Parameterizing the Dynamics of Slums

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Abstract

Over one billion people live in the world's 200,000 slums and informal settlements. We used data generated from mobile phones to better understand one of the largest slums, Kibera located in Nairobi, Kenya. Using call logs from June 2008 - June 2009 and theories from human geography, economics, sociology, journalists, and anthropologists as a basis, we tested the validity of a few prominent theories. In particular, we focused our research on migration patterns out of Kibera, inferring places of work, and tribal affiliations.

Introduction

> For the first time in history, more people live in cities than in the countryside. Our world is no longer simply going through the experience of urbanization. Our world has become urbanized. ... One billion people - or one in every three urban residents - now live in an urban slum, the vast majority of them in developing nations (Kramer 2006).

By 2015, there will be at least 500 cities whose population will be over one million (UN-Habitat 2008). It is estimated that by 2050, the world population will reach ten billion, with the majority of those people living in urban areas (Davis 2002). The brunt of this population growth will occur in developing countries. Ninety-five percent of the growth of the human population will occur in the urban areas of developing countries, whose population is expected to double to nearly four billion over the next generation (Yue-man 1997).

However, anthropologists and human geographers agree that we have very limited knowledge about what effect this growth will have on the world (Davis 2002), (Neuwirth 2006) (Goodman 1973) (Kramer 2006). Unlike the growth of cities during the industrial revolutions in Europe and North America, as a population we have never experienced such profound changes. Social scientists are working to better understand this growth and change. However, to date, little quantitative work has been done (Kramer 2006). The majority of research has been anecdotal evidence or case studies with very limited sample sizes. As more individuals move into urban areas, slums and slum dwellers become more prominent. A slum can be defined as "a residential area which has developed without legal claims to the land and/or permission from the concerned authorities to build; as a result of their illegal or semi-legal status, infrastructure and services are usually inadequate" (Davis 2002). Sociologists theorize that the majority of urban migration is filtered through slums and understanding the migration patterns is vital to understanding the growth of urban areas (Brown 1970) (Todaro 1997) (Turner 1968) (und 2002) (Un-Habita 2003) (UN-Habitat 2008). However, since slums are informally established, unplanned, and unrecognized by the government, scientists have a very limited understanding of the 200,000 slums worldwide and the billion individuals living there. We believe that this work is a step in the right direction towards quantitative results measuring slum dynamics.

This research focuses on using mobile phone data to gain an in-depth look and understanding into the slum dweller population. Currently, there are over four billion mobile phone subscribers around the world. The majority of these are in the developing world, where the rate of adoption greatly outpaces that of the developed world. In 2008, the number of mobile phone subscribers in Africa surpassed the number in North America with over 280 million subscribers. As a result, mobile phones are providing enormous behavioral data sets, especially for underrepresented populations in the developing world. Using mobile phone call logs, we can track human movement, infer socioeconomic status, and gain a comprehensive view into the functionality of societies and entire countries. As opposed to self-reported surveys or anecdotal evidence from field work, human behavior can be quantified using these data sets without human bias. Recently, work has been done to use mobile phones to increase our insight into human movement and behavior (Gonzales 2008) (Calabrese 2006). These comprehensive data sets are opening new doors for scientists to quantify human relationships and mobility on a scale previously unimaginable. Our research focuses on mobile phone data generated in Kenya from June 2008 - June 2009. In particular, we are focusing on the residents of one of the largest slums in Kenya, those living in Kibera, Nairobi, Kenya.

In Nairobi alone, nearly half the population, or two million people, live in one of 66 informal settlements and slums. In Kibera, the largest slum in Kenya, population estimates vary, with most agreeing the population is well

over 600,000 or around one-fifth of Nairobi's population (Kramer 2006). These residents live in only 5 percent of the total residential area without basic necessities, such as sanitation, water, healthcare, or education. However, even with these conditions, the population of Kibera grows at an annual rate of 12 percent (International 2009). From the characteristics of slums and typical slum residents, overarching trends and patterns of migration are extremely difficult to quantify. Nonetheless, through aggregate statistics we have found a number of trends that can further classify and understand slum movement in Kibera. This paper represents the exploratory phase of an ongoing research project using mobile phone data to develop mathematical models of slums.

