

**Combining cross-sectional survey data with geographic activity space to examine
the relationship between place and youth HIV risk behavior in Kenya**

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ABSTRACT

Adolescents (15-24) comprise 37% of the nearly 1 million new HIV infections in southern and eastern Africa each year (UNAIDS, 2016a), representing a particularly vulnerable and important at-risk population. Despite increasing recognition that HIV risk is driven by social and physical characteristics of an individual's community, assessment of socio-ecological HIV risk factors has remained a challenge. This investigation proposes a novel method of evaluating environmental risks through the use of GIS generated "activity spaces," and community identification of risk-areas. Through combining metrics of ecological risk with cross-sectional survey data on psychosocial correlates of HIV, this investigation reveals how participatory techniques can be used to identify ecological drivers of HIV risk.

INTRODUCTION

With an estimated 19 million HIV positive individuals, east and southern Africa houses over half of the world's HIV positive population (UNAIDS, 2016b). Of the nearly 1 million new infections that occur in Sub-Saharan Africa each year, 37% were among youth between the ages of 15-24, making programs that target adolescents a priority for policymakers (UNAIDS 2016a; UNAIDS 2016b). Efforts to curb HIV infection rates among adolescents have historically focused on individual-level interventions, which are often effective in the short term but show diminishing effects over time (DiClemente, Salazar, and Crosby 2007; Auerbach, Parkhurst, and Cáceres 2011). Increasingly, researchers are acknowledging that the characteristics of the social and physical environment – or social ecology – are important drivers of HIV infection, and shape an adolescent's risk of contracting the virus (DiClemente, Salazar, and Crosby 2013; Poundstone, Strathdee, and Celentano 2004). However, sophisticated tools to assess the HIV risk environment of specific populations are lacking (Auerbach et al., 2011). This study addresses these limitations through the use of “activity spaces,” a novel method utilizing statistical principles to assess HIV risk environment among youth in rural western Kenya.

The Social-Ecology Perspective

Social and structural factors have increasingly been recognized as drivers of HIV infection (Kaufman et al. 2014; Baral et al. 2013). These structural factors constrain or enhance the agency of adolescents to avoid HIV risks in their communities, and include economic, social, political, or other environmental influencers of HIV infection (Gupta et al. 2008; Sumartojo 2000; Blankenship et al. 2006). With increasing recognition of the

complex factors mediating HIV risk, integration of multi-level, structural factors into HIV intervention has become increasingly common (Kaufman et al., 2014). The socio-ecological model specifically emphasizes the role that social and physical environment plays in determining the health of adolescents, including their risk for contracting HIV/AIDs (DiClemente, Salazar, and Crosby 2013; Sumartojo 2000; Auerbach, Parkhurst, and Cáceres 2011; Poundstone et al., 2004).

Despite advances in the ecological understanding of HIV risk, most HIV prevention efforts reported in the literature have targeted changing individual characteristics (Kaufman et al. 2014; DiClemente et al., 2007). Analyses have focused on identifying broad risk factors and suggesting that social setting be taken into account, rather than applying this analysis to actual interventions (Blankenship et al., 2006). One potential explanation for the dearth of literature-supported interventions incorporating broader ecological factors is the challenges associated with measurement (Auerbach, Parkhurst, and Cáceres 2011; Blankenship et al. 2006; Gupta et al. 2008; Poundstone, Strathdee, and Celentano 2004). Without systematic methods for evaluating social settings, incorporation of social-ecological principles into HIV risk reduction interventions will be limited (Blankenship et al. 2006; Poundstone, Strathdee, and Celentano 2004; Gupta et al. 2008).

GIS and Spatial Mapping Methodologies

One potential solution to bridge this gap in evaluative methods is the use of spatial modeling methodologies. While mapping disease patterns is not a novel concept (Barrett, 2000), advances in geographical information system (GIS) technologies have made spatial modeling methods increasingly accurate and feasible (Richardson et al.

2013; Neutens, Schwanen, and Witlox 2011). GIS is an emerging tool for studying social-ecological aspects of communities, and has been used to incorporate local and technical knowledge into community mapping projects (Cromley & McLafferty, 2011; Sieber 2006; Ansumana et al., 2010). Latkin et al. argue that advances in GIS technologies have contributed to the increased application of social ecology principles to HIV research specifically (Latkin, German, and Vlahov 2013). In the HIV literature, GIS mapping techniques have been used in a variety of contexts, from mapping hotspots of HIV infection and risks (Brouwer et al., 2012; Connors et al., 2016), to quantifying access to HIV-related healthcare services such as needle exchanges (Fulcher and Kaukinen 2005; Martinez, Lorvick, and Kral 2014).

The concept of “activity space” holds unique potential in the context of quantifying HIV risk ecologies through spatial mapping. An activity space is a spatial measure that encompasses the locations that an individual visits during his or her daily activities (Schönfelder & Axhausen, 2003), and more generally serves as a model of each individual’s spatial movement (Sherman, Spencer, Preisser, Gesler, & Arcury, 2005). Activity-space analysis deviates from typical ecological and multi-level analyses, which have often relied on pre-defined spatial units – such zip codes or administrative units – to define an individual’s “environment” (Perchoux, Chaix, Cummins, & Kestens, 2013). However, static definitions do not necessarily reflect each individual’s unique engagement with his or her environment (Browning & Soller, 2014). Activity space improves upon static measures by emphasizing individuals’ “experiences of place” (Nemet and Bailey 2000; pg 1197) and by incorporating limitations, preferences and ability for movement. In fact, researchers have already used activity space to model risk

environments for adolescents, most prominently in the context of substance use (Mennis and Mason 2011; Lipperman-Kreda et al. 2015).

Activity spaces can be modeled in multiple ways. Standard Deviation Ellipses (SDE) have commonly been used to represent an individual's spatial movement (Sherman et al. 2005). The SDE is a bivariate, Euclidean measure that is calculated using distance and direction of frequently visited locations from an individual's home. The ellipse that it formed visualizes the maximum and minimum dispersion of a set of points from their mean center (Gesler & Albert, 2000). When assessing the result of activity space analysis, locations that lie within an individual's space are considered easily accessible, while locations outside of the space are interpreted as outside the individual's normal daily routine (Sherman et al., 2005).

Other approaches to activity space mapping exist, largely consisting of network-based measures that use paths and roads to construct routes between points (Kwan, 1998). While the resulting network-based result is more representative of travel routes, it also has limitations. Most prominently, network-based activity spaces require accurately mapped roads and footpaths, and detailed knowledge about travel paths taken by individuals (Sherman et al., 2005). Thus, SDE is the most feasible analysis strategy for use in low-resource settings, where capacity to support detailed road maps is minimal.

Psychosocial Correlates of HIV Risk Behavior

Within the HIV literature, various psychosocial correlates of HIV-related behaviors have been identified. Risky sexual behaviors including unprotected sex, and multiple sexual partners, and early sexual debut are often correlated, and result in increased risk of contracting HIV and other sexually transmitted infections. Sex-related

self-efficacy has been associated with decreased sexual risk taking, and increased condom use (Puffer et al., 2011; DiClemente et al., 2008; O’Leary, Jemmott, & Jemmott, 2008).

Caregiver relationships also play an important role in influencing adolescents’ risky sexual behaviors (Huebner & Howell, 2003). Parental monitoring has been associated with lower sexual risk-taking behavior (Luster and Small 1994; Sieverding et al. 2005; Li, Feigelman, and Stanton 2000; Romer et al. 1999), and decreased risk of contracting HIV (DiClemente, Crosby, and Wingood 2002). Adolescents who perceive less parental monitoring are also more likely to test positive for sexually transmitted diseases, have inconsistent condoms use, and have multiple sexual partners (DiClemente et al. 2001). Parental monitoring is linked to caregiver-child communication, as parents can only effectively monitor adolescents who disclose their whereabouts (Stattin & Kerr, 2000). Furthermore, communication between caregivers and adolescents regarding sexual risk may decrease risky behaviors (Hutchinson & Cooney, 1998), including increasing sexual-self efficacy and negation for condom use (Miller et al. 1998; Hadley et al. 2009; Romer et al., 1999; Hutchinson & Cooney, 1998).¹ Studies have shown that caregiver social support may also decrease HIV risk among adolescents (Tinsley, Lees, & Sumartojo, 2004).

Mental health may be associated with increased sexual-risk behaviors. Anxiety, traumatic stress, and depression have both been associated with increases in sexual risk

¹ A study conducted in rural Kenya, reported that youth noted a lack of communication with their caregivers in regards to HIV/AIDS and other sexually transmitted diseases (Harper et al., 2013). A systematic review of parent-child communication about HIV and sexuality suggests that lack of knowledge and skills, as well as cultural norms and taboos inhibit parent-child communication about sexuality in Sub-Saharan Africa (Bastien, Kajula, & Muhwezi, 2011). This suggests that caregiver-child communication and monitoring may mediate sexual risk behaviors among adolescents in Kenyan communities.

behavior (Hutton et al., 2001; Reyes et al., 2007; Klein, Elifson, & Sterk, 2008; Shrier et al. 2001). Similarly youth with higher self-esteem may engage in more frequent condom negotiation (Salazar et al., 2005), and other protective behaviors. Adolescents exhibiting conduct problems may also have heightened risky sexual behaviors, and thus increased risk of contracting HIV.

