Water International, 2013
Vol. 38, No. 1, 43–60, http://dx.doi.org/10.1080/02508060.2013.752315

Using GPS and recall to understand water collection in Kenyan informal settlements

Ben Crow[a]*, James Davies[b], Susan Paterson[c] and Julio Miles[b]

[a]*Department of Sociology, University of California, Santa Cruz, USA;* [b]*Department of Computer Science, University of California, Santa Cruz, USA;* [c]*Department of Economics, University of California, Santa Cruz, USA*

(*Received 5 February 2012; accepted 18 November 2012*)

This paper uses interviews and Global Positioning System (GPS) loggers to measure the time taken to collect water in two large informal settlements in Kenyan cities. Collection times were measured, and collection paths mapped, in two low-income urban settlements, comparing water access conditions in Nyalenda in Kisumu (where the utility has introduced a new piped water system) with Kibera in Nairobi (where no such improvement has been made). The use of GPS tracking provides a better understanding of time spent collecting water compared to interview data, but the two methods combined provide insights that neither could have suggested alone.

Keywords: water collection; GPS; time; Kenya; women's work; household reproductive work

Introduction

The authors investigated how much time is spent collecting water in low-income settlements and how that has been changed by the introduction of a new system of water collection. Time devoted to water collection has been recognized as a constraint on women's opportunities (Blackden & Woden, 2006; Cairncross & Cliff, 1987; Crow & McPike, 2010). Reducing the time spent collecting water could free up time for more productive tasks, including income generation and education. Global Positioning System (GPS) data seem to offer a range of new insights into the timing, temporal patterns, sources and spatial patterns of water collection. Rigorous data on water-collection times and the place of water collection in domestic work may shed light on the advantages and disadvantages of different systems of urban water provision.

This paper reports on preliminary, low-budget research using GPS to map women's water collection in two Kenyan settlements. Water-collection times in Kibera in Nairobi, where there is a market system distributing water illegally obtained from the utility mains, were compared to those in Nyalenda in Kisumu (western Kenya), where the utility has introduced a delegated-management model with a new piped water distribution system maintained by traders and community groups. Less time is spent in water collection in Nyalenda, probably as a result of the introduction of this new piped water distribution

*Corresponding author. Email: bencrow@ucsc.edu

system. Women nonetheless continue to use multiple sources of water, including springs and unprotected wells.

Household interviews are the current standard method of collecting this data. The present study finds that GPS provides new insights into the complexity of water collection, but cannot fully replace household interviews.

Household or domestic water collection is important because the quality and quantity of household water, and the time devoted to water collection, have wide repercussions on well-being. Water-borne diseases are a significant source of ill health in non-industrial countries. Limits on the quantity of water available may also constrain livelihood options and the productivity of domestic work, such as laundry, bathing and washing utensils. In addition, the time devoted to collecting water may crowd out other more creative or rewarding uses of time.

In Sub-Saharan Africa, time devoted to the collection of water is thought to contribute to the overwork or time shortage of women. Thus, Blackden and Wodon (2006) write: "Time poverty has long been recognized as a constraint to development in Sub-Saharan Africa, with women working especially long hours due in part to a lack of access to basic infrastructure services such as water and electricity." There is evidence that women may sleep fewer hours than men in response to the time demands of their various tasks (Crow, Swallow, & Asamba, 2012).

This paper makes two main contributions: (1) comparison of two water supply systems in two low-income informal settlements, providing quantitative and spatial data not previously available; and (2) comparison of two methods for measuring the time taken collecting water. It shows, on this second point, that neither GPS data alone, nor the recalled time estimates of water collectors, provide a full picture of the time and place of water collection. In combination, the two may uncover new data about where water is collected, the complex patterns of water collection from several sources, and how long is spent in water collection.

Literature on access to water

Access to water is addressed in a wide range of literatures, including contributions on how long people spend collecting water (e.g. for East Africa, Thompson et al., 2001), on the division of household work (Ilahi, 2000), on the quality of water and its health implications (e.g. Briscoe, 1993; Cairncross, Bartram, Cumming, & Brocklehurst, 2010), on informal sector work (Ahlers, Schwartz, & Perez Guida, 2012), on water markets (e.g. for Kenya, Gulyani, Talukdar, & Kariuki, 2005), on the finance and management of utilities, on urban planning and political ecology of water in cities (Gandy, 2004a, 2004b; Heynen, Kaika, & Swyngedouw, 2006), and household work and access to water (Crow & McPike, 2009; Page, 2005). The following is a summary of some key contributions on the measurement of water-collection times and on GPS tracking.

Measuring water-collection times

For some decades, international agencies have focused primarily on the health implications of the technology of water collection and tended to ignore women's work in collecting water (Crow & McPike, 2009; Rosen & Vincent, 1999). International statistics on progress in access to water focus on whether or not access is through an "improved" water source. Improved sources include piped water, boreholes, standpipes and protected springs – a range of technologically improved water sources – in contrast to open ponds, rivers, springs and other easily contaminated sources. These data do not describe the social conditions of water collection, who does the work, how long it takes, how infrastructure has arisen historically, or from whom the water is purchased (or obtained by other agreement). Recent experimental research (Devoto, Duflo, Dupas, Pariente, & Pons, 2011; Kremer, Miguel, Mullainathan, Null, & Zwane, 2008) has also focused primarily on technology and health.

There has been little systematic collection of data on how long water collection takes. A review (Crow & McPike, 2009) of the literature on women's water collection in slums suggests that water availability may be unpredictable on hourly, daily and seasonal time scales; water-collection sites may be distant; and public sources may be crowded, resulting in long queuing times. In Ghana, water-collection times vary from three-quarters of an hour per trip in times of plenty to two and a half hours in times of scarcity, but a significant number of women spend more than four hours collecting water (Buor, 2003). In the slums of India, women are reported to spend from two to four hours per day collecting water. Multiple trips may be required, each 15 to 25 minutes long (Sharma, 1999).

A review of rural household water access (Rosen & Vincent, 1999) summarized 12 studies of time taken in water collection; average water-collection times varied from 17 to 103 minutes per carrier per day, and minimum and maximum collection times from 7 to 264 minutes (four and a half hours).