Data

The datasets used for this research represents the social network topology and dynamics of Kenya's communication patterns. With over ten million callers making over ten billion calls in a given year, this data provides a comprehensive look into the communication and mobility of Kenyans. With each call, we can infer a number of individual characters such as spatial data (by the location of the cell tower that transmitted the call), economic data (the average length of each call, the amount of pre-paid minutes an individual has put on their phone, the type of phone), an individual's regional or tribal affiliation, and a radius of migration for groups of individuals (by the distance between locations of cell towers calls have been made from). From the longitudinal call logs (CDRs) and cell phone information, we are able to bootstrap a wealth of information about spatial orientation, regional affiliations, and social mobility. Moreover, using mobile phone data enables us to take an extremely large sample size of individuals to reduce bias, sampling issues, and loss of clarity about the underlying dynamics.

For this research, we used CDRs from Kenya from June 2008 till June 2009[1]. Our data is a log of each call made in Kenya with information including the caller, person called, cell tower received ID, duration of call, and date of call[2]. Moreover, we have the geographic coordinates of the over eleven thousand cell towers in Kenya. With each tower servicing around 80,000 calls, we are able to gain an in-depth view of individual movement patterns and approximate the location of the caller with reasonable accuracy. The magnitude and fine detail found from this dataset allows us to look at a slum residents on a scale and level of detail previously unobtainable.

Methods

Kibera has one cell tower location inside the slum, identified with six unique cell tower IDs. In order to form a sample of Kibera's residents, we classify a caller as living in Kibera if they meet all of the following criteria:

[1]February 2009 is missing from the data set

[2]Note: all callers identifications are unique hashed IDs

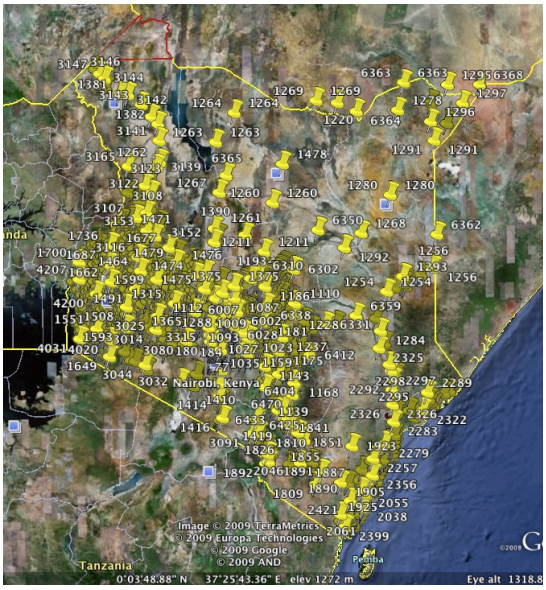

Figure 1: Google image with cell tower locations marked.

1. Over fifty percent of their total calls between the hours of 6 PM and 8 AM have been made from one of Kibera's towers.
2. The total number of calls made in a month is between 3 and two standard deviations from the mean number of calls made by those living in Kibera.

We realize that our sample is not necessarily a random sampling of the entire population. One objection is that we are only sampling individuals who can afford mobile phones. However, with the rate of mobile phone adoption and prevalence of cell phones in Kenya we believe that our sampling is not entirely biased towards wealthier slum residents. Moreover, we are not considering all individuals living in Kibera. Nonetheless we are considering a sample size of around 18,000 total callers in Kibera over the course of the year which is considerably larger than previous studies. In any given month, there are between 2,090 and 3,068 callers in Kibera making between 53,868 and 74,489 calls per month.

Using this identification of callers, we are looking at three key components of slum dynamics: migration trends, work trends, and tribal affiliations. A better understanding of these three components will be instrumental to understanding the dynamics of slums. In particular, we are using aggregate statistics to test a prominent theory from human geography that slum residents move to better urban living conditions when they leave a slum(Davis 2002). In terms of work trends, we want to better understand what areas provide the most stable and largest possibilities for work. Since sociologists state that Kibera's size is largely due to its proximity to the center of Nairobi as a place for work, we want to test if such a relationship is evident. Finally, since tribal affiliations drive many of the political dynamics of Kenya, we want to assert if there are any strong ties with a specific

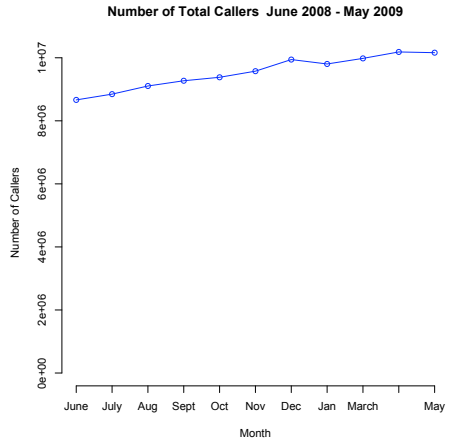

Figure 2: This graph represents the total number of callers in Kenya per month from June 2008 - May 2009.