Gender Effects

Gender is a known mediator of HIV risk among youth. Globally, 15% of all HIV positive women are between the ages of 15 and 24, and 80% of these women live in Sub-Saharan Africa (UNAIDS 2014). In Sub-Saharan Africa, women acquire HIV infection at least 5-7 years earlier than men, and young women 15–24 years old in are twice as likely as young men to be living with HIV (UNAIDS 2014). In Muhuru Bay, young women face unique regional challenges. Located on the shores of Lake Victoria, “fish-for-sex is a well-documented phenomenon (Puffer et al., 2011) that contributes to the high HIV burden among the Muhuru Bay community. This transactional sex occurs between traveling fisherman and community women, and has been linked to the spread of HIV/AIDs in lakeside communities (Béné & Merten, 2008). Women participating in the “fish-for-sex trade” have decreased negotiation and transaction power, and the fishing industry maintains a deep “genderization” that favors male sexual dominance (Béné and Merten 2008; pg 889). Engagement in transactional sex has also been linked to multiple HIV risk factors, including alcohol use, sexual or physical abuse, inconsistent condom use, and multiple partners (Chatterji et al., 2005). High rates of transactional sex, paired with limited access to education, perpetual gender inequality, early marriage, and high

poverty rates (Ellis et al., 2007), make young women in Muhuru Bay particularly vulnerable to HIV infection.

In the context of activity space, gender may serve as an important predictor of activity space area. In a study conducted in South Africa, Hallman and et al. found that while girls and boys in 5th grade reported activity areas of similar sizes, girls in grades 8 and 9 reported activity areas one-third the size of their male peers, and two-fifths the size of 5th grade girls (Hallman et al. 2015). However, more extensive research on this phenomenon has not been conducted. Gender may also serve as a mediator for parental monitoring. Some research suggests that adolescent girls receive greater parental monitoring than their male peers (Rai et al. 2003; Svensson 2003), while other studies have noted no difference in monitoring between boys and girls (Stattin and Kerr 2000; Huebner and Howell 2003). However, these studies have all been conducted in developed, high resources countries. Parenting styles may have different affects in different ecological niches (Jacobson & Crockett, 2000), making additional research into gendered patterns of parental monitoring in low-resources settings necessary.

Study Aims & Hypotheses

The aim of this study was to use GIS generated activity spaces to understand the effects of adolescent's interaction with their environment on their HIV risk behaviors in Muhuru Bay, Kenya. My hypotheses were informed by the social-ecological understanding of HIV risk, which emphasizes the influence of social and physical environment's on adolescent sexual risk (Sumartojo 2000; DiClemente, Salazar, and Crosby 2007; Auerbach, Parkhurst, and Cáceres 2011; Poundstone, Strathdee, and Celentano 2004). In regards to activity space area, I hypothesized that area would be

inversely correlated with parental monitoring, and that activity space would be smaller among girls. In terms of environmental risk, I hypothesized that risk scores would be correlated with participation in risky sexual behaviors and engagement in vaginal sex. My overarching goal was to identify how GIS could be used to systematically evaluate ecological patterns of HIV risk among adolescents in low-resource communities, and ultimately inform public health interventions.

This thesis was conducted using data collected by Dr. Eric Green and Dr. Eve Puffer in 2009. My contributions to the present investigation included designing the analysis plan, proposing the use of three ecological risk score variables, and generating the subsequent univariate and multivariate regressions.

METHODS

Setting and Participants:

Data were collected in 2009 in Muhuru Bay, a small, rural town on the shores of Lake Victoria that borders the northernmost tip of Tanzania (Figure 1). Muhuru Bay is located within the former Nyanza province, which at the time of the study had the highest HIV prevalence in the country at 14.9% (Puffer et al., 2011). In 2010, Kenya reorganized their administrative levels, and Muhuru Bay is now located within Migori County (population 971,170).

Participants in the study included adolescents aged 10-18, parents, teachers, community leaders, and health workers from local clinics. Adolescents recruited were part of a larger correlational study, and were randomly selected from students in Standards 5-8 in 14 schools in the Muhuru Division of Nyanza Province (Puffer et al.,

2011). The number of eligible students in each school ranged from 21-339, totaling 1,847 eligible students. Of the 353 adolescents selected, 325 participated, 25 could not be located, one declined, and one was later determined to be out of the age range.

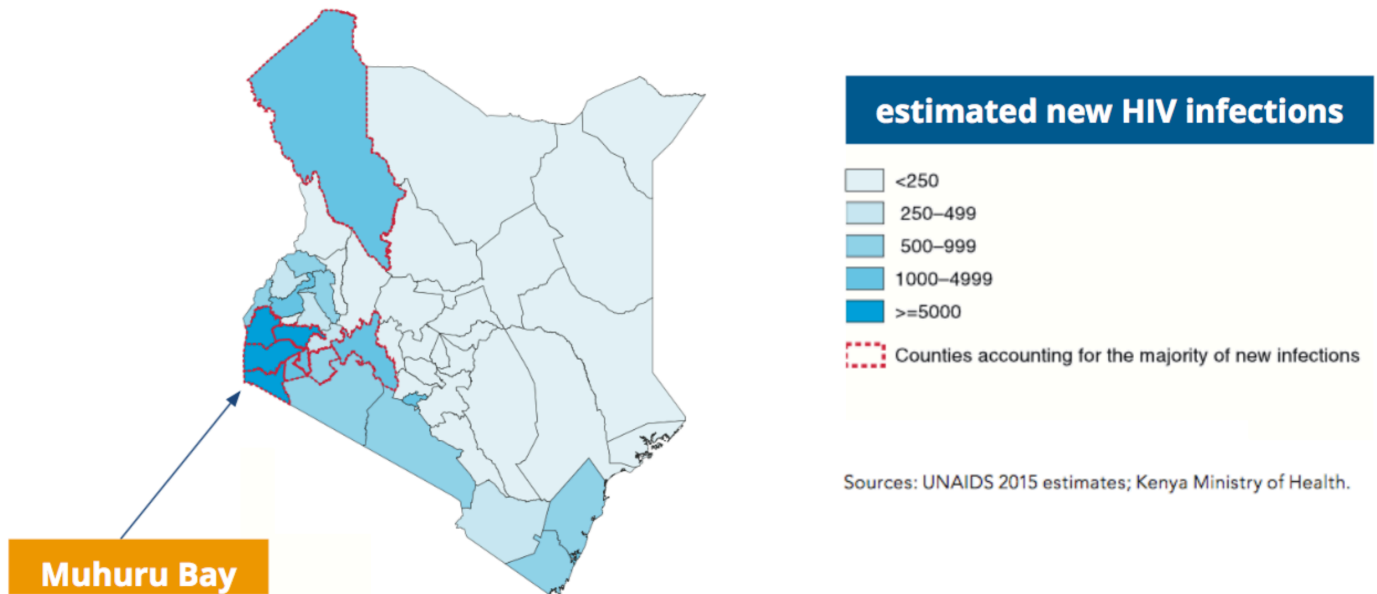


Figure 1: Map indicating Migori County, Kenya. 65% of the country's new infections occur in 9 counties of the country's 27 counties. Migori is one of them. (UNAIDS 2016)

Cross-Sectional Survey: Psychosocial Correlates of HIV Risk Behavior

Adolescent surveys

All 325 adolescents participated in a 90-min structured interview administered by trained research assistants. These surveys were administered near the participants' homes or schools in private spaces. All survey questions were translated into Dholuo, and back translated by native Dholuo speakers also fluent in English to ensure accuracy of translations. The Institutional Review Boards at Duke University and Kenya Medical Research Institute approved these procedures for data collection (Puffer et al., 2011).

From the survey responses, measures were constructed to quantify four categories psychosocial factors and behaviors: 1) sexual risk behaviors, 2) HIV-related psychosocial factors, 3) caregiver relationship and social support factors, and 4) mental health factors

(Puffer et al., 2011). The measures are shown in Table 1. Information was also collected on participants' family histories, including whether the participant's mother and/or father were living. Participant characteristics and descriptive statistics were computed for all survey measures using means and proportions tests.

Sexual Risk Behaviors: The survey categorized adolescents into discrete categories on several sexual risk behavior axes. History of sexual activity (including vaginal, anal, and/or oral sex), sexual activity in the past year, and condom use at last sexual encounter were collected on a yes/no scale. Number of sex partners in the past year was collected numerically. Sexually active youth were categorized into two "sex risk" categories. Adolescents who reported having more than one partner in the past year, or not using a condom at last sexual encounter were categorized as high risk. Those who reported having only one partner and using a condom at last sexual encounter were categorized as low risk. Participants who had never engaged in sexual activities at the time of the survey were also categorized as low risk.

HIV-Related Psychosocial Factors: Two concepts were assessed regarding HIV-related psychosocial factors: sex-related self-efficacy and sex beliefs. **Sex-Related Self-Efficacy** was measured on a 5-item scale, including 4 questions about condom use and sex refusal efficacy (Sayles et al., 2006) and one question about self-efficacy for refusing sex with an older person. Items were adapted from a longer scale based on previous studies conducted in Sub-Saharan Africa (Sayles et al. 2006; Hendriksen et. al. 2007). **Sex Beliefs** were assessed via a 16-item scale assessing agreement with statements regarding acceptability of risk behaviors, condom use and effectiveness, and acceptability of forced and transactional sex. Answers were reported on a 4-point Likert scale, and sum

scores calculated. A high score indicated that the participant's beliefs were more risky (Puffer et al., 2011).