All of the urban data appear to be based on recall estimates made during interviews. In rural areas, some estimates of time taken in water collection have been made by direct observation (Cairncross & Cliff, 1987). This may be a feasible method for collecting reliable data in rural areas where many people use a small number of water sources and seasonal and daily variability of sources is small. For urban areas, with high variability and multiple water sources, it does not seem feasible.

None of this existing research provides quantitative measures of water-collection times in Kibera or Nyalenda.

GPS measurement

GPS has been used for tracking a wide array of activities and movements, including buses in a transportation system (Anderson et al., 2009), the movement of livestock (Samuels, Allsopp, & Knight, 2007), flight patterns of albatross (Weimerskirch et al., 2002), pigeons (Biro, Guilford, Dell'Omo, & Lipp, 2002), and city pedestrians (Shoval & Isaacson, 2006). GPS has also been used to survey water and locate water points for both livestock (Klintenberg & Verlinden, 2007) and humans (Gutierrez 2007; Smith 2008), but not (as far as the authors are aware) to map and document household water collection.

GPS was used here, in approximately the same way as in previous tracking research, to measure water-collection times, distances and routes, reporting on the successes and difficulties of its use in this context.

Research sites

Informal settlements, or slums, in Kenya and much of Sub-Saharan Africa suffer from several problems with respect to water and sanitation. These settlements arose from the historic rural–urban migration of the last 50 years, in which a large part of rural populations have moved to cities in search of jobs and a better life. Services have not kept up with the unprecedented growth of urban areas. As a result, both urban utilities and consumers face problems, but of two different types.

Utilities are unable to collect payments for many legal water connections and categorize the majority of their water as "unaccounted-for" or "non-revenue" water because it is either withdrawn illegally or lost to leaks and breakages. Utilities' ability to invest in expanded water supply is therefore constrained.

Households, on the other hand, have to seek water where it is available, often from illicit water traders who sell it by the jerry can (20 litres). (In both areas studied, the 20-litre jerry can was the predominant container for transporting and storing domestic water. Where other containers were used, volumes were calculated accordingly.) This water may be expensive, particularly in the season of shortage, and its availability is uncertain. There is limited storage capacity in the system, partly because it is illicit. Seasonal shortages may lead to rationing by the utility and there may be other shortages when particular sources run out or water "cartels" restrict supplies.

Water collection was studied in two informal settlements in Kenya: Kibera, in the capital, Nairobi, and Nyalenda, in Kisumu on the shores of Lake Victoria (Figure 1). Some 60% of the population of Nairobi lives in some 170 informal settlements, of which Kibera is thought to be the largest.

Kibera is an iconic slum of 170,000 people in the industrial area of Nairobi. It was founded as a settlement at the end of World War II for Sudanese soldiers who had fought with the British Army. Like many recent settlements in Africa, it has suffered from limited government attention because the post-colonial government tried to restrain rural–urban migration by denying land and other rights to migrant communities. In the late 1990s, the government recognized that this policy was not effective, and threats of bulldozing the slum stopped. However, the 50-year absence of land tenure rights, regular policing and government services has contributed to the settlement's character as an ungoverned space. In some Nairobi settlements, such as Mathari, organized crime has emerged in place of government.

It is informative to contrast water-collection conditions in Kibera with those in Nyalenda, Kisumu, because a water system introduced in Nyalenda in 2005 has been lauded as a model for water supply in African cities (Castro, 2009) and the water utility in Nairobi has been experimenting with the introduction of a system modelled on that of Nyalenda in several settlements in Nairobi (Crow & Odaba, 2010). Nyalenda is the largest informal settlement in Kisumu, with a population of about 50,000.

The Kenyan Water Act of 2002 institutionalized a series of reforms seeking to decentralize water governance and increase community participation in water management (von Dach, 2007). The reforms included the separation of utilities (water service providers) from managers and regulators (water services boards) and the establishment of a Water Services

Figure 1. Location of the informal settlements, Kibera in Nairobi and Nyalenda in Kisumu.

Trust Fund to finance innovative water schemes. Experimental water systems in Kibera and Nyalenda have emerged in part through these new arrangements (Crow & Odaba, 2010).

Innovative water supply initiatives have been tried in both Kibera and Nyalenda. In Kibera, Maji Bora Kibera (Better Water for Kibera) was an unsuccessful attempt to build an association of the existing, illegal water traders. This system would have addressed the problems of the water utility through the payment of bills, legalization and upgrading of water-pipe connections to traders. Water shortages, high water prices, and uncertainty of supply experienced by households would also have been addressed. But the innovation failed as a result of miscommunication between the water traders' association and the utility and, subsequently, police action against organized crime and illegal water and electricity connections (Brocklehurst, Mehrotra, & Morel, 2005; Crow & Odaba, 2010).

In Nyalenda, by contrast, water supply innovation has been implemented effectively, with improvements for both the utility and the households (Katui Katua, 2010). Prior to the introduction of this new system, Nyalenda was largely supplied by water traders who made illicit connections to a "trunk" water main running along the north side of the community. This system was comparable to that currently prevailing in Kibera. In place of this informal and unregulated system of water supply, which generated significant returns for the traders (interviews with traders), a "delegated management model" (DMM) (Brocklehurst, Mehrotra, & Morel, 2005) has been introduced with new pipes and community organizations to manage them. The delegated management model draws on reforms in Mozambique, Malawi, Dhaka and Manila (Castro, 2009).

The innovation introduced "spur" mains that bring water from the trunk main into the settlement. At intervals along these spur mains, concrete meter chambers were constructed (see Figure 2), with the idea that community organizations or water traders would take responsibility for the meters and the connections to them. Each meter chamber has a

