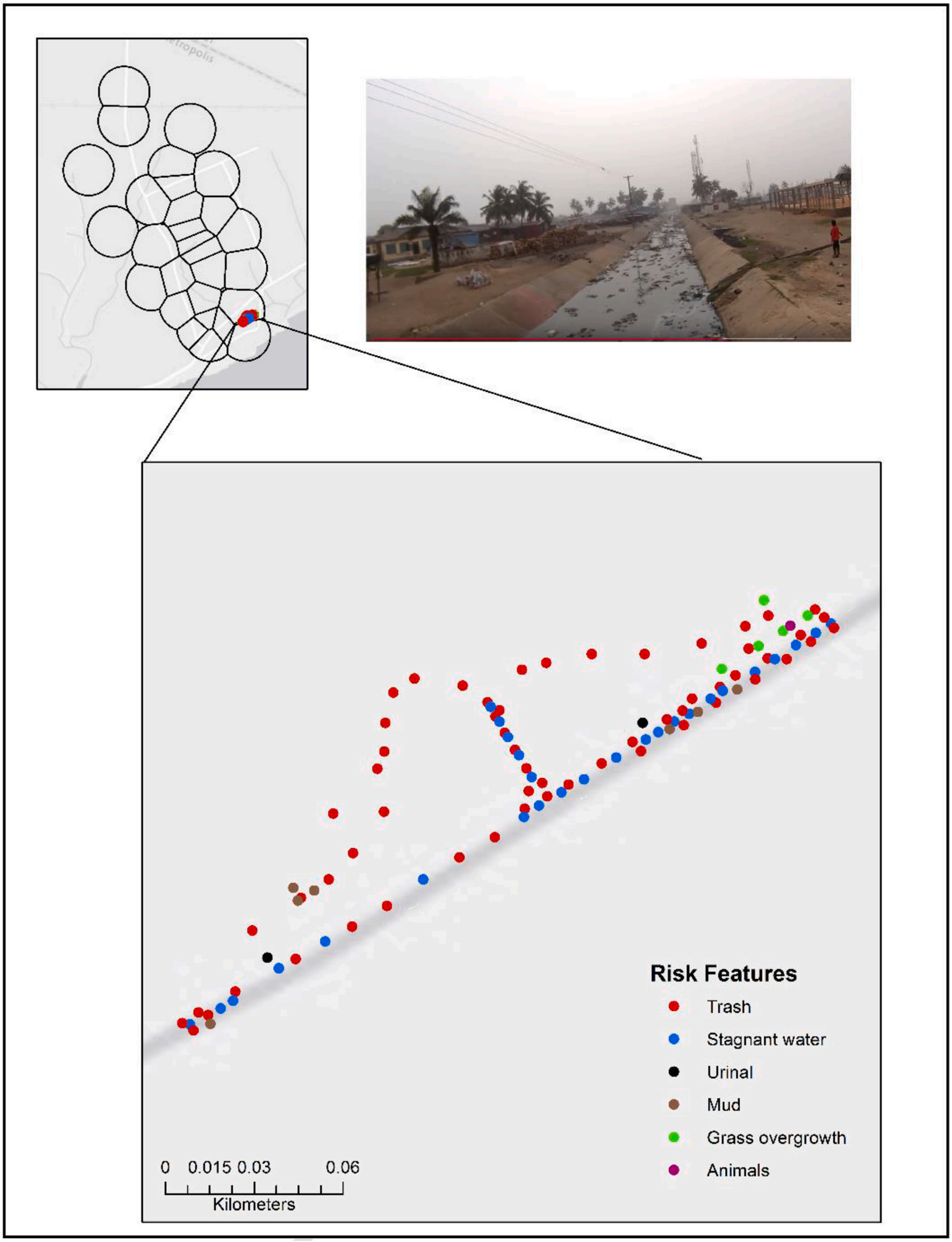

Fig. 5. An example of risk digitizing along one of the most problematic drains in the Teshie township. The picture on the top right corner shows the drain.

highest number of reported malaria cases occurred in Tsui Bleoo and Teshie Camp 2. Both communities also received good SV coverage and had a corresponding high relative environmental risk rate. Interestingly Ayorkor Wuor had the highest number of health risks (251 units) and was one of the highly clustered communities (211 structures) and yet had a low number of clinical cases (Fig. 6).