Caregiver Relationship and Social Support Factors: To assess caregiver relationships and social support factors, adolescents were asked to identify 1-2 adults living in their home and involved in their daily care and supervision. Three domains related to the caregiver relationship were assessed: caregiver monitoring, caregiver social support, caregiver-youth communication, and emotional support. **Caregiver monitoring** was assessed on a 7-item scale, in which caregiver supervision and knowledge about whereabouts were captured on a 4-point Likert scale (Baptiste et al., 2006). Participants also reported the frequency with which they left the house at night on a 4-point Likert scale. **Caregiver-youth communication** was evaluated through two measures. Five items from the Parental Adolescent Communication Scale (Sales et al., 2008) and two additional items about puberty and circumcision captured frequency of communication about sex and HIV between adolescents and caregivers on a 4-point Likert scale. Barriers to communication were assessed with 16 items from the Parent/Adolescent Communication – Jaccard Measure (5-point Likert scale) (Jaccard, Dittus, & Gordon, 2000). **Caregiver social support** was assessed through 8 items adapted from the Parental Social Support for Adolescents (PSSA) scale (Aneshensel & Sucoff, 1996). Participants reported level of caring and understanding in their relationship with their caregiver on a 4-point Likert scale.

Mental Health Factors: Mental health constructs, including emotional and conduct problems, trauma, traumatic stress symptoms, self-esteem and hope were also assessed using various validated scales. **Emotional and conduct problems** were

assessed using the Strengths and Difficulties Questionnaire (SDQ) (Goodman, Meltzer, & Bailey, 1998), which has been used in multiple studies in Sub-Saharan Africa (Whetten et al., 2009; Cluver & Gardner, 2006).

Trauma was assessed using a subset of 10 items from the Things I Have Seen and Heard Child Self-Report (Ritchers & Martinez, 1992). In this measure, children reported whether they had experienced traumatic events, including physical and sexual abuse, and injury. **Traumatic stress symptoms** were measured using the Abbreviated UCLA PTSD Reaction Index for DSM IV, which has been validated in multiple contexts, including Mozambique (Steinberg et al. 2004). Participants rated the extent to which they experienced symptoms related to the event that has caused them the most distress.

Self-esteem was assessed with the Rosenberg Self-Esteem Scale, in which participants rated 10 items related to their perception of their abilities and self-worth (Rosenberg, 1989). The Rosenberg Self-Esteem Scale has been validated in multiple contexts in East Africa (Schmitt & Allik, 2005). **Hope** was measured with 6 items from the Children's Hope Scale, rated on a 3-point scale. Participants responded to questions regarding how capable and likely to do were to do well in various domains of their life.

Parental Survey

Caregivers of the 325 adolescents were also invited to participate in structured interviews about the emotional, psychological and behavioral characteristics of their child. These interviews were conducted in the caregiver's home, or a nearby private location. Caregivers were asked questions from the Strengths and Difficulties Questionnaire regarding the child's conduct, experience of peer pressure, emotional behavior. These constructs (with an additional measure of hyperactivity) collectively

generated a general emotional and behavioral difficulties (EBD) score for each participant, according to the SQD scoring guide. Caregivers also answered 7-questions assessing their perception of their parental monitoring. Demographic information, including caregiver age, gender, education level, marital status and weekly household income was also collected.

Table 1: Domains and Sub-Domains of Psychosocial Measures: Adolescent Survey

	<i>Measure</i>	<i>Measure Content</i>	<i>Quantitative Metric</i>
Sexual Risk Behaviors	Sexual Risk Categories	Sexual activity and condom use (yes/no), number of sex partners	“High risk” vs. “Low risk”
HIV-Related Psychosocial Factors	Sex-Related Self-Efficacy	4 questions: condom use/sex refusal efficacy. 1 question: self-efficacy for refusing sex with an older person	Sum score
	Sex Beliefs	Risk behaviors, condom use/effectiveness, transactional sex (16-items)	Sum score
Caregiver Relationship & Social Support Factors	Caregiver Monitoring	Caregiver supervision/knowledge about whereabouts (7-items) Frequency of leaving house at night	Sum score
	Caregiver-Youth Communication	<i>Frequency:</i> Parental Adolescent Communication Scale (5-items) + puberty + circumcision. <i>Barriers:</i> Parent/Adolescent Communication – Jaccard Measure (16-items)	Sum score
	Caregiver Social Support	8-items adapted from Parental Social Support for Adolescents (PSSA) scale. 4-point Likert scale.	Sum score
Mental Health Factors	Emotional and conduct problems	Strengths and Difficulties Questionnaire (SDQ)	Sum Score
	Trauma	Things I Have Seen and Heard Child Self-Report (10-item subset)	Sum Score
	Traumatic stress symptoms	Abbreviated UCLA PTSD Reaction Index for DSM IV	Sum Score
	Self-esteem	Rosenberg Self-Esteem Scale	Sum Score
	Hope	Children’s Hope Scale (6-item subset)	Sum Score

Digital Data Collection

Three primary sources of digital data were collected, including participatory community maps, dot map focus groups, and satellite assisted activity logs.

Community Mapping

Community mapping techniques were utilized to create a digital basemap of the Muhuru Bay community (Figure 2). Researchers first identified an existing shapefile that outlined the Muhuru division, and this map was used to define the boundaries of the basemap. Shapefiles are frequently used to spatially plot points, lines, and polygons, which can be used to represent community features such as villages, roads and administrative boundaries (Green et al. 2016).

Three young adults were recruited to join a mapping team, and trained in how to use GPS units to identify, locate and digitally capture community features, with Muhuru Bay's boundaries. This team travelled through the community for two weeks, collecting coordinates of prominent landmarks and making routes (paths or roads) through capturing coordinate strings. The team's work was informed by high-resolution satellite imagery captured by the Geo-Eye-1 Satellite a few months prior, which allowed facilitated planning of daily mapping activities. Mapping team members confirmed location and sub-location boundaries visible on the basemap with dozens of residents and community informants throughout their daily activities. After collection, GPS data was compiled into basemap layers using QGIS (version 1.1), a free open-source GIS program.

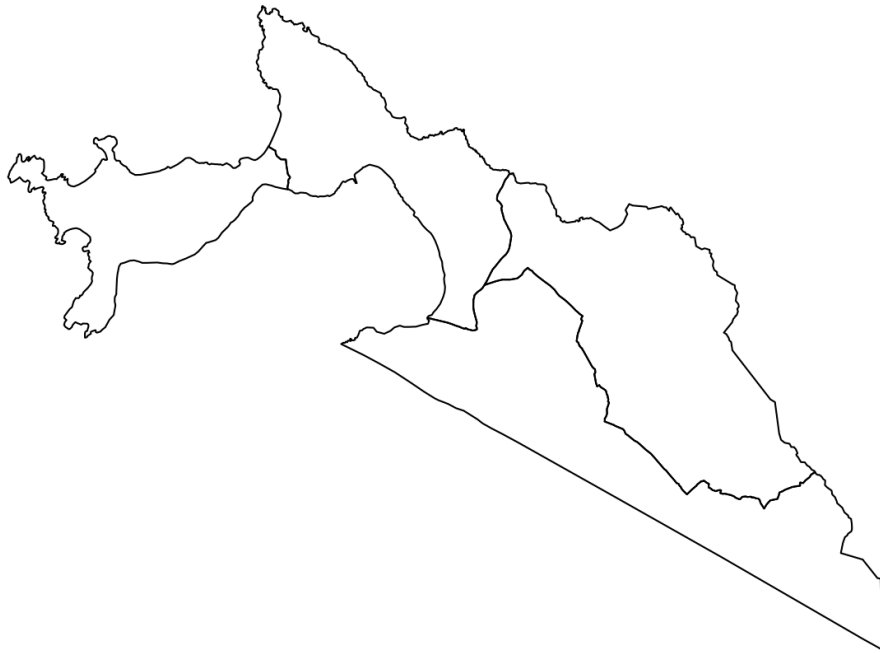


Figure 2: Basemap of Muhuru Bay

Dot Map Focus Groups

Following the creating of the basemap, “dot map” focus groups were conducted with various community members to identify the locations of positive and negative youth activities within the community. The focus groups engaged adults in the community in 3 groups—1 with health workers (n = 5), 1 with traditional male chiefs (n = 7), 1 with women leaders (n = 4), and 12 with parents (n = 26) and teachers (n = 16) across 4 school-segmented locations.

Paper copies of the basemap were distributed at the start of each focus group, and participants received a brief orientation to the map. Basic map reading skills were tested through asking participants to identify 4 commonly known community landmarks and mark them with stickers on the map. Focus group facilitators then asked participants a series of questions regarding the reputations of locations in the community (such as “What are places where youth can get in to trouble?”) and participants responded through

placing colored stickers on the map corresponding to the locations (green for positive questions, red for negative questions). An example dot map is shown in Figure 2. The resulting dot maps were scanned and saved as a PDF, and then imported into ArcGIS (version 9.3) and georectified (ESRI, 2008). The digital scans were aligned with the original digital shapefiles from the community mapping activity, and each sticker dot was converted into a map waypoint (longitude and latitude coordinated) associated with that participant's unique identification number. The result was a map containing points for all participants superimposed on one basemap.