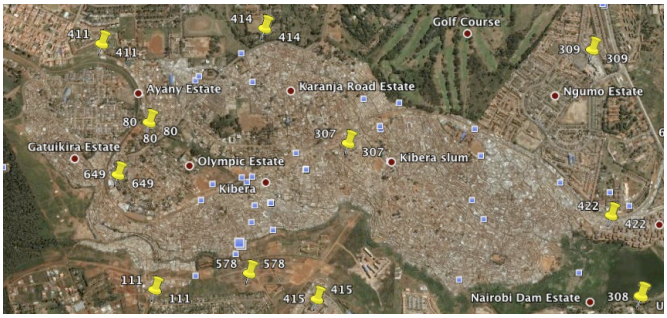

Figure 3: Google Earth image of Kibera with cell phone tower site IDs marked

tribal group. Aggregate statistics about these three topics will help guide future work about developing models of human behavior and movement in Kenya's slums.

Results

Migration Trends

The prominent theory from human geography conjectures that slum residents move from rural areas to urban areas for the prospective of improving living conditions. In theory, as individuals are able to improve their quality of life, they are able to move out of slums into an area that provides more stable housing, job opportunities, and lower rates of crime. "Yet, the question remains as to whether the informal sector is merely a holding ground for people awaiting entry into the formal sector (middle class areas) and, as such, is a transitional phase that must be made as comfortable as possible until it is absorbed by the formal sector, or whether it is here to stay and should, in fact, be promoted as a major source of employment and income for the urban labor force" (Todaro 1997). By following individuals' movement patterns out of Kibera to other parts of Kenya, we are testing to what extent this idea about the role of slums holds true. If the theory proves to be true, we should notice obvious patterns of

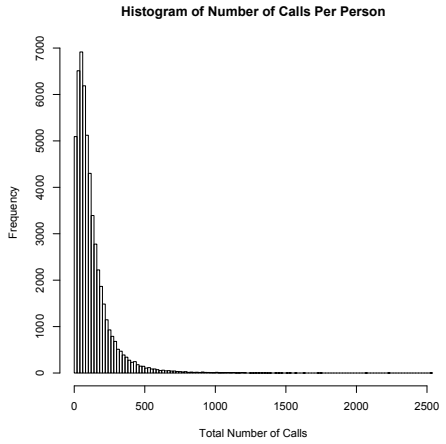

Figure 4: This graph represents the number of calls made for each caller living in Kibera in June 2009. Overall, the mean for each caller is around 25 calls per month

movement out of Kibera into wealthier neighborhoods.

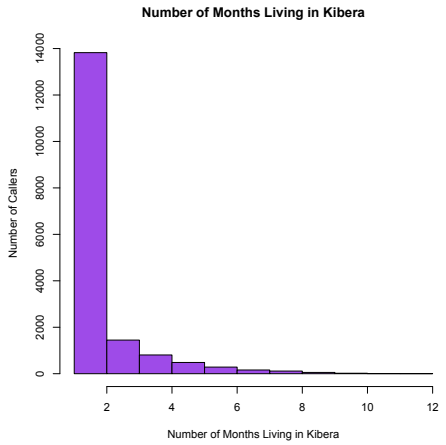

Figure 5: This chart represents the number of people who have lived in Kibera for a specific number of total months.

In order to identify the demographics of migration out of Kibera, we further classify callers in Kibera as those who have moved out of the slum and consider their call patterns for the first month living elsewhere. As Figure 5 shows, the majority of people live in Kibera for less than two months, with the mean at 1.95 months. This result supports the theory that slums act as a filter as opposed to a sink where there is a large amount of flux within the slum population. This is evidence that Kibera has an extremely high turn over rate month to month. We refine this figure later in the paper.

The measure defined in the beginning of the previous section was used to determine individuals living in Kibera. However, in order to classify the area where an individual has moved to, we use the spatial location of the user's call history and cluster towers within one km of each other.

The cluster most frequently called from is classified as their home location.