While the SV mapping offers a means to compare environmental and social risks across communities, and while these layers offer interesting discussion points when compared with the clinical case data, potential limitation in disease surveillance, and the understanding that malaria risk is a complex interaction of physical features and human actions means that it is vital to also add in local context. To achieve this, eleven participants comprising of residents, community health workers, nurses and lab workers at the LEKMA hospital were the subjects of SVG rides (Fig. 7). Once these narratives were transcribed and then mapped using Wordmapper, several malaria themes emerged (Fig. 8) with regards local disease transmission and the geographic distribution of cases.

As with previous SVG work, the following results comprise a

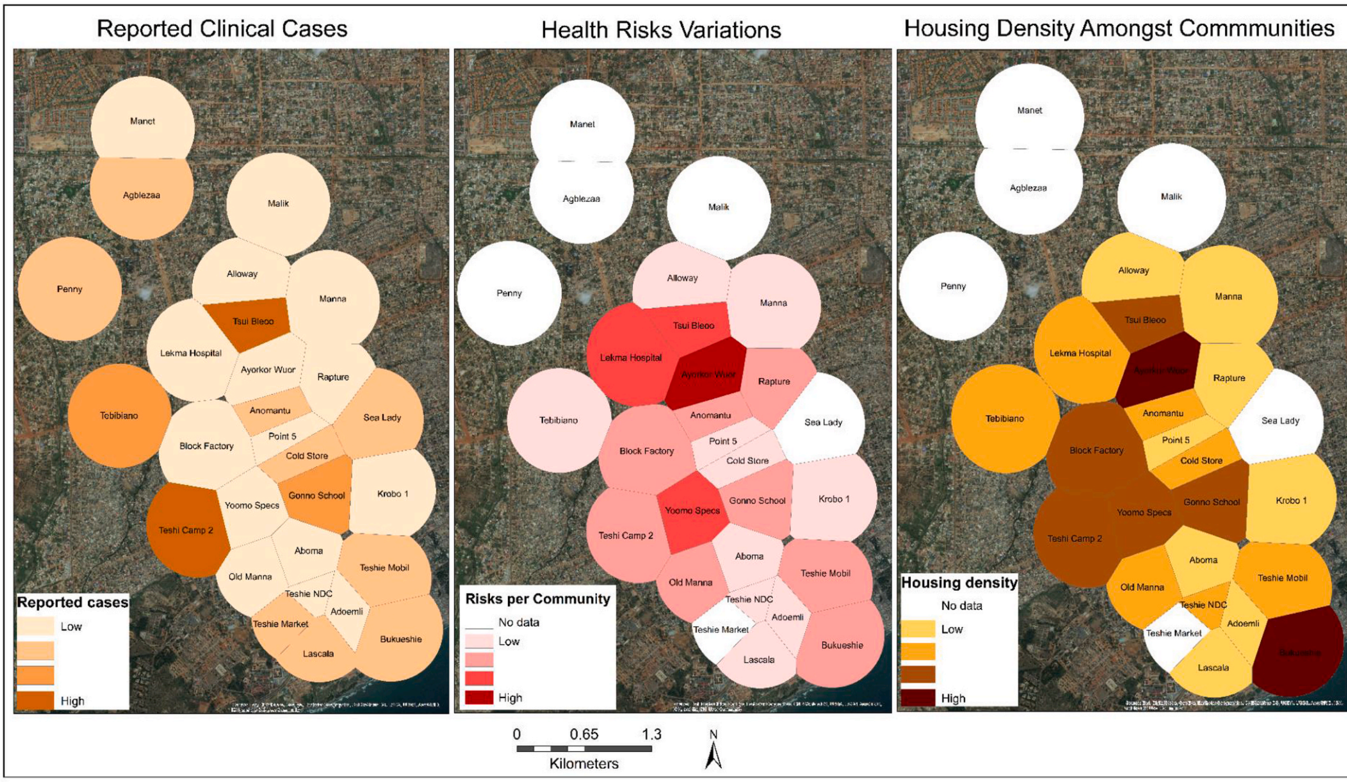

Fig. 6. Identifying the association between health risks, housing and reported cases amongst the various communities. Reported clinical cases were the number of cases per community as a percentage of the total number of cases. Similarly, the health risk was the number of digitized risks as a percentage of all risks digitized. Housing density was based on the percentage of structures identified from the videos taken and fall within the 0.5 km boundary created divided by all structures digitized. White areas indicate communities where data was unavailable.

synthesis of all narratives supported by selected quotations (Curtis et al., 2019b; Curtis et al., 2016b).

3.1. Physical risk factors

As mentioned throughout this paper, the open drainage channels found throughout the communities are a primary cause for concern with all participants. While multiple risks were mentioned in association with the drains, for example the proximity of food vendors to a channel often containing human excrement,[4] the malaria specific risk focused on the dumping of trash into the channel. Even though there were trash removal services in the neighborhoods, their cost made them an unrealistic option for many residents.