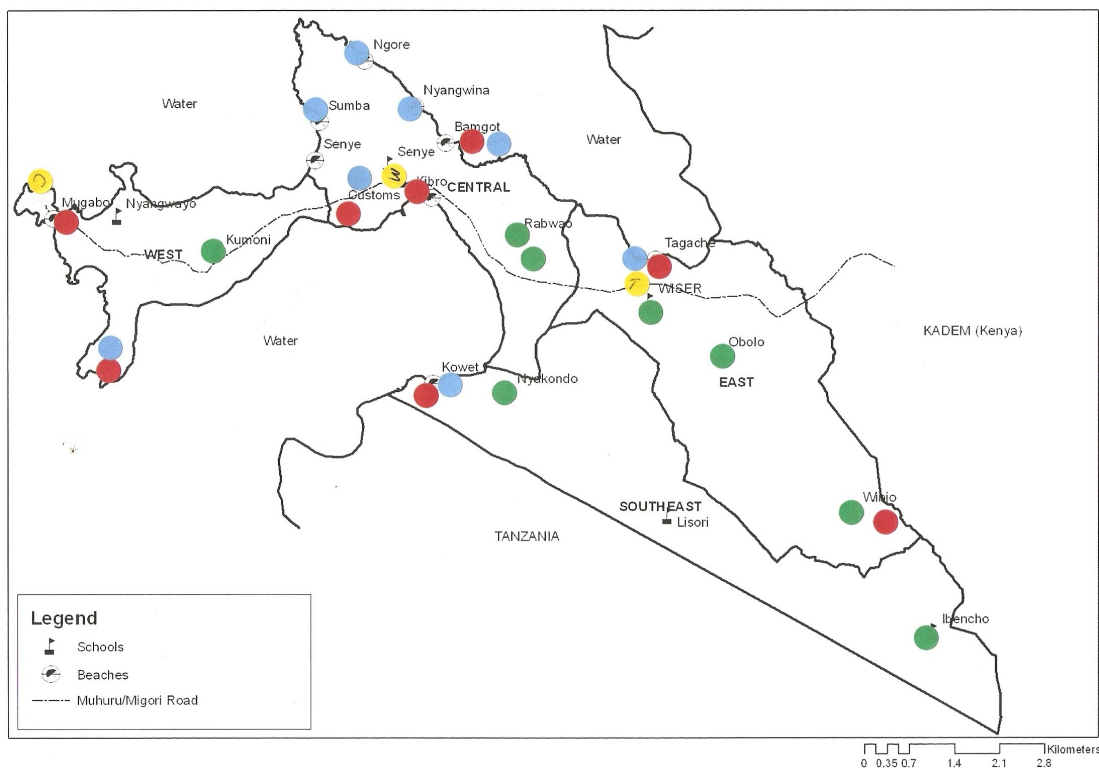


Figure 3: An example dotmap created by one participant

Satellite Imagery-Assisted Activity Logs

Finally, 318 of the 325 adolescents participating in the cross-sectional survey of psychosocial correlates of HIV risk behavior completed a 20-minute individual interview about their daily activities. Participants first described the location of their home, and

researchers navigated to this location on a high-resolution satellite image displayed on a laptop. After locating the participant's home, the researchers marked a waypoint in an individual shapefile created for that participant. The participant was then prompted to walk through his or her activities, from waking up until going to sleep, on a certain day within the past week. For each new location that the participant described and identified on the satellite map, researchers created a digital waypoint in the participant's unique shapefile. One researcher asked questions and navigated the computer, while another collected the information (including waypoint ID numbers) on a paper form. Using this process, a personalized log was created for each participant documenting times, spatial locations, and typical frequency of activities. Each point representing a visited location was categorized as type 1. Facilitators followed-up this exercise by asking participants to identify additional places that they go when they have free time, and report how often they go to these places. These points were categorized as type 2.

Activity Space Generation

Standard deviation ellipses were used to quantify the activity spaces of adolescents, based on their reported daily activity logs. These ellipses were generated in R Studio using the open-source "aspace" package. "Aspace" has been used by various researchers to study an individual's engagement with their physical environment through standard deviation ellipses (Buliung & Remmel, 2008). Specifically, "aspace" provides a collection of functions for computing centographic statistics for observations taken at point locations. An un-weighted activity space was generated for 218 of participants with the `calc_sde` function. 100 of the 318 participants were excluded from the activity space

generation due to incomplete/corrupted shapefiles (n = 90), insufficient number of points (n = 8), or missing data in the parental survey dataset (n = 2).

The ellipses were generated using both the points from the participant's daily activity logs (type 1) and the additional locations that they go during their free time (type 2). The EPSG:32736 (WG8436S) coordinate reference system was applied to each set of coordinated before activity space generation. Figure 3 shows the standard deviation ellipse of one participant, representing his or her activity space.

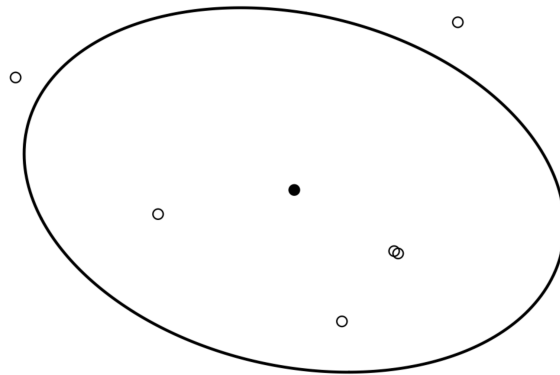


Figure 3: An example participant activity space

Data Analysis

In their methods paper on activity space generation Sherman et al. constructed three main variables from their measures of activity space: 1) the area of the space in square kilometers, 2) a dichotomous yes/no variable indicating whether any points of interest (in their case primary care centers) were located inside a participant's activity space, and 3) a count of the number of points of interest located inside each participant's activity space (Sherman et al., 2005). Similarly, adolescents' activity spaces were analyzed to construct four major variables: 1) activity space area 2) a dichotomous

(yes/no) variable indicating whether each activity space contained any red locations in the community (binary ecological risk score), 3) the number of red locations contained within each space (count ecological risk score), and 4) the density of red locations contained within each activity space (density ecological risk score).

The area of each respondent's activity space was calculated in square kilometers using the `calc_sde` function of the "aspace" package. Red locations were defined by plotting the "dot map" focus group data onto a basemap of Muhuru Bay (Figure 4). Each point represented a red location reported by a focus group participant.

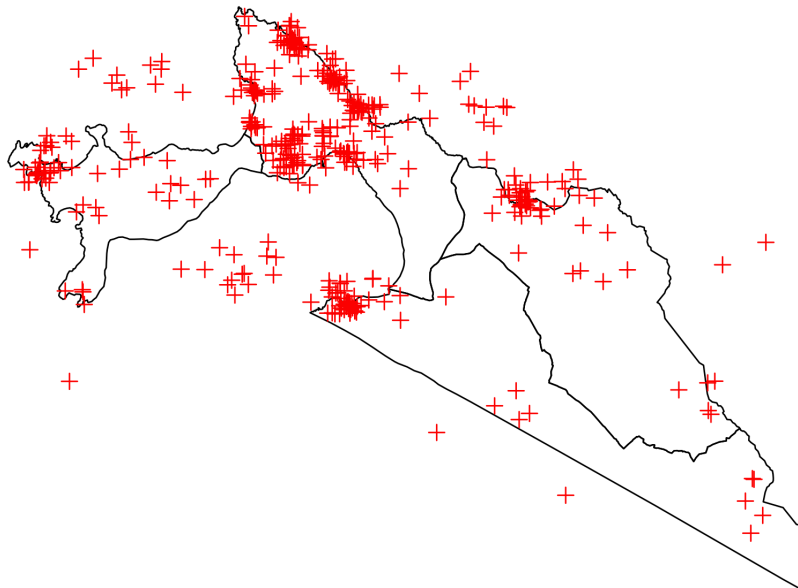


Figure 4: each point represents a report of a dangerous location by a focus group participant

This "dot map" was used to calculate both binary and count ecological risk scores. The activity space of each participant was overlaid onto dot map, and the open source R package `GIStools` was used to identify the presence of red locations contained within each activity space. This package was also used to count the number of red locations within the bounds of each participant's activity space. Figure 5 demonstrates the overlap of one participants' activity space with 4 red locations.

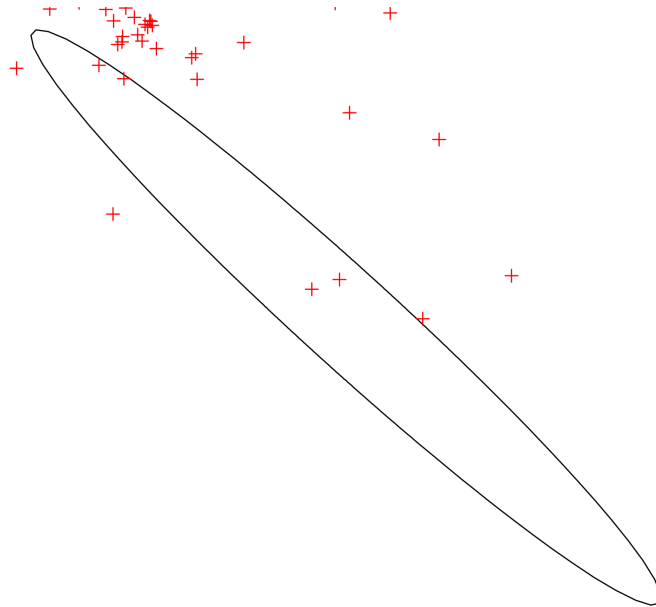


Figure 5: Activity space overlapping 4 red locations

To calculate the density of “bad” locations contained within each activity space, “spatstat,” an open-source R-package for spatial point pattern analysis, was used. The density function applies kernel density estimations to a set of input points (in this case participant sticker waypoints) and interpolates a density raster. Figure 6 shows the rasterized dot map data, with red representing higher danger areas, and grey representing lower danger areas.