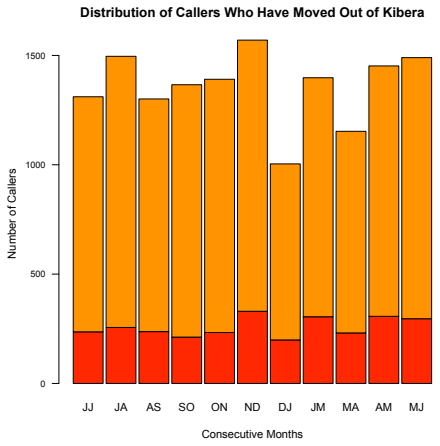

Figure 6: Distribution of calls who have moved out of Kibera. The light bar represents those who have moved to another region of Kibera. The dark bar represents those who have completely moved out of Kibera. Note, months are labeled consecutively pairwise, i.e. JJ represents June-July, JA represents July-August, etc.

We discovered that the majority of individuals still continue to make calls from the towers on the border of the Kibera, Figure 3. As a result, we have differentiated between those most likely moving from the center of Kibera to another section of Kibera. Expanding our definition of 'living' in Kibera to include those who have moved to another section of Kibera, we have refined our previous assertion about Kibera's turn over rate. As Figure 7 shows the mean number of months a person is 'living' in Kibera is now 1.559[3] and there are more people living for longer amounts of time. However, these results still show that the average time 'living' in Kibera is still very low and this is further evidence of a high turn over rate in the slum.

As Figure 6 shows, the majority of individuals who have moved out of Kibera, have actually moved to other regions of Kibera. This shows that while there is a large proportion of people moving from our original definition of living in Kibera, the majority of these people are most likely still slum residents. These results most likely suggest that there is a high level of movement within Kibera before moving to other parts of Kenya. In addition, by using the spatial locations of a individual's new living regions, we found little evidence of individuals moving to similar locations or moving to wealthier neighborhoods.

Work Trends

Work is the prime motivation for moving into Kibera (International 2009) (Brown 1970), (Byerlee 1974) (Davis 2002) (Todaro 1997) (Turner 1968). To determine regions of

[3]The decrease can partially be attributed to the larger sample size of individuals living per month in Kibera

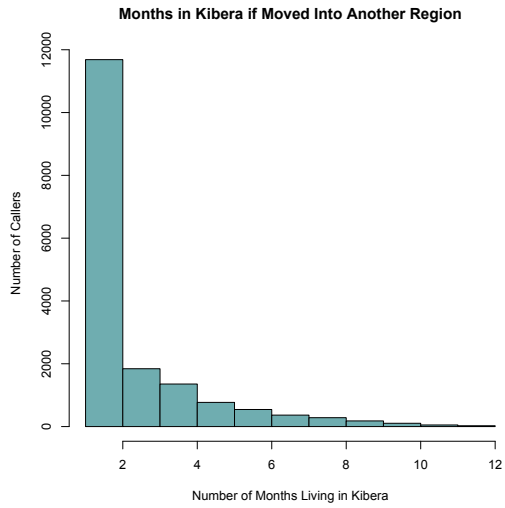

Figure 7: If we consider the people who have moved out of Kibera, but stayed in another part of Kibera, and the number of people who live in Kibera for a month, this is the number of months a person is 'living' in Kibera.

Nairobi providing employment opportunities for Kibera's residents, we consider their calls made at cell towers in Nairboi, excluding the towers in Kibera. First note that the percentage of calls made at any of these towers is extremely low with a maximum value at 0.008% of total calls. This can be attributed to the density of towers in Nairobi and the fact that the majority of calls made by Kibera's residents are made from cell towers in the slum[4].

By ordering the towers by the total number of calls, we considered the top 50 towers per month. From this subset of towers we have identified the towers with the greatest overlap from month to month. For this analysis, we first considered the distribution of the percentage of calls made at these towers over the course of the year. Finally, we plotted the location of these towers in Google Earth to associate locations with possible working environments. These towers most likely indicative stable regions for work. This method enabled us to determine the average number of months a work region tower is listed. With the mean 1.95, we see that there is little overlap in work region towers from month to month. This result would suggest that on the micro level of Nairobi by tower location, there are few places providing very stable work environments. Next, using longitude and latitude coordinates we have determined where top work regions are located in proximity to Kibera. As Figure 8 shows, there appear to be two distinct groupings.

On the macro level, this method shows a strong connection between Kibera and the center of Nairobi. Moreover, this methodology has allowed us to begin analyzing the dis-

[4]We have also run our analysis by constructing regions (in the same fashion as the construction of living regions). However, we feel as though those results are less illustrative then this methodology.