> "Sometimes when it rains, people come from their houses and they put rubbish into the gutter, a lot. And sometimes it would go straight to the *big gutter we saw behind us* and sometimes it would choke there when the rain stops, then the mosquito breeding would start."

The outcome of such dumping includes trash washing into downstream communities (and homes) and contaminating fishing stocks when the water drains into the sea. The specific malaria association was that when the rain stops, pools of water are formed because of the detritus. As a result, these breeding pools of water lead to malaria outbreaks even during the dry season. While verifying the drains as a risk factor, the SVG goes beyond their mapping to reveal other important contextual factors. Different reasons were given as to why the trash dumping occurred. For example, there was a lack of a local political voice in the poorest neighborhoods, and a change away from more proactive residents wanting to keep the drains clean. While different examples were given, one participant mentioned an abandoned infrastructure project which now resulted in a "drain to nowhere".

> "That drain that was constructed by the previous administration has been abandoned. So now, when they bathe, most of them have connected their pipes to it. Where would the water go? The water will be stagnant there. *And looking at it*, it is as nice place for a mosquito to breed inside, and they have forgotten that when the mosquito breeds in there, they will come and bite them."

In other SVGs the blame was directed at the local population, and a lack of education (and respect), that leads to such trash dumping. Also, a between community (between tribe) prejudice emerges in the SVG with regards who is the worst culprit. Local youth groups had previously been mobilized to help clean the gutters, and it was suggested these, with a little financial incentive, could provide a solution. However, there was also a feeling of inevitability about the situation.

> "For (the local hospital) once in a while do a cleanup exercise where the staff comes to clean the environment, but … even when you clean today the next moment when it starts raining, people will just pile their heap of rubbish and come and throw them in the gutter."

In additions to the drains, the unfinished roads pose other malaria specific risks. The dust generated by traffic on the roads caused respiratory problems, which was one reason given why bed nets were not used, because the mesh trapped the dust and makes breathing harder. The potholes in the roads also got filled with water providing favorable conditions for mosquito breeding. These, like the trash filled drains meant that there were always cases of malaria even during the dry season. Where intervention could be targeted was that the water filling these holes was not just rainwater, but also grey water dumped onto the

[4] All of the senses can trigger a comment or recall in the SVG. Usually these triggers are visual, but in these SVGs the smell was frequently commented on.