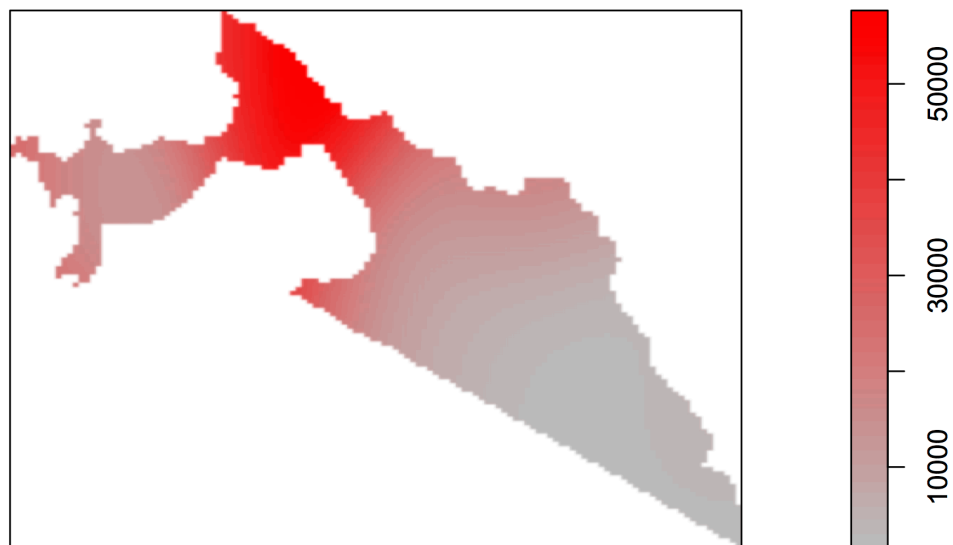


Figure 6: Density map representing red location areas in the community as red

The density map was then overlaid with the activity space of each participant, and a sum of the density was taken to quantify the “density of risk” located within each participant’s activity space, or density ecological risk score (Figure 7)

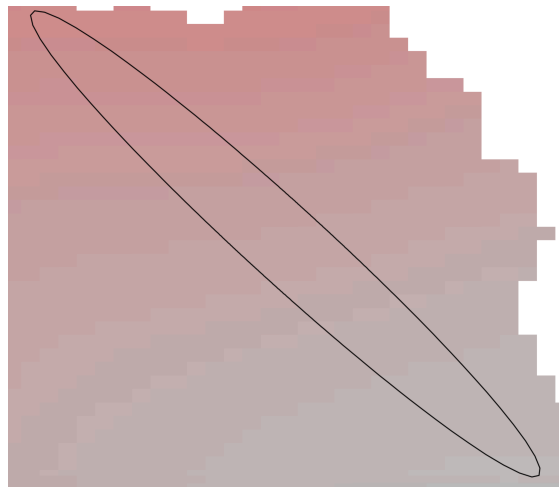


Figure 7: A participant’s activity space overlaid onto the density map

Descriptive statistics for psychosocial predictors and the each activity space and ecological risk variable were calculated using means and proportions.

Regression Models: Univariate & Multivariate

Univariate and multivariate regressions were run between each of the four activity space variables and the psychosocial predictors listed in table X. Histograms of generated activity space areas and ecological risk scores revealed positively skewed distributions of scores, due to outliers with unusually large activity space areas. The shapefiles of all participants in the upper 95th percentile for activity space area were examined for data entry errors. To mitigate the effect of these outliers on the generated models, a logarithmic transformation variable was applied to activity space size and density

ecological risk scores, to center the distribution more normally. In addition, each numeric psychosocial variable was divided by two times its standard deviation, in order to place the variables on the same scale and facilitate interpretation of regression coefficients. Among a set of predictive variables containing both binary and continuous values, dividing numeric variables by 2 SD allows for the numeric variable coefficients to be interpreted similarly to binary inputs (Gelman, 2008).

Univariate regressions were first conducted for each of the four dependent variables: activity space size, binary ecological risk score, count ecological risk score, and density ecological risk score. Confidence intervals were constructed using $\alpha = 0.05$. These univariate models informed the construction of clustered-robust standard error models. For activity space size, predictors in the in these multivariate models included age, gender, caregiver monitoring score (youth and caregiver reported), and night out frequency, as well as all predictors significantly associated with activity space size (p -value < 0.05). For the binary, count and density ecological risk scores, age, gender, caregiver monitoring score (youth and caregiver reported), and night out frequency, as well as all variables that were statistically significantly associated with ecological risk score in one of the three univariate models (p -value < 0.05) were included in the clustered-robust standard error model for all three ecological risk variables. In all clustered-robust standard error models, the grouping effects of school-level randomization were taken into account. All analyses were conducted in R.

RESULTS

Participant Demographics

Of the 218 adolescents included in the analysis, 100 were male and 118 were female. Ages ranged from 10-18 years old, with a mean of 13 years. The average number of years of education was 6.31. Median parental income was 400 KES per week, or approximately \$5.29 USD at the time of data collection. Of the 218 caregivers that participated in the study, 54 were male and 164 were female. The mean age was 41.43 years. Married caregivers (traditional, legal and church) comprised 77.1% of those surveyed (Table 2).

Table 2: Adolescent and caregiver demographics

Participants	n	Female (%)	Age		Education (years)		Married (%)
			Mean	SD	Mean	SD	
Youth	218	54	13.96	1.57	6.30	1.11	-
Caregivers	218	75	41.43*	12.36	-	-	77.1

* 14 caregivers refused to provide a specific age: 80-89 (3), 60-69 (2), 50-59 (2), 40-49 (3), 30-39 (3)

Participants in the dot map focus groups included 26 parents, 15 teachers, 7 chiefs, 5 women leaders, and 4 health workers. The breakdown of gender, age, education levels and marriage status within these participants is summarized in Table 3.

Table 3: Focus group demographics

Participants	n	Female (%)	Age		Education (years)		Married (%)
			Mean	SD	Mean	SD	
Parents	26	38	40.5	16.6	8.2	3.4	96
Teachers	15	20	35.5	12.3	12.7	0.4	80
Chiefs	7	0	50.1	3.7	11.1	1.8	100
Women leaders	5	100	54.3	6.5	9.5	2.6	100
Health workers	4	40	34.2	12.5	12.2	1.3	60

Adolescent Psychosocial Scores

Overall, 77.9% of the participants had living mothers and 64.2% had living fathers. Table 4 lists the mean scores on indicators for sexual risk characteristics, HIV related factors, caregiver relationships and mental health factors for these 218 participants. Parental ratings of adolescents' conduct, hyperactivity, experience of peer pressure, emotional behavior and pro-social behavior. There was no significant difference between the psychosocial characteristics of the larger 325 participant dataset², and the subset of 218 participants included in the analysis, as determined by linear models of key psychosocial variables.

² See Puffer et al. 2011 for descriptive statistics for the full 325 dataset of psychosocial variables.

Table 4: Youth psychosocial scores/statistics by gender

	Total <i>(SD)</i>	Male <i>(SD)</i>	Female <i>(SD)</i>
Family characteristics			
Percent mother living	77.98	78.00	78.67
Percent father living	64.22	64.00	64.41
Sexual risk characteristics (of sexually active youth, past 12 months)*			
Number of sexually active youth	81	45	36
Percent engaged in vaginal sex	37.16	45.00	30.51
Percent high sexual risk score	25.23	38.00	14.41
HIV-related factors			
Mean sex-related self-efficacy score	18.97 (5.16)	19.50 (5.11)	18.52 (5.18)
Mean “risky” sex beliefs score	28.61 (4.49)	29.11 (4.97)	28.20 (0.62)
Caregiver relationships			
Mean caregiver monitoring score (youth report)	24.70 (2.69)	24.49 (3.03)	24.89 (2.36)
Mean going out at night frequency	0.67 (0.98)	0.85 (1.04)	0.51 (0.89)
Mean communication frequency score	6.32 (5.84)	5.28 (5.13)	7.19 (6.26)
Mean communication barriers score	37.95 (10.50)	38.60 (11.00)	36.38 (9.99)
Mean caregiver social support score	38.03 (13.07)	40.06 (14.46)	36.31 (11.56)
Mental health			
Mean emotional problems score	4.26 (2.34)	4.04 (2.42)	4.46 (2.25)
Mean conduct problems score	0.78 (1.05)	0.78 (0.97)	0.80 (1.11)
Mean traumatic events score	3.75 (2.79)	3.71 (2.90)	3.78 (2.71)
Mean traumatic stress score	13.08 (5.59)	12.48 (5.69)	13.51 (5.50)
Mean self-esteem score	20.83 (3.68)	21.45 (3.46)	20.30 (3.79)
Mean hope score	8.09 (2.23)	8.15 (1.98)	8.04 (2.43)
Caregiver descriptions of child			
Mean caregiver monitoring score (caregiver report)	24.95 (2.55)	24.29 (2.95)	25.42 (2.06)
Mean child conduct score	1.49 (1.31)	1.60 (1.49)	1.40 (1.13)
Mean child peer pressure score	2.64 (1.86)	2.63 (1.78)	2.65 (1.93)
Mean child emotion score	4.11 (2.13)	4.15 (2.08)	4.08 (2.18)
Mean child EBD score	11.29 (4.67)	11.97 (4.60)	10.71 (4.66)

Activity Space & Ecological Risk Measures

The mean area of activity space was comparable between male and female participants, with mean areas of 2.24 km² and 3.14 km² respectively. For the three measures of ecological risk, the percent binary ecological risk score was 90.3% (90.3% of participants have an activity space overlapping with one “bad” area), the mean count ecological risk score was 19.76 (the activity space of the average participant overlapped with 19.76 “bad” areas), and the mean density ecological risk score was $(3.8 \cdot 10^6)$ (Table 5). There were no significant differences in activity space area or ecological risk score (binary, count or density) between male and female participants (t-test analysis).