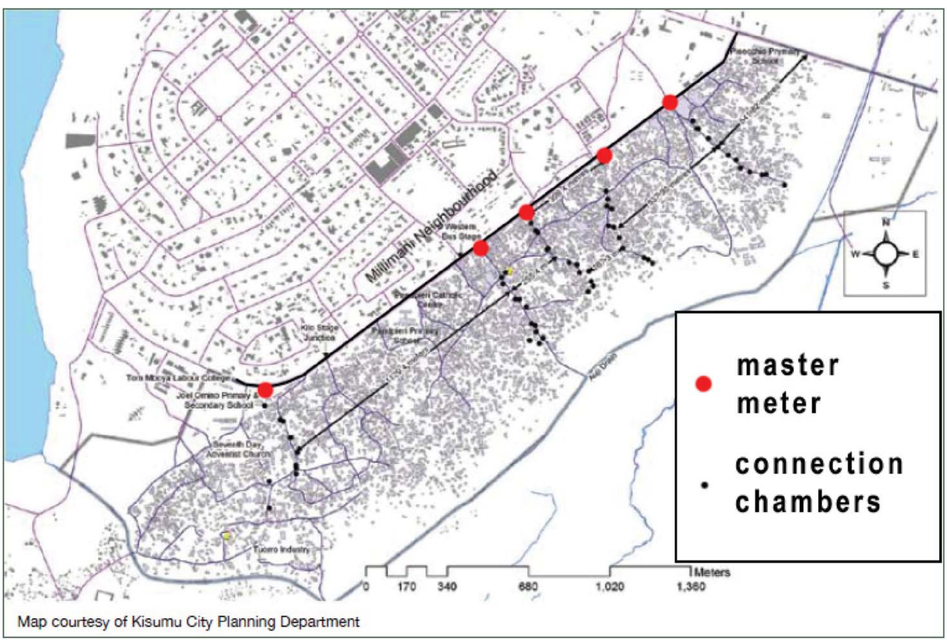

Figure 2. Delegated water management in Nyalenda. The map shows new pipes, master meters and connection chambers built by the utility and managed by community organizations.

heavy, padlockable concrete lid to deter theft and interference, and has space for two dozen meters. In addition to this change in the physical infrastructure of water supply, the DMM envisaged that the pipes, chambers and meters would be maintained and managed by community organizations. These organizations are known as master operators. They have taken responsibility from the utility for meter reading, bill collection and the stopping of leaks.

The new system was not introduced without opposition. Many of those selling water under the previous unregulated system strongly opposed the building and operation of the new system. Interviews with key informants in the community describe a year-long program of sabotage undertaken by community youth in return for payment. Twenty-eight of the existing water traders held regular Sunday meetings at which acts of theft of meters and pipes would be planned. Young men of the community were employed for KES3000–4000 (USD30–40) per night for these acts of sabotage, and traders from the group would go along to supervise.

In response, the utility organized a community meeting of about 1500 people, bringing in senior regional politicians and officials and providing a truckload of free soda. They then built a concerted campaign with flyers and a "task force" of community volunteers to police each line coming into the community.

Subsequently, some of the young men who had undertaken sabotage were employed in the new water system, and the influence of the water traders comprising the opposition gradually declined. The utility achieved the goal of having its bills paid and reducing the quantity of water lost to illicit connections and leakage. This transition to a new delegated management model provided the basis for one model of best practice water supply for slums in other parts of Kenya and Africa. The present study investigated whether this new system provides more accessible water compared to the situation in Kibera, Nairobi.

Two methods for studying the work of collecting domestic water

The primary objective of this work is to obtain quantitative measures of water-collection times. The initial plan was to employ household interviews and surveys to obtain this data. The engineer among our authors joined the project accidentally as a result of the offhand statement, "Why don't you just use GPS? It's cheap and specifically designed to measure this sort of thing." This proved to be correct, but also naive, a topic addressed in later sections. At the same time, GPS provided a wider range of information than could easily be obtained from interviews: frequent information about the water collector in space and time. This paper reports on two rounds of survey, from the summer of 2010 and the fall of 2011.

Household interviews

A total of 50 households were surveyed in Kibera and Nyalenda in the summer of 2010. To ensure effective use of the GPS data loggers, 10 households were selected from the households known to local field workers of a non-govenmental organization, the Kenya Water for Health Organization (KWAHO). In both Kibera and Nyalenda, households known to the program staff of KWAHO were chosen, to ensure a basic level of cooperation and mutual trust. It was not known what security and privacy questions might arise for households. As a result, this sample was biased toward households concerned about water questions. Many of these households had been involved in activism around water. Some in Kibera were involved with a women's water committee, and most in both communities had some contact with KWAHO's solar water disinfection campaign.

To situate the GPS-tracked households in the general population of the two settlements, 40 households were selected as controls. This random sample of 40 was chosen by walking several transects through the communities and choosing households at regular intervals along each transect. GPS households were told they would receive a small payment for their participation in the study, and were given KES500 (USD6.70) at the end of the study period. Control households did not receive payment.

In 2011, an attempt was made to capture GPS tracks for household water collection in Kibera during the July-to-October period, when local water shortages have often led to long water-collection trips. In an attempt to reduce costs, only one research assistant was used, compared to three in 2010. Reliable GPS tracks were obtained for several weeks, but there was some doubt about the tracks recorded for the longer period. Monthly payments encouraged one or two households to make trips that would not otherwise have occurred. This probably did not happen in 2010, when a single payment was made at the end of the research period.

Research assistants, fluent in Kiswahili and Luo, interviewed members of each household, generally the woman collecting water, to explore a range of questions: water storage facilities of the household; where and when they had travelled to get water in the past two days, and who went; how long it took, and how much they paid for the water; whether they had been short of water in the past week; which household activities took the most time; and a series of questions about livelihoods, income and rent.

GPS

The initial plan was to buy GPS units, attach them to the water-collection cans of households, and obtain near-perfect measurements of the routes and travel times involved in water collection. Data was collected for 10 days at each of 20 households (10 in Kibera and 10 in Nyalenda).

The households were not paid for participating in surveys, but the 2010 GPS households were promised a small gift for agreeing to take care of the units. In practice, they were given KES500 after the experiment.

The ideal GPS unit would be small, inexpensive, and indestructible; provide data in a standard format; have a long battery life; run unattended; and provide simple data download. After testing several commercially available units, Davis, Crow, & Miles (2012) determined that the Holux M-1000C best matched the requirements. This model costs USD69, has a battery life of 20 hours, has a swappable, rechargeable battery, has no external interface other than an on-off switch, and records data to an internal memory chip. Data is retrieved using custom software and a USB connection. A small Windows netbook was used to download data. Data analysis requires a desktop with projection facilities, and visualization software because the satellite photography and mapping need high resolution and magnification for local details of slum tracks and buildings to be identified.