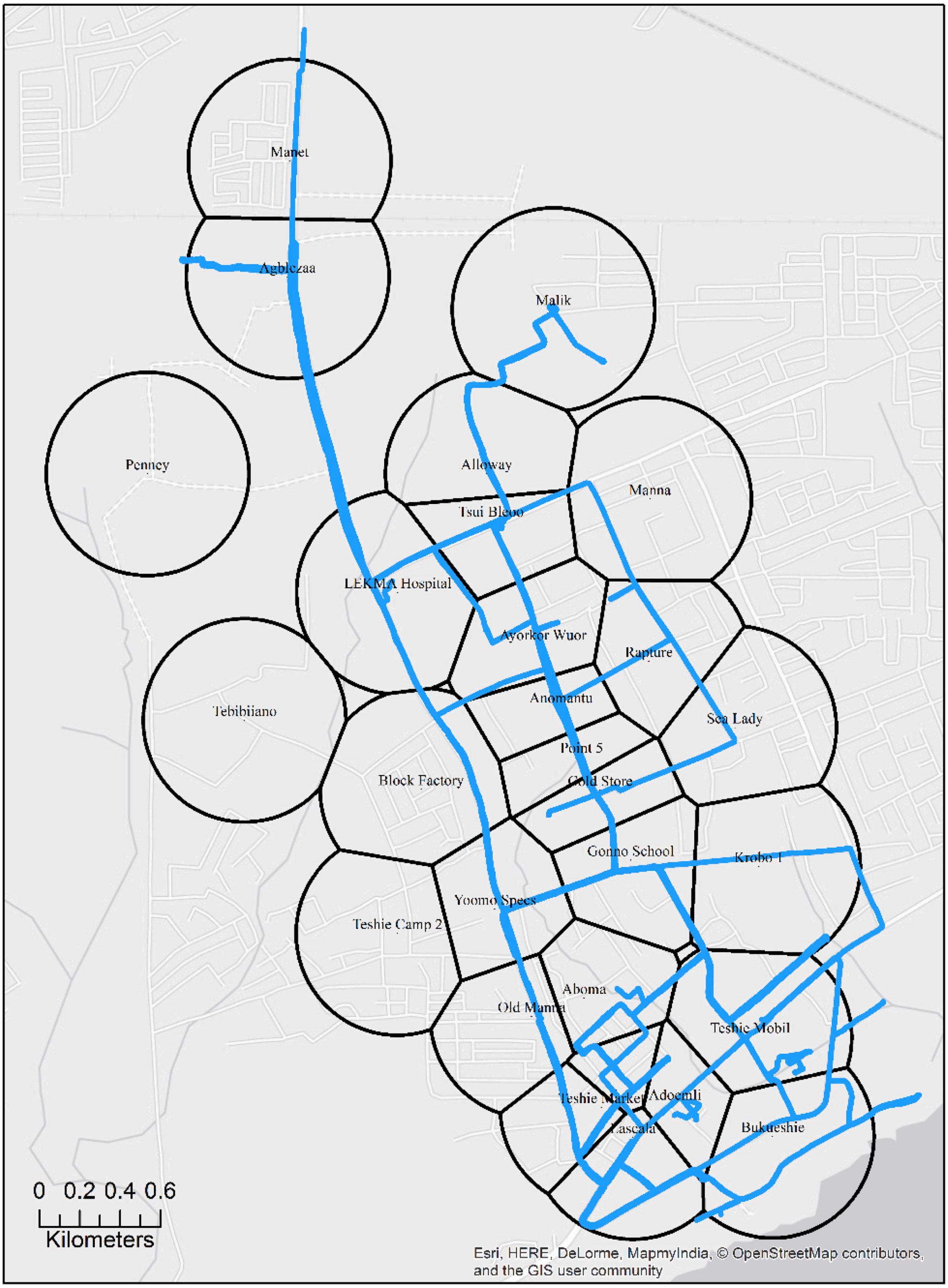

Fig. 7. SVG paths within the Teshie township. These paths were either walked or driven during SVG data collection.

road by the residents. Changing this activity, along with educating about the dangers of having water stored in uncovered containers around the home could reduce localized risk.

Two locations of note were the cemetery which was described as a multi-risk environment in more than one of the SVGs, and the environment around the LEKMA hospital.

"I realize that even around the hospital there is a lot of trash. Once in a while we collaborate with the community and we do a cleanup exercise. But as you can see, I mean this road too is not helping us at all, when they finish the road it will help. But even within the hospital, there are mosquitos. My advice is they should come and fumigate the area. Because even within the hospital, there are mosquitos inside. The particular problem is the Teshie Kpeshi (river)

> … the rain in the river gets choked and it breeds a lot of mosquitos. I mean millions of mosquitos. And then when the military barracks spray the river, then the mosquitos migrate to the town and it's very severe. They will be biting people here and there, you will be walking and there will be mosquitos in the air."

> "In the night when you *come here* you will see the mosquitoes. They normally come out in the night. *You see them all over here. At times you cannot even walk pass this road.* Because you will walk into them. They are gathered and you have to pass through them before you get to the other end."

3.2. The impact of poverty

Other behavioral factors beyond those already mentioned include the misuse of mosquito nets. Reasons were often tied to the condition of the home and the high density of people sleeping in a room. This led to the logistical challenge of how to hang the nets, there not being enough for everyone, and the general discomfort often resulting in people preferring to sleep outside.

> "Actually, their main problem is ventilation. When they build, they do not put enough ventilation in their building … when mosquitos enter the room, they tend to breed in the rooms. So that when they are bitten by mosquitos a lot of people acquire the same mosquito parasite in the same room, because the room is so congested that when they are sleeping the place is not airy …"

Even with the last point, the underlying contributing condition to malaria risk is poverty. In Teshie, there are a lot of single mothers, most are traders who leave early in the morning and return late. As a result, the children are left unsupervised, playing outside where they can easily be bitten. Even older children are prone to mosquito bites because of the lack of mosquito control around the parks and open spaces where they play games and sports.

> "When they roam in the night and they've been bitten by the mosquito, when they get home and their parents are back, they fix the mosquito nets for them to sleep in it. Now when the child falls sick, starts getting signs and symptoms of malaria, what happens is that because most of the parents are single mothers and they are very busy with their work schedule, they usually keep their children and give them first aid until it worsens and then they come rushing to the hospital for medical treatment."

This last quote also touches on another common theme in the SVGs, how economic insecurity means that many families were excluded from the official medical system, reliant instead on local herbal remedies. Alternatively, when a child (for example) displayed malaria like symptoms, the first stop was not the clinic, but instead a local drug store where a non-medical professional made a diagnosis based on the described symptomology. The parent was then sold an "appropriate" drug. This is described below from both a mother and a professional's perspective.