Table 5: Activity space and ecological risk score measures

Descriptive measures	Total (SD)	Male (SD)	Female (SD)
Mean area (km ²)	2.72 (5.80)	2.24 (3.66)	3.14 (7.12)
Percent binary ecological risk score	90.3	91.0	90.0
Mean count ecological risk score	19.76 (24.11)	18.23 (19.11)	21.06 (27.67)
Mean density ecological risk score	$1.3 \cdot 10^7$ ($1.6 \cdot 10^7$)	$1.2 \cdot 10^7$ ($1.3 \cdot 10^7$)	$1.3 \cdot 10^7$ ($1.8 \cdot 10^7$)

Predictive Models: Univariate and Multivariate Regressions

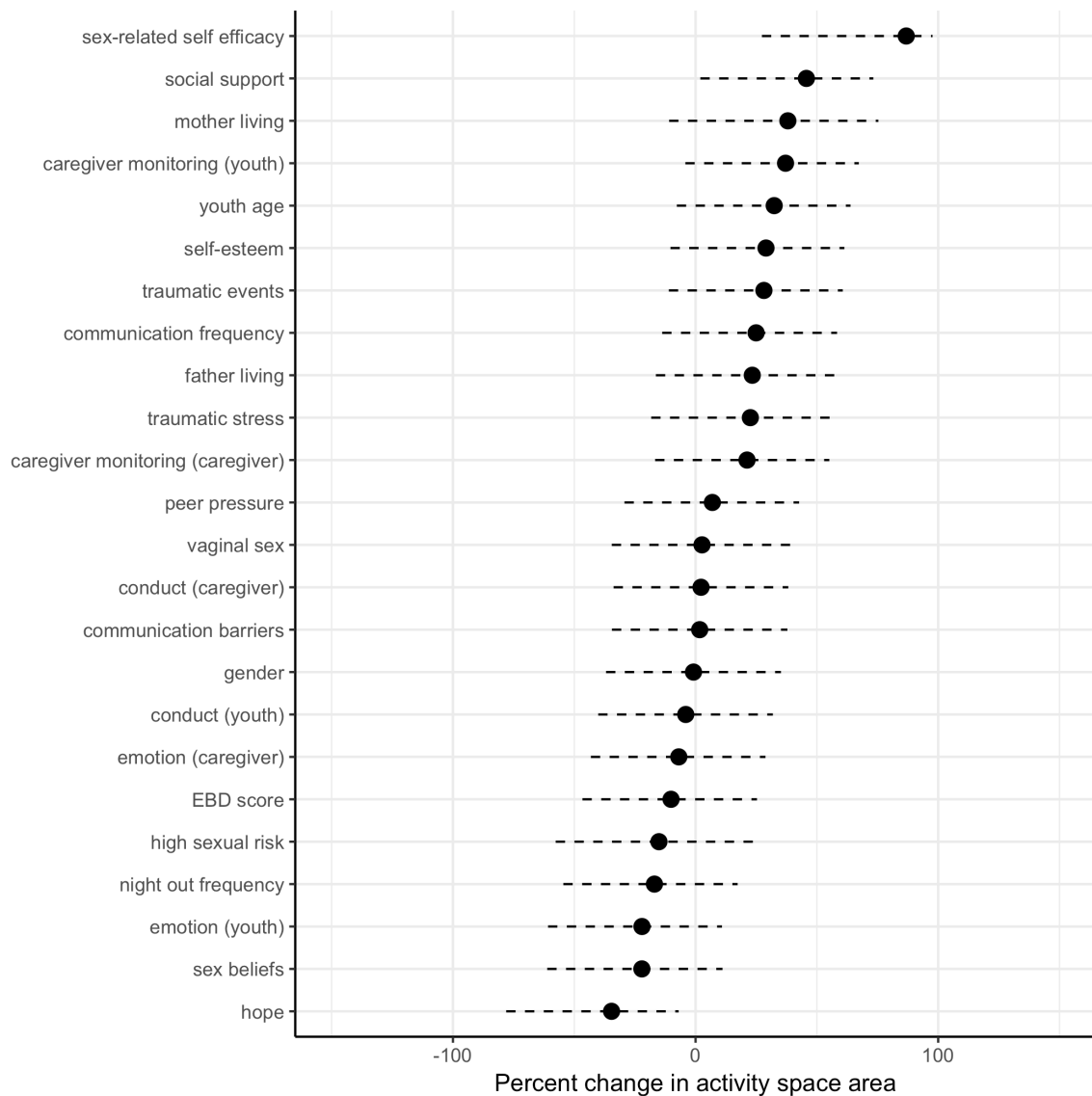
Univariate regressions between activity space area and the psychosocial characteristics revealed that the log of activity space size was associated with sex-related self-efficacy, hope and social support score ($\alpha = 0.05$) (figure X). Most significantly, an increase in two standard deviations in youth-reported sex-related self-efficacy was associated with an 86.8 percent increase in activity space area. Significant predictors within the univariate regressions are shown in Table 6, and all regressions are shown in Figure 8.

Table 6: Significant univariate predictors of activity space area

Predictor	Estimate	P-value	95% CI
Mean sex-related self-efficacy score	86.83	0.0006***	27.33, 97.68
Mean hope score	-34.63	0.0194**	-78.06, -6.95
Mean social support score	45.68	0.0387**	1.97, 73.28
Mean caregiver monitoring score (youth report)	37.09	0.0836*	-4.22, 67.31

*p < 0.1; **p < 0.05 ; *** p < 0.01

Figure 8: Univariate regression of activity space area on youth characteristics



The clustered-robust standard error model for activity space area also revealed a significant association between log of activity space area and sex-related self-efficacy ($0.05 > p$), as well as social support ($0.05 > p$), and youth age ($0.05 > p$) (Table 7).

Table 7: Multivariate regression of activity space area on youth characteristics

	<i>Dependent variable:</i>
	Activity space area (log)
Constant	.12 (.16)
z.yselfeffsum	.52** (.23)
z.yhopesum	-.37* (.21)
z.socsuptot	.40** (.19)
z.nightoutfreqN	-.10 (.16)
z.youthage	.60** (.25)
c.ygender	-.02 (.15)
z.CaregiverParMonSum	.22 (.20)
z.yparmonsum	.32 (.23)
c.vagsexever	-.01 (.17)
c.highRisk	-.11 (.16)
z.youthage:c.ygender	-.41 (.32)
Observations	217
R ²	.13
Adjusted R ²	.08
Residual Std. Error	1.29 (df = 205)
F Statistic	2.79*** (df = 11; 205)

Note: *p<0.1; **p<0.05; ***p<0.01
Cluster robust standard errors in parentheses

Univariate regressions revealed that log of binary ecological risk score was associated with whether the participant’s father was living (Figure 9). The log of count ecological risk score was correlated with youth age (an increase in youth age of two standard deviations was associated with an increase of 7.30 adult-reported “bad” areas within an individual’s activity space) (Figure 10). Finally, the log and density ecological risk score was correlated with communication barriers (an increase of two standard deviations in communication barriers was associated with a 47.4 percent increase in ecological risk) (Figure 101. Selected associations identified in the univariate regressions are shown in Table 8.

Table 8: Significant univariate predictors of ecological risk score

Predictor	Estimate	P-value	95% CI	Variable
Father living	-0.09	0.0307**	-0.17, -0.01	Binary
Mean peer pressure score	0.07	0.0955*	-0.01, 0.15	Binary
Mean youth age	7.30	0.0254**	0.91, 13.69	Count
Mean emotional problems score	5.54	0.0906*	-0.88, 11.97	Count
Mean communication barriers	47.43	0.0261**	5.70, 89.16	Density
Mean night out frequency	41.58	0.0506*	-0.10, 83,26	Density
Mean emotional problems score	40.91	0.0544*	-0.78, 82,61	Density
Mean social support score	40.10	0.0594*	-1.61, 81.81	Density
Mean youth age	37.27	0.0799*	-4.48, 79,03	Density

*p < 0.1; **p < 0.05

Figure 9: Univariate regression of binary ecological risk score on youth characteristics