It was considered important to make the process as simple as possible for the families, so GPS units were obtained that could stay powered on permanently and would require no direct manipulation by the women collecting water. In practice, the measured data was significantly noisier than expected. Thus, after two days, a decision was made to ask the women to turn the units on when they left home to collect water, and off again upon returning home. A research assistant downloaded the data and replaced the batteries every one or two days.

The GPS units were enclosed in plastic bags to protect them from water and attached to the side of one water-collection jerry can in each household, as shown in Figure 3.

Figure 3. GPS unit attached to a jerry can. The study participant is carrying a jerry can of water weighing 20 kg from a vendor's tap to her home.

In Nyalenda this was changed: the women carried the unit in a pocket when they went to collect water (turning it on and off at the beginning and end of each trip). After this change, information was obtained about many more water-collection trips, perhaps because the GPS unit was no longer restricted to one jerry can.

Relationship between GPS and control households

Figures 4 and 5 show the percentage of GPS and control households by income category in both settlements. In Kibera (Figure 4), the GPS households were at the low end of the income range. In Nyalenda (Figure 5), GPS households represent much of the income range of households. Average incomes in Kibera villages selected are higher than average incomes in the villages of Nyalenda.

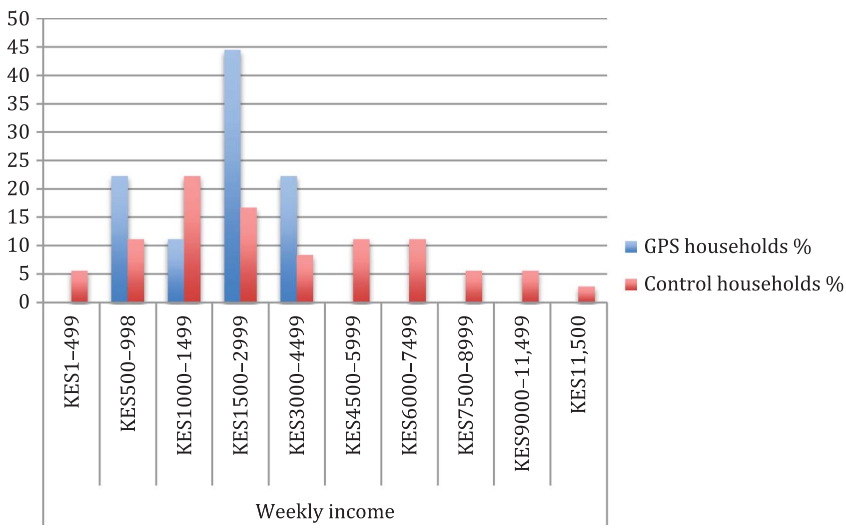

Figure 4. Kibera: distribution of GPS and control households by income.

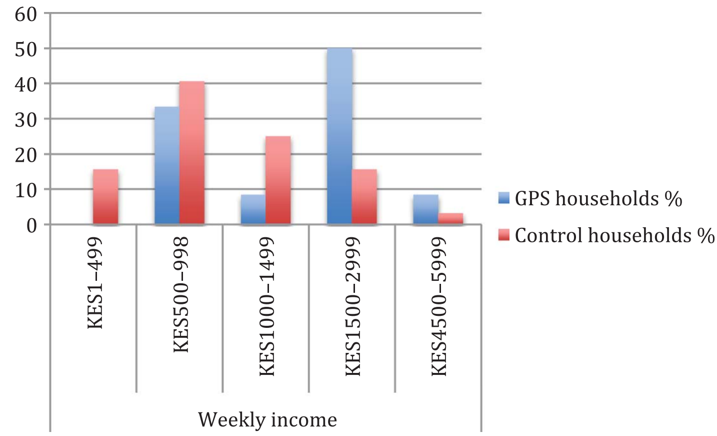

Figure 5. Nyalenda: distribution of GPS and control households by income.

Tin roofs

The first difficulty encountered was excessively noisy data measured by the GPS units. One expects data-points with an error of less than 10 m. On looking at the tracks from the first couple of days of captured data, what appeared to be a random cloud of points extending for more than 100 m were discovered. Figure 6 compares one of these data tracks to the type of track that was expected. It was hypothesized that the noise was caused by the jerry can that the GPS unit was attached to being stored indoors under a tin roof for most of the time it was not actively being carried to collect water. To reduce the amount of noise, the women collecting water were asked to turn the units on when they left home, and off when they returned. This substantially reduced the number of outlier data points and made the data usable. Nevertheless, a substantial number of outlier measurements remain in the data.

Routes that should be excluded

One woman (V.) recorded a route an order of magnitude longer than other families, apparently walking more than a kilometre and taking several hours to collect water. Figure 7 shows her route. The data were very clean, and it was tempting to include it in our average estimates; however, the implausible route aroused suspicion. One of the field assistants

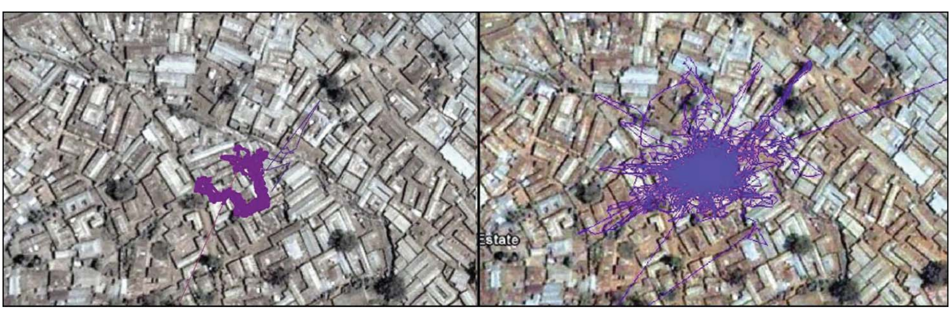

Figure 6. Noisy GPS readings (right). The magnitude of the noise is greater than the intended track recording distance (left).