> "Sometimes it's not our fault. Its poverty. I'm a single mother of four with no assistance from anywhere. I don't have that much money to afford hospital bills. So, my kids sometimes get sick and I am compelled to keep them at home and use traditional herbal methods. It's because I don't have money. So, I am always thinking maybe it's a stomach infection, so I use the herbs to treat or I get some dewormer for them. But there is always a relapse. "

> "What happens is that most of the parents because there is no money what they usually do is that they keep their children in their house for a very long time. So, when they come, there's still no money. It's not as if they have gotten any money but because the condition is worsening, so they just have to rush. They come to the hospital, there is no charity organization, therefore, the health worker has to look for money from his or her own pocket to get some of the drugs and other things the child would need. Like last week. The woman came with just twenty cedis. Treatment is 50 cedis if you don't have health insurance. So then she doesn't have enough, therefore, we should give her the child to go back home and the child has malaria. We couldn't. So, we had to look for money, get some of the drugs ourselves for the child's medical expenses. So everything boils down to the money."

If the health condition of the child continued to worsen, eventually he/she will be taken to the clinic as a last resort. This perpetuated a local belief (erroneous) that the clinic should be avoided if possible, because of the high mortality rate. For many going to the clinic not only was beyond their means, but the cost of losing a day's work was unthinkable. And delays to being seen by a physician, it seems, can be considerable, with reasons including doctors not being available or willing to work at night, to lab results taking too long, to inappropriate signage making patients wait in the wrong line. This situation was compounded when the clinic runs short of supplies.

> "So, the supplies are sometimes not enough even though we do have them. The clinic gets supplied, but there are always not enough. That's a problem. It affects people coming … because if you come for malaria testing and we don't have the supplies we need to carry out the test, we must refer you to somewhere else. I don't think the next time that person would come in again to us."

The lack of medical follow-ups for those who are treated also contributes to a growing concern in the area to the parasite becoming drug resistant.

> "Yeah, malaria is still a big problem in Ghana as a whole. That is why the malaria drugs are changing every time because lumefantrine, artesunate, amodiaquine, and a lot of drugs have become resistant. The parasite has become resistant to the drug. Because the people when they get the parasite or they get the malaria do not complete the medication. And even if they don't have malaria and they have temperature or fever, they go to the drug store and the pharmacist will issue malaria drugs. The pharmacist thinks that it is malaria so they will issue malaria drugs to you. And by the time that you yourself-you have malaria in your bloodstream and you are taking such drug again, it won't work. Because now the parasite has become resistant to the drug you've taken before. So sometimes you have to be given an infusion and injection for it to work for you. So malaria is a very big problem here in Teshie and everywhere in Ghana."

3.3. Outreach

With so many income-related impediments to utilizing the clinic system, outreach becomes even more vital, as described by some of the SVG participants who were actively involved in malaria education initiatives. One consensus was that although there was some understanding of the malaria disease system, indeed many believing they "knew" all about the disease, this knowledge was usually incomplete with daily actions often causing additional risks. One misconception was that sleeping under a net was enough and somehow negated the rest of the day's exposure. Much of these education strategies revolved around safe home practices, including how best to use the mosquito nets, not, for example, using them as curtains to stop mosquitos flying into the home. Other topics needing constant education included the role of open containers and trash in mosquito breeding, and the importance of properly disposing of grey water.

Again though, in describing what it was like to be involved in outreach, the impact of poverty dominated. Even if the outreach worker had the ability to provide field tests, and if these tests revealed that a family member had malaria, there still was no money to afford the

Fig. 8. Two examples of SVGs showing where specific references were made to environmental features. The pictures in the top right corners show the features that were being referred to.

subsequent treatment. This led to frustration, especially as the outreach had no free medication to dispense. A frustration that sometimes manifested into hostility, a situation that could become even more tense if the worker was not from the local area. The outreach workers also conveyed their own sense of frustration because they believed that no matter how many times they described the unsafe practices in and around the home, little would change, and malaria would continue.

> "When they come, we ask them the signs and symptoms. If they are feeling feverish, maybe vomiting, or diarrhea. And ask them do you have a temperature? And then we do rapid diagnostic testing for them. And actually at times we get confirmed cases. We give them a referral to the hospitals around the area so that they can get treated. The thing is that most of them don't sleep under a bed net or when you ask them if they sleep under treated bed net, they say no. Some of them they will tell you when they were doing the registration for the mosquito net, they didn't come to their area. So, sometimes when we finish, they will be demanding for this treated mosquito net. But we are just an outreach team. And then some of them too will be demanding that we give them medicine … the ones that are found positive and that do not have money."