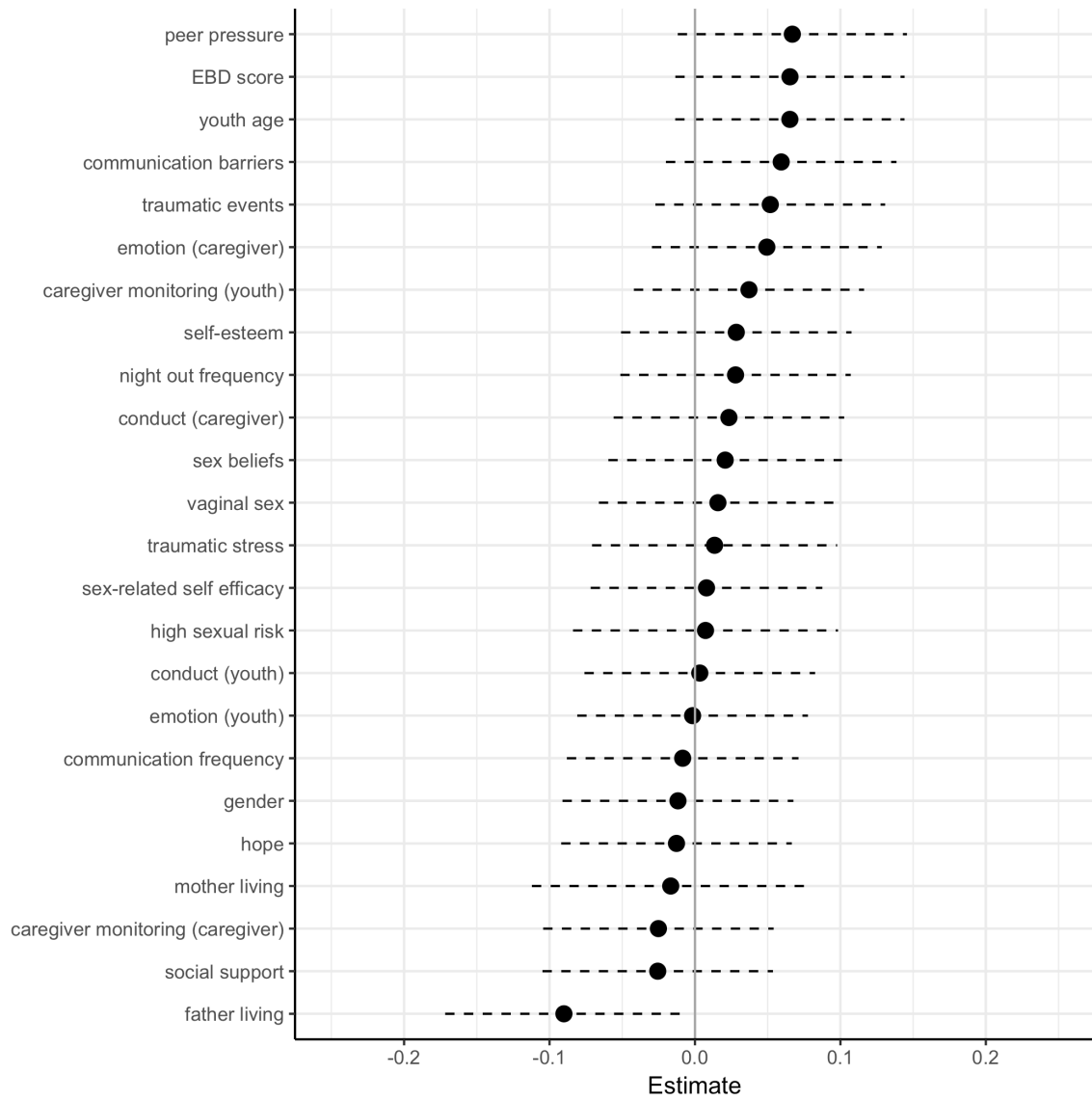


Figure 10: Univariate regression of count ecological risk score on youth characteristics

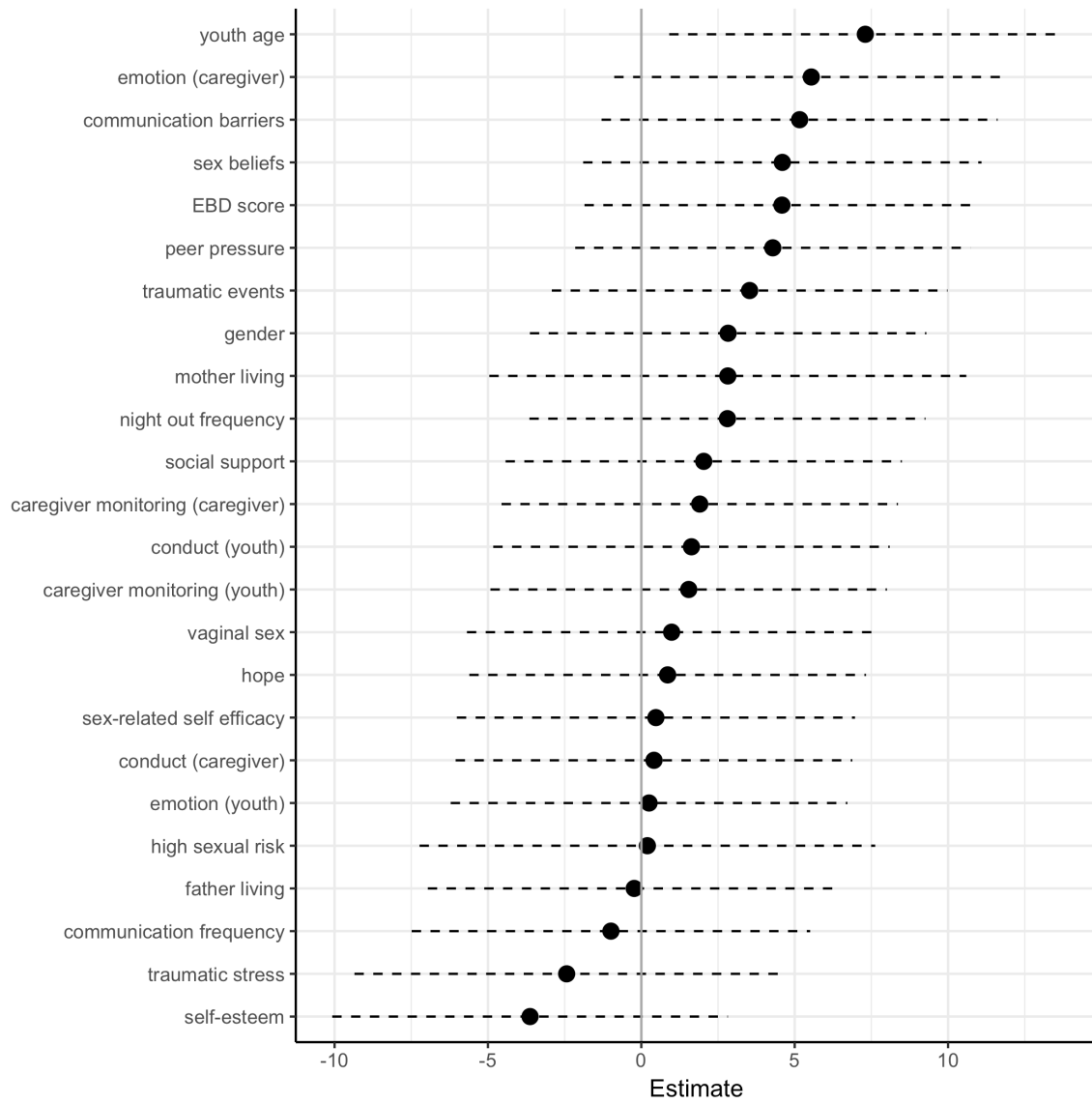
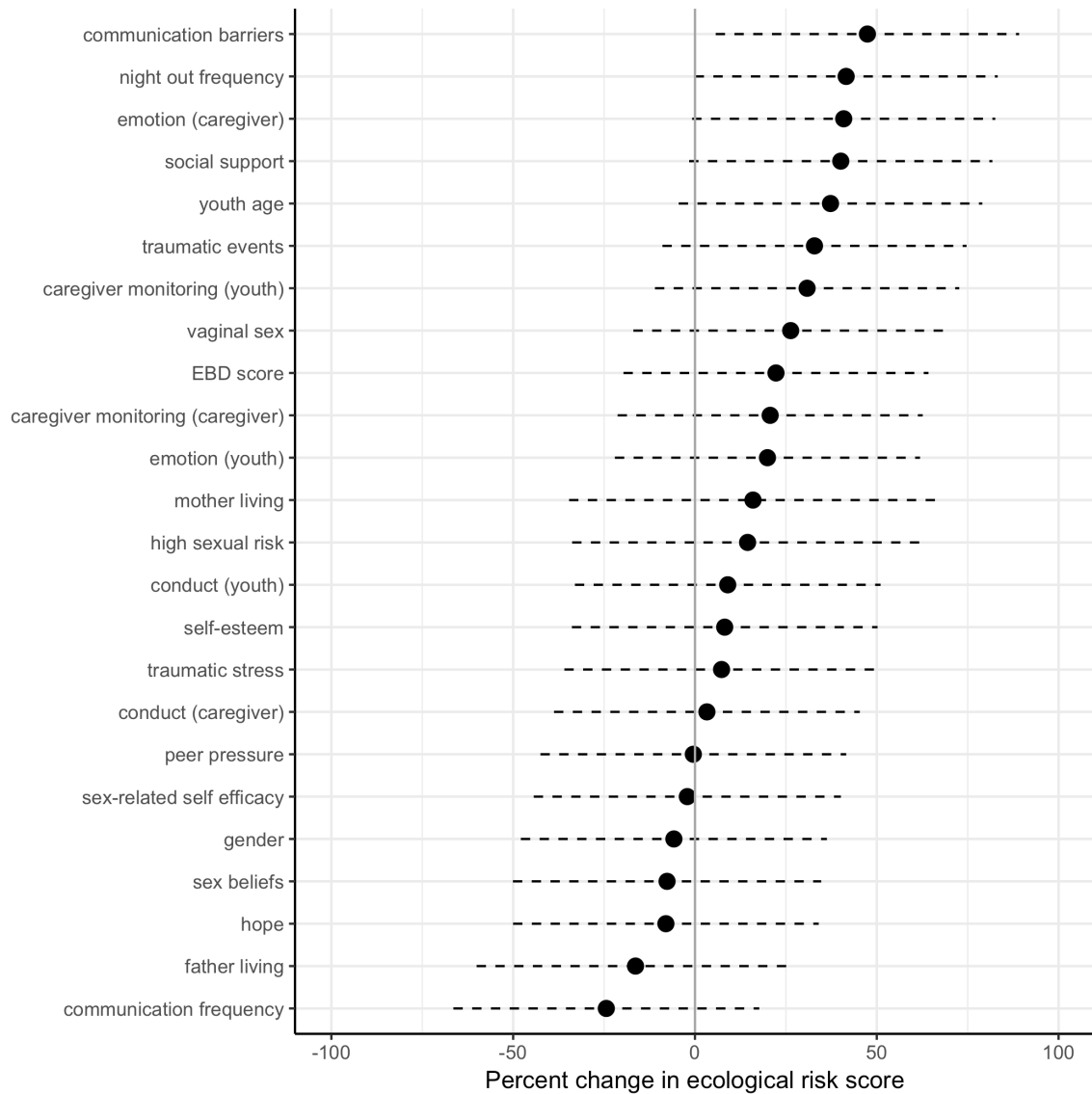


Figure 11: Univariate regression of density ecological risk score on youth characteristics



Clustered-robust standard error models for ecological risk score variables revealed a significant association between youth age, social support and night out frequency with density ecological risk score ($0.05 > p$). Communication barriers were significantly associated with count ecological risk. Clustered-robust standard error models did not reveal any statistically significant associations between binary ecological risk score and psychosocial correlates (Table 9).