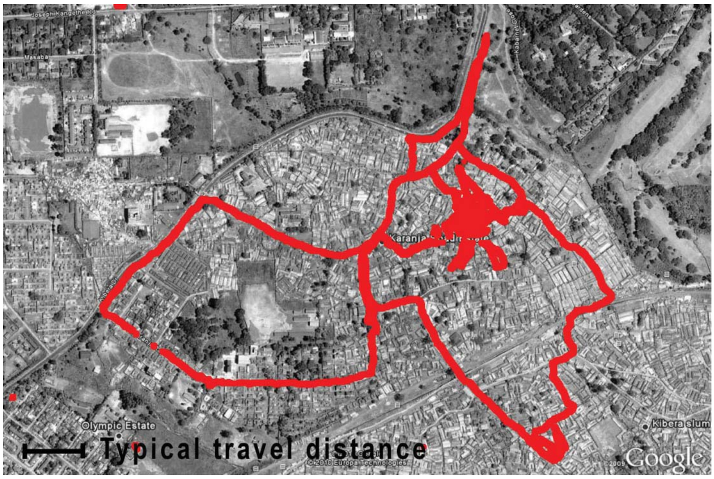

Figure 7. Routes of one study participant taking a jerry can with attached GPS unit on a distant journey (perhaps not just collecting water).

was asked to investigate, and after a couple of attempts to understand, at least two stories emerged. This participant may have been concerned to avoid theft of the GPS unit or may have included trips unconnected with water to accentuate water-collection time (perhaps expecting greater payment). Routes like this were excluded from our analysis.

Results about water

This section discusses two aspects of the data gathered on water collection. First, water-collection times collected through interview data from households with GPS data loggers are compared to interview data from the control households without data loggers. As expected, the GPS households give higher estimates for time collecting water than the more representative control households give. Second, aggregate daily water-collection times estimated by GPS are compared to those estimated by interview. Discrepancies emerge between households' recall of collection times and the estimates made using GPS. However, given the small sample sizes in this study, the discrepancies are not always significant.

Comparing two groups: water-collection times of GPS and control households

In both settlements, the GPS households estimated more time spent collecting water than did the control households (Table 1). This is to be expected because, as noted earlier, the

Table 1. Daily water collection times for GPS and control households.

	Average time spent collecting water (minutes/day)	
Household	Kibera	Nyalenda
GPS households	105 ± 95	45 ± 27
Control households	64 ± 47	28 ± 18

GPS households were selected through the Kenya Water for Health Organization. They were sufficiently concerned about water questions to have contact with KWAHO. This suggests that the GPS data is likely to be an overestimate of average collection times across the entire community.

Comparing two methods: water-collection times estimated by GPS and by interview recall

Most households make multiple trips for water, with more trips being made on days when laundry is to be done. Households that run informal businesses, such as "hotels" (that is, bamboo-and-tin roadside cafes serving breakfast and lunch), require many trips to meet the water needs of the business. We began to understand these many trips as they were mapped with GPS on satellite maps (Figure 8; see also Figure 11) and as we talked about the purpose of the trip and use of the water with individual households.

Table 2 summarizes the average daily time spent collecting water both from household interviews and from GPS tracking. GPS and interview data were not necessarily from the same day. Since the GPS data contain thousands of data-points along hundreds of routes, the reported quantitative data was averaged across all available days of information on a

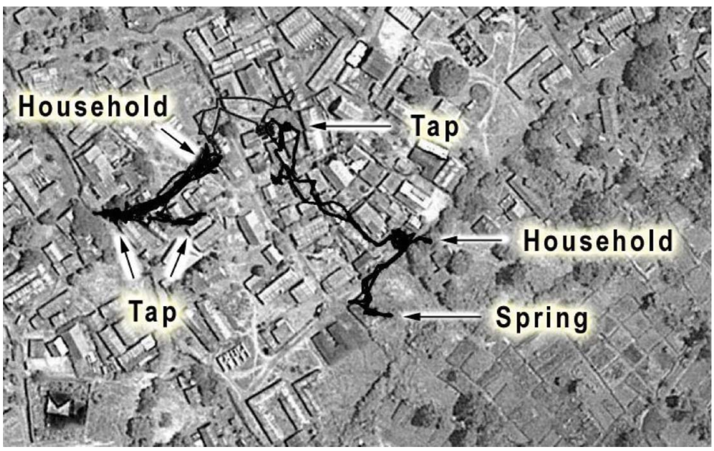

Figure 8. GPS tracks for two households. One household collects water from two different water vendor taps. The other household sometimes collects from a spring.

Table 2. Daily water collection times in Kibera and Nyalenda by interview and by GPS tracking.

	Average time spent collecting water (minutes/day)		
	Interview	GPS	p-value for t-test ($\mu_{reported} = \mu_{GPS}$)
Kibera (2010)	102	46	0.11
Nyalenda (2010)	40	62 (36*)	0.06 (0.05*)
Kibera (2011)	60	35	0.04

*Data with outlier household excluded. This household runs a roadside café, and frequent daily water trips reflect the needs of dishwashing and cooking.

per-household basis. Note that the GPS data is reported on a per-trip basis, rather than as daily totals.

Table 2 suggests a discrepancy between data originating from interviews (households asked to report on water collection of the previous day and the day before that) and from GPS (individual trip times multiplied by the number of trips reported by households). For Kibera, interview recall provides estimates about double those of GPS mapping. For Nyalenda, the difference is in the opposite direction: household estimates are lower than those of GPS tracks. However, the sample sizes are small. Only in the case of Kibera in 2011 are the differences significant at a 5% level.

To investigate further the differences between interview and GPS data, interview data were converted to a per-trip basis by dividing the reported daily totals by the number of reported trips. Figure 9 shows the GPS and interview data for single water-collection trips for all households in Nyalenda and Kibera surveyed in 2010. There is a greater discrepancy for water-collection trips in Kibera than in Nyalenda. It is possible that long-standing perceptions of water problems, particularly for the GPS households (known to be concerned about water), lead households to overestimate the time taken in collecting water. It is also possible that a disaggregation of trips according to the use of water, such as for laundry, cleaning, cooking or business, might shed further light on this difference. Such disaggregation cannot yet be accomplished for more than a few households.