4. Discussion

Teshie is a suburb of Accra, Ghana typified by multiple intersecting health risks that result in a landscape of poor health outcomes (Jankowska et al., 2011). Malaria traditionally thrives on the levels of economic distress found in the area (Kreuels et al., 2008). One problem is that, as in many similar environments across the globe, there is a lack of available data to understand the severity of the situation, where the risk is greatest, and how best to target the limited available resources for intervention. In this paper we combined the available malaria surveillance data with a novel on-the-ground environmental surveying approach to establish risk variations between the Teshie communities. The SV captured many of the structural problems found within the communities, including sub-standard housing and multiple environmental risks, especially open drains, often filled with trash, all of which have malaria implications. These locations were digitized to create the only available risk maps for the area. However, the power of these videos is that they also set these risks into a broader hazardscape (Mustafa, 2005). The drains are more than just lines to be mapped; seeing the urinals scattered along their length, close to food vendors, the piles of trash, and the way people (especially children playing) play in and around the channel helps us understand the magnitude of the potential health risks involved (Fig. 9). Contributing factors can also be seen, such as sources of water feeding the drains, including residential disposal of grey water.

To address this complexity, SVGs were used to contextualize the map, helping to explain where and why risks occur and perpetuate. Poverty manifest in various forms, including the illegal dumping of trash, the poor surface of the local roads, overcrowding in the homes leading to mosquito net misuse, the lack of supervision of children, and the inability to use local health care when the need arose. Added to this was a lack of understanding (again poverty related and tied to limited education) how certain actions increased the risk of malaria. While education initiatives attempted to target many of these problems, even here there was a geographic imbalance as not all communities could afford to entice in such outreach.

One outcome of our findings was the unreliability in local malaria surveillance data. For example, in Ayorkor Wuor (Table 1; Fig. 6), one would expect high numbers of malaria cases. Yet this is not reflected in the reported cases at LEKMA. There were many reasons why locals don't use the clinic; one was the likelihood of spending almost an entire day seeking treatment, because of the low physician to patient ratio (MOH, 2014). So low-income families who cannot afford to see a doctor (Aboagye et al., 2011; Adam et al., 2003) save money and time by going to the local pharmacies (Ladner et al., 2017). While this is problematic in terms of receiving appropriate care, and even contributing to drug resistance, it also means that there will be an underreporting of disease data in the most impoverished communities. Added to this was a lack of an accurate geocode even in those cases reported. The best that could be hoped for was an assignment to a fuzzily designated community.

Another explanation for the observed risk versus cases discrepancies, is the flight range of the *Anopheles* mosquito. Considering the flight range of this mosquito and wind speed at any point in time, it is possible for the mosquito to "spill over" into neighboring areas (Santiago and