Table 9: Multivariate regressions of ecological risk on youth characteristics

	Measures of ecological risk		
	Risk Score (log)	Count of Bad Places	Any Bad Places
	(1)	(2)	(3)
Constant	15.73**** (.22)	18.86**** (2.37)	.97**** (.03)
z.ycommbarrtot	.42 (.28)	4.82** (2.33)	.05 (.04)
c.fatherliving	-.28 (.29)	-.03 (3.49)	-.08 (.05)
z.pemotion	.35 (.22)	5.23* (3.03)	.03 (.04)
z.socsupptot	.67** (.28)	4.95* (2.83)	.02 (.03)
z.youthage	.62** (.30)	7.20 (6.71)	.03 (.03)
c.ygender	.07 (.15)	4.18 (2.86)	-.001 (.03)
z.CaregiverParMonSum	.24 (.19)	1.80 (3.25)	-.03 (.04)
z.yparmonsum	.36 (.33)	1.89 (2.52)	.05 (.05)
z.nightoutfreqN	.44** (.22)	3.48 (3.09)	.03 (.04)
c.vagsexever	-.04 (.24)	-5.11 (3.34)	-.03 (.06)
c.highRisk	-.12 (.19)	1.96 (3.50)	-.01 (.07)
z.youthage:c.ygender	-.33 (.40)	4.15 (7.56)	.06 (.09)
Observations	217	217	217
R ²	.12	.07	.05
Adjusted R ²	.07	.01	-.003
Residual Std. Error (df = 204)	1.52	23.98	.30
F Statistic (df = 12; 204)	2.27**	1.26	.96

Note:

*p<0.1; **p<0.05; ***p<0.01
Cluster robust standard errors in parentheses

DISCUSSION

Through the creation of four measures of HIV ecological risk, this study demonstrates a novel use of activity space analysis to assess HIV behavior patterns. While previous studies have leveraged activity space analysis to analyze risk environments (Mason et al. 2015; Mennis and Mason 2011; Lipperman-Kreda et al. 2015), application to HIV risk environments has remained limited. Within the HIV literature, studies have mapped distance to health resources and locations of risk (Martinez et al., 2014; Brouwer et al., 2012). However, quantifying the overlap of adolescent movement patterns with locations of community-identified risk is a unique approach to HIV risk environment assessment. By leveraging community knowledge this approach uniquely combines participatory methods with individual-level risk analysis, and provides a methodological tool for future investigations.

This investigation was framed around two groups of hypotheses, concerning activity space area and ecological risk scores. In regards to activity space area, I hypothesized that adolescents with higher caregiver monitoring would experience smaller activity spaces. As parental monitoring often serves to limit adolescent's exposure to risky activities (Sieverding et al. 2005), I hypothesized that one method of limiting risky behaviors may be through limiting movement in the community. Contrary to expectations, no significant associations between parental monitoring and activity space area were observed. These findings may support theories that the parental monitoring may lower sexual risk behaviors through encouraging attitudinal changes, rather limiting exposure to risky environments (Romer et al. 1999).

I also hypothesized that adolescent girls would experience smaller activity spaces than boys. Hallman et al. found that as girls transitioned through puberty into adolescence, they experienced a decrease in activity area, while boys experienced an increase in activity area (Hallman et al., 2015). However, this investigation found no significant difference in activity space area between male and female participants. This discrepancy may be due to methodological differences. In their study, Hallman and colleagues asked youth to draw freehand their community on a piece of paper, and mark safe and dangerous areas. The research team then analyzed these maps, plotting features on Google satellite images. The resulting plots were used to calculate “community size” boxes for participants. The present study similarly incorporated participatory methods and spatial mapping, but had participants directly identifying the locations that would later comprise their activity spaces. In addition, the points incorporated into the activity spaces were indicative of actual visited locations, rather than the participant’s perception of his or her community boundaries. Furthermore, the use of curved standard deviation ellipses (constructed from visited points), rather than square boundaries demarcating community limits, provides more accurate assessment of community movement as experienced daily by adolescents. Due to these limitations, the original findings may be a result of poor study design, rather than actual differences between groups.

Exploratory analyses did reveal interesting associations between both activity space area and ecological risk score, and various psychosocial correlates of HIV risk. Youth age was a significant predictor of activity space area, and density ecological risk scores in multivariate models. Specifically, an increase in two standard deviations in youth age was associated with a 60% increase in activity space area, and a 62% increase

in total ecological risk density. This was consistent with evidence in high-income contexts, which have found that as youth grow older their activity space increases (Spilsbury, 2005). The results of this investigation suggest that this pattern of expanding activity space extends to low-income communities, and that this expansion may be coupled with increased adolescent exposure to risky environments.

Social support was also significantly associated with activity space area and density ecological risk score in multivariate models. While evidence has mostly suggested that increased social support is associated with decreased HIV risk behaviors among adolescents (Tinsley et al., 2004), others have found that caregiver social support may increase engagement in sexual activities (Puffer et al., 2011). The association between social support and increased ecological risk score may reflect inconsistencies in the literature regarding the affect of social support on adolescent sexual risk patterns (Qiao, Li, & Stanton, 2014), suggesting the need for further studies to unpack the specific mechanisms through which social support influences adolescent risk behaviors.

Multivariate models also revealed a significant association between decreased communication barriers and increased activity space overlap with “dangerous” community areas (count ecological risk score). These findings stand in contrast to suggestions in the literature that effective caregiver-child communication decreases risky sexual behaviors (Hutchinson & Cooney, 1998). Similarly, increased sex-related self-efficacy was associated with increased activity space area, yet various studies have shown sex-related self-efficacy to be associated reduced sexual risk behaviors (Puffer et al., 2011; DiClemente et al., 2008; O’Leary, Jemmott, & Jemmott, 2008). These two

findings suggest that predictors of “risky sexual behaviors” may relate to individual-level sexual choice (such as condom use), but not avoidance of physically unsafe areas.

Notably, binary ecological risk score analyses demonstrated no statistically significant correlates in multivariate models. The lack of significant correlation in the binary multivariate model may be due to the large variability in the definition of “risky” activity areas within this variable. With a high of 188 “bad” areas and a low of 1 “bad” area, variability may be too high to accurately represent the continuum of ecological risk that exists within participant activity areas with a binary scale. This suggests that other metrics of ecological risk, such as density ecological risk score, may be more effective tools for evaluating adolescent risk environments.

However, the count and density ecological risk models did not reveal the predicted significant association between ecological risk score and both 1) engagement in vaginal sex and 2) sexual risk score. This may be due to a true lack of association between these variables, or a result of noisy measures in the study. Within this study, a few limitations may have affected the observed results. First, the activity spaces of participants were not weighted according to frequency and/or duration of visit due to insufficient data. Weighting of activity space allows for more frequently visit locations to be weighted more heavily (Sherman et al., 2005), and creates an activity space that more accurately reflects time spent in various community locations. In addition the use of one daily logs poses potential challenges. One the one hand, using single day, self-report introduced possibilities for recall bias. Longitudinal logging or tracking may have more accurately captured total community movement patterns (Connors et al., 2016). However,

in depth tracking may lead to dishonest selective reporting, as participants are aware of being carefully tracked.

Furthermore, the present study was conducted with a limited sample size, and many of the participants were lost to incomplete data collection. While analyses demonstrated that there was no significant difference between the analysis group and original sample, a larger sample size may clarify some of the ambiguous relationships identified in this study. Selecting via schools also introduced selection bias into the results, and future studies should attempt to include out-of school youth, who may have different risk patterns. Finally, HIV risk may be difficult to understand among the selected age group, where a small proportion is sexually active. Analyses may benefit from a longitudinal rather than cross sectional dataset, or the inclusion of an older and more sexually active adolescent population.

Conclusion

As calls to incorporate ecological risk factors into HIV prevention efforts continue to grow, the development of efficient and cost-effective methods to analyze risk environments are increasingly relevant. This study demonstrates the feasibility of quantifying adolescent risk environments through community informed, participatory techniques and leveraging GIS technology. In particular, the use of summed density maps to represent risk continuously rather than through discrete point locations is a novel technique of risk analysis. The modeling methods presented in this paper are unique, easy to use tools that can be applied to assessing the effect of social-ecology on HIV risk. Ultimately, these methods may facilitate development of multi-level, ecological interventions to address the spread of HIV among adolescent populations.

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