GPS data also provided us with estimated distances of travel. This information was requested in interviews as well, but research assistants reported that women were reluctant to even guess, having no idea of the distances travelled. Figure 10 shows distance versus time for all round-trip routes for which data were collected. It has not been aggregated per household, and thus there are many more data-points available. Data analysis showed that many households used the same one or two water points repeatedly, so many data-points share a common route distance, but of course the time required for collection might vary from trip to trip. As with collection time, the majority of trips in Nyalenda are of

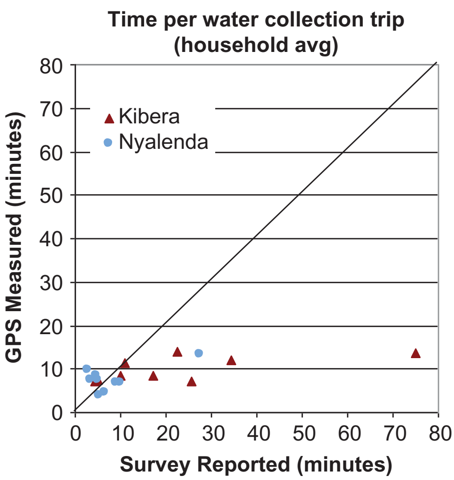

Figure 9. Discrepancy between interview and GPS estimates of collection times. Participant recall of water collection times, during interviews, suggested longer trips, particularly in the case of Kibera, than were recorded by the GPS unit.

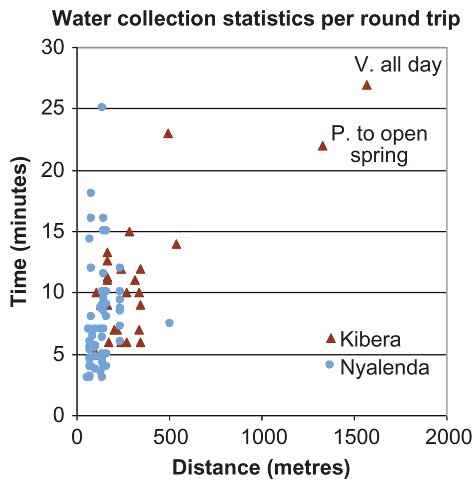

Figure 10. Time and distance per trip. The distance estimates would have been difficult to obtain without GPS.

slightly shorter distance than trips in Kibera. Also, most trips in both communities are less than 10 minutes and cover a distance of less than 400 meters. While this is not nearly as convenient as an in-home tap, it is substantially different from walking for hours per day over many kilometres to collect water, as may happen in rural areas.

Two data-points in Kibera appeared to be outliers from the rest of the data, prompting more careful investigation. The data were deemed to be true outliers. The case of V. was described earlier and is shown in Figure 7. The case of P. is discussed below under Qualitative Findings.

Discussion

Two different methods were employed to measure time spent collecting water. Following the conventions of many social sciences, people were interviewed. Following the convention of engineers, technology was used to measure the time and the route taken. It was assumed that interviews would be better for capturing a qualitative understanding of people's behaviour but would be of low reliability with regard to numerical data. It was also assumed that technological measurements would be great for obtaining vast quantities of precise quantitative data, but would not lead to any new qualitative understanding of behaviour. These assumptions turned out to be wrong. The GPS data would have been nearly useless without the understanding that came from interviewing people. Similarly, the interviews missed important qualitative insights that were revealed only through the quantitative data.

One trip per day

We had hoped to use GPS to measure average time spent collecting water per day. In Kibera, for most households our data provide precise time and distance for one or two trips per day, but do not reliably indicate the number of trips taken. Had we not had interview data indicating the number of trips taken per day to correlate with our technological measurements, we would not have been able to estimate total water-collection times.

Numerical data are subjective

We intended to use GPS with a large number of households, reasoning that it would be easier and faster to aggregate the objective numerical data coming from the GPS units than it was to understand and process the more subjective interview and survey data. This turned out to be more difficult than anticipated. The outliers and noise in the raw measurements could certainly have been dealt with automatically; filtering noise in time-series data is a staple of engineering work. However, the behaviour of the users was not sufficiently consistent to automate the process of interpreting and aggregating the data. Some people used the instrumented jerry can for all their trips, and some used it for only one trip per day. We also observed that in some cases the GPS did not track or was not turned on until halfway to a water point. Some users walked 5 minutes to a water point, stayed there for 2 hours, and then walked 5 minutes home. Should that be counted as 10 minutes to collect water, or 2 hours? From the 2011 data, we have been able to estimate waiting times (Table 3). In general, however, both GPS tracks and interviews or logs are required to attribute meaning to household activity.

Interpreting the data from our 2010 survey required all authors to sit together for long hours and make educated guesses about probable water routes. Plausible tracks were

Table 3. Water collection and wait times from GPS tracks in Kibera, 2011.

	Average collection time (minutes)	
	Individual trip	Daily aggregate
Travel time	6.5	21.5
Wait time	4.2	13.8
Total time	10.6	35.1

separated from noise by speed. (Noise tracks often shift rapidly, far faster than walking speed.) Plausible water-collection routes also follow tracks and alleys between buildings shown on satellite imagery. And it is often possible to identify water tanks in the satellite photos. Even this would have been difficult if one of the authors had not previously walked the physical route with the women as they performed their routine. As such, the precise numerical data are indeed precise, but they are also a function of a lot of qualitative estimation.

In 2011, we asked households to keep logs of their water trips and tasked our research assistant with comparing logs and GPS tracks when downloading data (once a week). Some households kept logs enthusiastically; others were less diligent or too busy. The lower level of research support in 2011 (household training, number of research assistants, checking) led to a gradual decline in the frequency and quality of reporting.

Qualitative findings

We did not initially anticipate that the GPS data would provide new qualitative understanding of water-collection practices. Nevertheless, we discovered, for example, one long GPS trace travelling some distance out of the community. Figure 11 shows the tracks of a woman vegetable seller in Kibera (see also the data-point labelled "P. to open spring" in

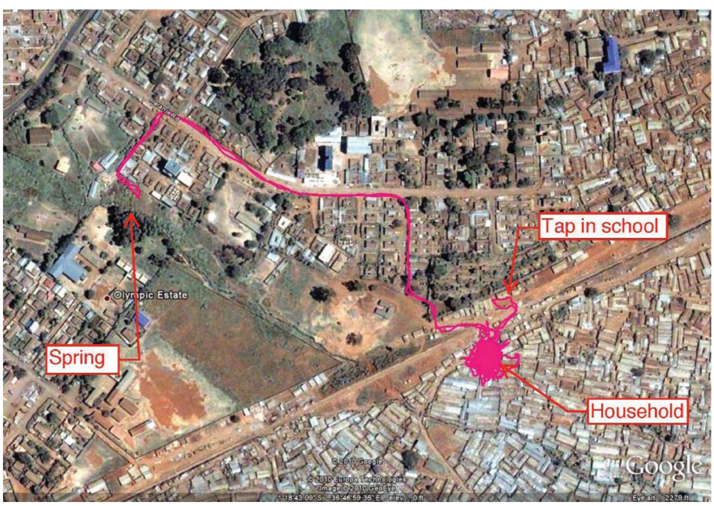

Figure 11. Map of unexpected water activity – in this case a woman selling vegetables and collecting free (but probably contaminated) water from a spring in Kibera.