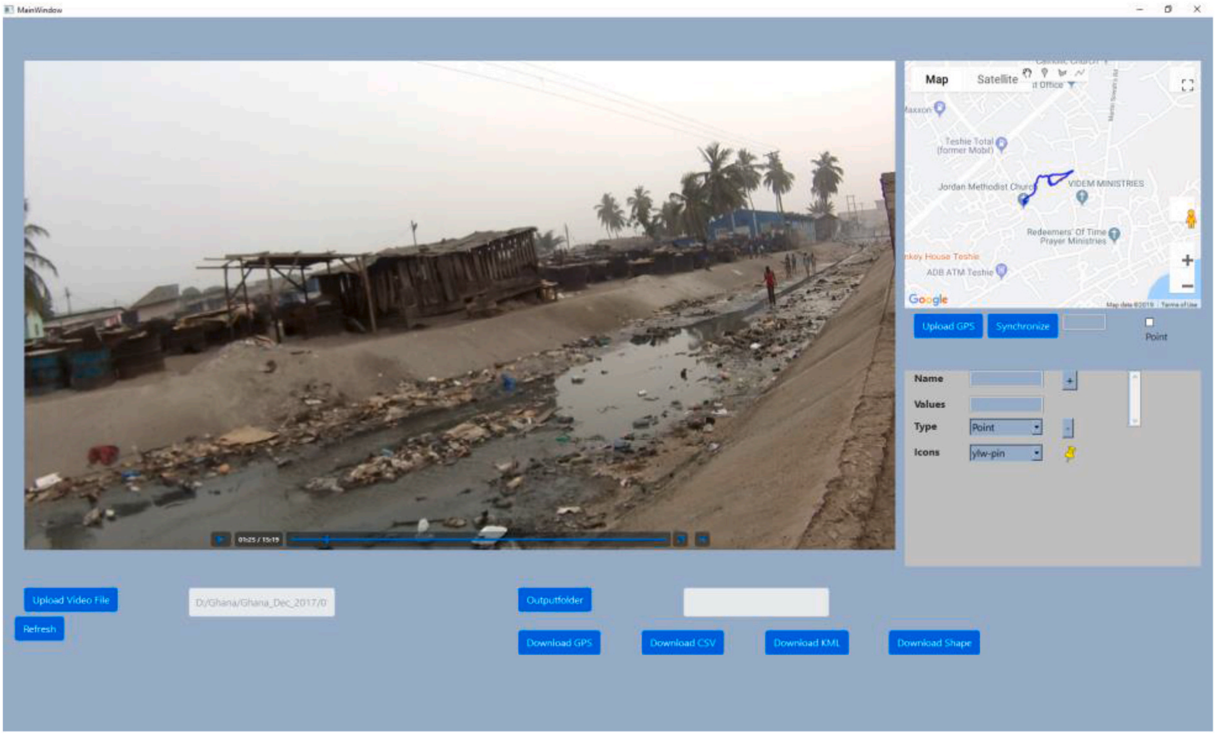

Fig. 9. Showing one of the open drains (in CameraPlayer mode) full of trash and pooled water, with people walking in the channel.

Russell, 1934). This might explain some of the discrepancies between the observed health risks and actual cases. A typical example being neighboring communities Yoomo Specs and Teshie Camp 2, both with high housing densities (Fig. 6). It is possible that mosquitoes bred in the high-risk zone of Yoomo Specs, and under favorable environmental conditions traveled to Teshie Camp 2 to feed.

In this regards our findings *generally* support Fobil et al. (2012) in establishing that socioeconomic and neighborhood urban environmental conditions serve as risk factors in contributing to urban malaria (Somi et al., 2007; Worrall et al., 2002; Fobil et al., 2012), a relationship established in many similar environments beyond Ghana, such as India, (Qayum et al., 2015), Bangladesh (Haque et al., 2010), and Mali (Gaudart et al., 2006). However, the use of SV and SVGs also produce an alternative to the surveillance data. Locations of specific risk are identified, either where environmental problems can be found that might lead to mosquito breeding, or where higher concentrations of malaria cases are known to exist. Many of these locations might go unmissed if mapping solely relied on surveillance data, and certainly the granularity of "hotspots" is markedly improved, such as around the cemetery and ironically in proximity to the hospital (Fig. 10). Having said that, this work also gives further justification for improving local surveillance systems as the combination of both certainly lead to synergistic insights.

These maps of risk, whether digitized from the video or extracted from the narratives of institutional knowledge, can be used to show where intervention and outreach should be targeted.

But more than this, by understanding the local context, and the reasons leading to those risk locations, more tailored outreach strategies can be developed based on the local set of physical risks, the cultural backcloth and the institutional knowledge of those who work these areas. Indeed, that local knowledge can also produce locally appropriate solutions, as can be seen in Fig. 11 which shows "sand winning", meaning digging out the sand from the drains to be sold for construction. By encouraging this activity, trash would be removed which in turn should reduce the number of mosquito breeding sites. The SVG method provides a means to convey these ideas, many of which are already being implemented but at ineffective scales.

What is more, SV and SVG data collection is relatively inexpensive, easily implemented and therefore can become part of a longitudinal solution to contextualized map making and updating. This type of temporal data collection can be used to evaluate the success of

Fig. 10. Environment around the main hospital in Teshie. "A" show the front part of the hospital whilst "B" shows the back of it during the data collection period.