Figure 8: This Google image highlights the top working towers occuring in the highest number of months. In the bottom left-hand corner is Kibera and the top right-hand corner is the center of Nairobi.

tance traveled by slum residents. The distance shown in Figure 8 would suggest that Kibera's residents do not travel long distances for work. We plan on using this result to help guide future research questions about the radius of mobility for slum residents.

Tribal Affiliations

Similar to the rest of Kenya, Kibera is greatly effected by tribal affiliations. In order to infer tribal affiliations in Kibera, we considered callers who have moved away from Kibera and determine the region where they have moved. To accomplish this, we first associated all cell towers with a tribal dialect by their geographic coordinate, as a proxy for tribal affiliation. We then calculated an individual's new home cluster and associated each cluster with a tribe. As we can see in Figure 10 , the majority of residents have moved to Nairobi or an unknown region of Kenya. It is interesting to note that the regions represented for the entire year remain constant, even though no prominent tribal affiliations are obvious from this methodology.

We realize that there are obvious improvements to be made to this process. We are currently working on associating a tribe with each person in Kenya. From this information, we will take a closer look at calls made from Kibera's residents and inferring tribal affiliations of individuals Kibera's residents have called. We believe this will provide a better assessment of tribal affiliations in Kibera.

Conclusion

Although universal laws of human movement are difficult to harness, research using mobile phone tower locations and large sample sizes help address this problem. Out of all results, the most striking is the high turn over rate in Kibera. Using this methodology and data set, we found that in Kibera close to 50% of individuals are moving, whether to other parts of Kibera or elsewhere, per month. The transient nature of this population was evident in our analysis and made harnessing any fundamental properties of Kibera's residents difficult. When attempting to infer new places of residence, tribal affiliations, and work regions there seemed to be little

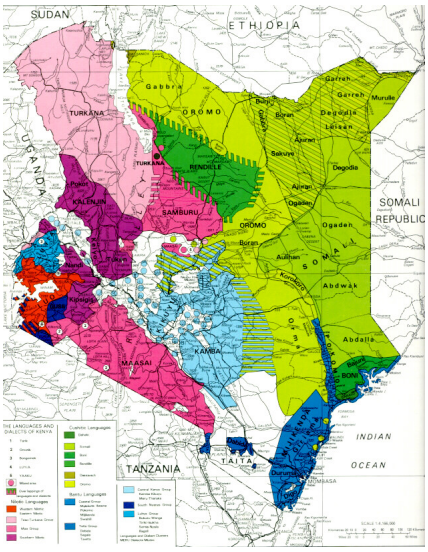

Figure 9: This map shows the division of Kenya by dialect. In our analysis, we are using dialect as a proxy for tribe.

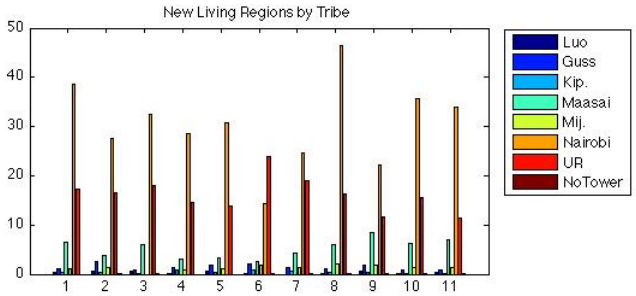

Figure 10: This plot represents the number of individuals who have moved to the following tribal regions.

overlap from month to month. We did find that a large proportion of place of work are in the center of Nairobi, which supports the theory that Kibera has been able to continue to grow as a result of its close proximity to the center of the city.

Our analysis has been conducted on a much larger scale than previous studies. Even though 18,000 people living in Kibera is lower than the estimated 600,000 residents, this sample is at least one hundred times larger than any previous study (Davis 2002) (International 2009) (Un-Habita 2003) (unh 2009) (UN-Habitat 2008). Overall, this research represents an exploratory study as part of a larger ongoing research agenda. This work is a first step in harnessing the power and possibilities arising from behavioral data sets of this magnitude. Most importantly this work has raised new questions and avenues for future research.

Can we identify an individual's motivation for moving to a city? How can we better understand human mobility to aid urban planners when designing where roads, latrines, and schools should go? Can we quantify, using behavioral data sets, the change in a person's socioeconomic status as they

move into a slum? Can we quantitatively understand the growth of slums and help predict where the next slum will form? Answers to these types of questions provide deep insights into better understanding society. Previously, answers to these types of questions were unobtainable. Now with a combination of existing theory, computational tools, and large data sets, scientists are able to work to achieve answers to these questions.

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