Figure 10). We were surprised by the repeated long tracks shown for this household. It was only when one of the authors walked with her that we understood that she was collecting water from an open spring feeding the Kibera River. She collects water from a school not far away, but that school does not allow consumers to fill more than two jerry cans in a day, and it charges for the water. So, to get the more than two jerry cans of water needed for washing vegetables, and to reduce the cost of water, this woman travels some 1500 m to obtain water from an open spring. Unfortunately, the area surrounding the spring is used as an area for open defecation, so the water is probably contaminated, and provides a clear public health hazard for water-borne infection. Workers for KWAHO were unaware of the use of this open spring for household and business water. In 2012, we learned that this particular vegetable seller had returned to her rural village. Others selling vegetables in this Kibera village do not appear to use this water source.

Conclusion

We set out to obtain quantitative data for water-collection times of women in two informal communities in Kenya, Nyalenda and Kibera. Water-collection work constrains women's livelihoods, education and leisure. Less time spent collecting water could allow an increase in preferred activities.

The data were taken using both interviews and GPS tracking. We believe that this paper is the first to report the use of GPS for this purpose.[1] The introduction of GPS tracking allowed us to obtain distances travelled, to map the routes used by households, and to work out the distances and (not reported here) temporal patterns of collection. This is information not normally available from interviews. Importantly, the time and distance data gathered provide some support for the hypothesis that the new water delivery system in Nyalenda is advantageous not only to the water company but also to women living in the community. The utility loses less water to illicit withdrawals and leaks, and its bills appear to be paid. Households have water sources that are believed safe. They continue to use open water sources, wells and springs, for laundry and house cleaning.

Both GPS and interview data suggest that water-collection times in Nyalenda are slightly less than in Kibera. This may reflect the introduction of the delegated water management in Nyalenda. We do not, however, have data from before the introduction of the new system, and there are significant differences between the two communities. We do not, therefore, consider this conclusive evidence that the delegated management system of water distribution reduces the time spent collecting water.

The GPS data indicated that water-collection times and distances differed from interview data, particularly in Kibera. It is possible that when asked to recall, women overestimate water-collection time. The difficulty and labour of water collection, carrying 44-pound (20 kg) jerry cans, may contribute to the perception of long duration. We are attempting to explore this question further. If this reporting difference arises in other communities, then care should be taken when interpreting quantitative estimates of water-collection time derived from personal recall. In the two communities reported here, the more precise GPS data indicates many short trips of less than 10 minutes (Table 4). Further reductions in water-collection time are thus not a matter of getting a single water point into the community, but would probably require household connections.

We had originally expected that technological measurement would provide accurate quantitative data, and interviews would provide qualitative understanding. In practice, we found the methods to be complementary, with technology providing access to qualitative insights, and interviews being necessary to aggregate the quantitative information. We were

Table 4. Average times of water collection trips from GPS tracks.

Average time of a single water collection trip (minutes)	
	Minutes/trip
Kibera (2010)	9.9
Nyalenda (2010)	7.7
Kibera (2011)	10.6

not surprised that the methods of different fields have their own disparate strengths, but their strengths are far more coupled than we expected.

GPS tracking of water collection provides a richer set of data than can be easily obtained from interviews. The paths taken to water, the range of water sources used, the frequency of water collection and the times of day of collection are more easily documented with GPS tracking than with interviews. But we have not yet been able to decouple GPS tracking from interviews. GPS data logging does not provide information about the purpose of the trip; it could, for example, be a shopping or work trip combined with water collection. GPS data also do not record the price paid for water, and the quantity of water carried.This information requires either household interviewing or logs carefully maintained by the household. Taking this technique to a larger scale, say 100 households rather than 10, under present conditions would require the continued involvement of researchers to combine GPS tracks with interview data, illuminating the purpose, meanings and character of those trips.

Acknowledgements

We are indebted to the women in many households in Kibera and Nyalenda for giving their time and attention to this research. For research assistance, the authors wish to thank George Rachuonyo, Phelistus Waithera, Martin Koinange, Samson Wambisa, Beatrice Dina Panyado and Paul Ochieng. Additional advice came from Elizabeth Were, Leah Onyango, William Mboya, Shagun Mehrotra and Edmond Odaba. Alyssa Trakes carried out invaluable data cleaning and manipulation. The research was funded by a Special Research Grant and subsequent small grants from the UCSC Committee on Research.

A first draft of this paper was presented at the Information and Communication Technology for Development conference *ICTD2012*, July 2012, in Atlanta, Georgia, USA. This draft has been substantially rewritten in the light of a referee's insightful comments, new data and new field work.

Note

1. (The 2012 paper of Chaudri et al. came to our attention as we were completing this paper. It is a fascinating pilot study using lowpower sensors and smart phones to measure time taken collecting water in rural areas of Ethiopia. Few data have yet been reported from this use of sensors. Like GPS, the data from these sensors need household interviews to make sense. Unlike GPS, the sensors do not provide maps of water tracks.

References

Ahlers, R., Schwartz, K., & Perez Guida, V. (2012). The myth of 'healthy' competition in the water sector: The case of small-scale water providers. *Habitat International*, published online 25 August. doi:10.1016/j.habitatint.2012.06.004

Anderson, R. E., Poon, A., Lustig, C., Brunette, W., Borriello, G., & Kolko, B. E. (2009). Building a transportation information system using only GPS and basic SMS infrastructure.