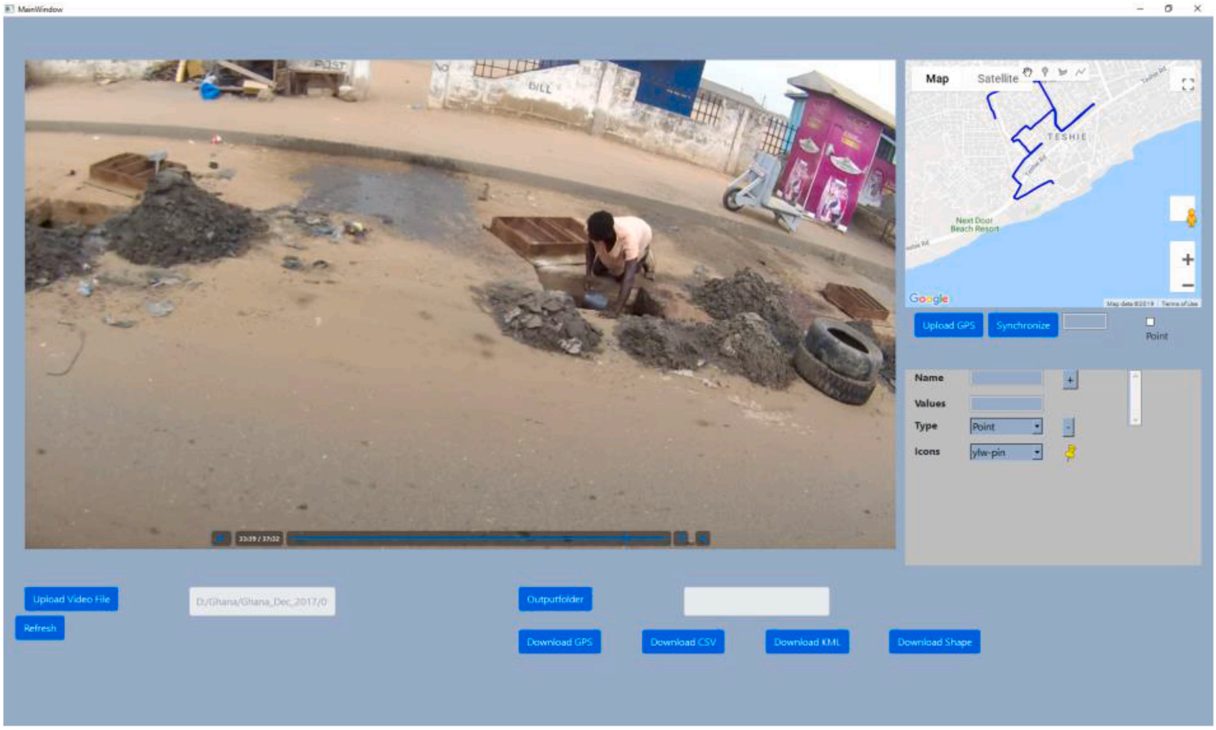

Fig. 11. Displays someone digging out sand from the drain to sell to local construction. Also visible are some of the objects that had to be removed first.

interventions, both visually validating improvements and hearing from the voices most impacted. While sceptics might point to the effort required for such intense local data collection, the counter argument would be that many solutions also must be developed and implemented at the local scale. Adding SVG into normal operating procedure should be possible and the benefits could be immense.

Indeed, technological advances continue to improve these methods. Advances in spatial programing now allow for software to be developed for each location, tailored for the particular needs and challenges faced (Curtis et al., 2019a; Curtis et al., 2018). Machine learning is proving useful in being able to automatically identify risk features from the video. When these images are matched back to the coordinates attached to each frame of the SV, then it should be possible to create automatic mapping solutions.

The rationale for undertaking such work at a granular scale is important not just from a public health perspective. A common confounding factor in the analysis of immune responses and protection from malaria is the differences in malaria risk among study participants. A better geographic understanding of where a case originates would better characterize local relative risk, which in turn could be factored into an analysis for identifying immune correlates of protection.

4.1. Conclusion

Malaria is endemic in the Teshie township in Ghana. As with many similar locations across the country, risk is an expression of local factors; not all communities have the same likelihood for exposure, and not all people living in those communities are equally at risk. Arguably the biggest challenge, cutting across all risk factors, is the localized effect and expression of poverty. Leading to unsafe practices in and around the home, while also providing a limiting factor in seeking appropriate medical care when needed. This paper has revealed the environmental, spatial and behavioral intersections that can be used to understand, and map, that heterogeneity of risk. In so doing it provides the first step in improving local data gathering to provide the operational support needed to start to make reductions in malaria risk across the communities.

4.2. Limitations

Clinical data had various limiting factors. Case entries often only listed “Teshie”, and as such had to be excluded from the study. It is possible that there was a bias in terms of where these patients came from. For those that did list a community name, the choice to use a Thiessen polygon surface with a 0.5 km buffer might obviously lead to errors in placement. There was also incomplete video coverage in some of the communities due to poor local road quality. As a result, some of the communities were underrepresented. Future work would address this problem by utilizing other modes of transport, such as bikes or walking where it was deemed safe.

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Declaration of competing interest

Authors declare no conflict of interest. Funders had no influence in the design of this research, data acquisition, interpretation of data nor the publishing of these results.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2020.102382.

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