Proceedings of the 3rd international conference on information and communication technologies and development (ICTD), 233–242. doi: 10.1109/ICTD.2009.5426678
Biro, D., Guilford, T., Dell'Omo, G., & Lipp, H. P. (2002). How the viewing of familiar landscapes prior to release allows pigeons to home faster: evidence from GPS tracking. *Journal of Experimental Biology, 205*, 3833–3844.
Blackden, C. M., & Wodon, Q. (Eds.). (2006). *Gender, time use, and poverty in Sub-Saharan Africa* (Working Paper 73). Washington, DC: World Bank.
Briscoe, J. (1993). When the cup is half full: Improving water and sanitation services in the developing world. *Environment*, *35*(4), 6–37.
Brocklehurst, C., Mehrotra, S., & Morel, A. (2005). *Rogues no more? Water kiosk operators achieve credibility in Kibera* (Field Note). Nairobi: Water and Sanitation Program – Africa.
Buor, D. (2003). Water needs and women's health in the Kumasi Metropolitan Area, Ghana. *Health and Place*, *10*, 85–103.
Cairncross, S., Bartram, J., Cumming, O., & Brocklehurst, C. (2010). Hygiene, sanitation, and water: What needs to be done? *PLoS Medicine*, *7*(11), e1000365.
Cairncross, S., & Cliff, J. L. (1987). Water use and health in Mueda, Mozambique. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *81*(1), 51–54.
Castro, V. (2009). *Improving water utility services through delegated management: Lessons from the utility and small-scale providers in Kisumu, Kenya*. Nairobi: Water and Sanitation Program - Africa.
Chaudhri, R., Sodt, R., Leiberg, K., Chilton, J., Borriello, G., Masuda, Y., & Cook, J. (2012). Low-power sensors and smartphones for tracking water collection in rural Ethiopia. *IEEE Pervasive Computing, 11*(3). Retrieved from http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6171153
Crow, B., & McPike, J. (2009). How the drudgery of getting water shapes women's lives in low income communities. *Gender Technology and Development*, *13*, 43–68. doi: 10.1177/097185240901300103.
Crow, B., & Odaba, E. (2010). Access to water in a Nairobi slum: Women's work and institutional learning. *Water International*, *35*, 733–747.
Crow, B., Swallow, B., & Asamba, I. (2012). Community organized household water increases rural incomes, but also men's work. *World Development, 40*, 528–541.
Davies, J., Crow, B., & Miles, J. (2012). Measuring water collection times in Kenyan informal settlements. In *ICTD '12 Proceedings of the Fifth International Conference on Information and Communication Technologies and Development* (114–121). New York NY: ACM, doi:10.1145/2160673.2160689.
Devoto, F., Duflo, E., Dupas, P., Pariente, W., & Pons, V. (2011). *Happiness on tap: Piped water adoption in urban Morocco* (Working Paper 11-05). Retrieved from http://www.nber.org/papers/w16933
Gandy, M. (2004a). Rethinking urban metabolism: water, space and the modern city. *City*, *8*, 363–379.
Gandy, M. (2004b). Water, modernity and emancipatory urbanism In L. Lees (Ed.), *The emancipatory city? Paradoxes and possibilities*. London: Sage.
Gulyani, S., Talukdar, D., & Kariuki, R. M. (2005). Universal (non)service? Water markets, household demand and the poor in urban Kenya. *Urban Studies*, *42*, 1247–1274.
Gutierrez, E. (2007). Delivering pro-poor water and sanitation services: The technical and political challenges in Malawi and Zambia. *Geoforum*, *38*, 886–900.
Heynen, N., Kaika, M., & Swyngedouw, E. (Eds.). (2006). *In the nature of cities: Urban political ecology and the politics of urban metabolism*. Abingdon, UK: Routledge.
Ilahi, N. (2000). *The intra-household allocation of time and tasks: What have we learnt from the empirical literature?* Washington, DC: World Bank.
Katui Katua, M. K. (2010). *Final report: Evaluation of delegated management model implemented in Kisumu Water and Sewerage Company (KIWASCO), Nyalenda, Kisumu, Kenya*. Water and Sanitation Program of the World Bank.
Klintenberg, P., & Verlinden, A. (2007). Water points and their influence on grazing resources in central northern Namibia. *Land Degradation & Development*, *19*, 1–20.
Kremer, M., Miguel, E., Mullainathan, S., Null, C., & Zwane, A. P. (2008). *Social engineering: Evidence from a suite of take-up experiments in Kenya*. Retrieved from http://www.economics.harvard.edu/files/faculty/36_WG_2011_CLEAN_04_14_MKWITHOUT%20COMMENTS.pdf

Page, B. (2005). Naked power: Women and the social production of water in anglophone Cameroon. In A. Coles & T. Wallace (Eds.), *Gender, Water and Development*, 57–73. Oxford: Berg.
Rosen, S., & Vincent, J. R. (1999). *Household water resources and rural productivity in Sub-Saharan Africa: A review of the evidence*. Cambridge, MA: Harvard Institute for International Development.
Samuels, M. I., Allsopp N., & Knight, R. S. (2007). Patterns of resource use by livestock during and after drought on the commons of Namaqualand, South Africa. *Journal of Arid Environments*, *70*, 728–739.
Sharma, K. (1999). *Waiting for water: The experiences of poor communities in Bombay*. Mumbai: Society for the Promotion of Area Resource Centres (SPARC). Retrieved from http://www.ucl.ac.uk/dpu-projects
Shoval, N., & Isaacson, M. (2006). Application of tracking technologies to the study of pedestrian spatial behavior. *Professional Geographer*, *58*(2), 172–183.
Smith, W. J. (2008). The place of rural, remote and least-wealthy small islands in international water development. *Geographical Journal*, *174*(3), 251–268.
Thompson, J., Porras, I. T., Tumwine, J. K., Mujwahuzi, M. R., Katui-Katua, M., Johnstone, N., & Wood, L. (2001). *Drawers of water II: 30 years of change in domestic water use & environmental health in East Africa*. London: Institute for Environment and Development.
von Dach, S. W. (2007). *Water sector reform in Kenya: First experiences are positive. Interview with engineer Mahboub Maalim, permanent secretary of the Kenyan Ministry of Water and Irrigation*. Berne: InfoResources. Retrieved from http://www.inforesources.ch/pdf/maalim_interview.pdf
Weimerskirch, H., Bonadonna, F., Bailleul, F., Mabille, G., Dell'Omo, G., & Lipp, H. P. (2002). GPS tracking of foraging albatrosses. *Science*, *295*(5558), 1259.