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Socio-economic aspects of domestic groundwater consumption, vending and use in Kisumu, Kenya

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A B S T R A C T

Shallow hand-dug wells are commonly used to supplement partial or intermittent piped water coverage in many urban informal settlements in sub-Saharan Africa. Such wells are often microbially contaminated. This study aimed to quantify the amount of such groundwater consumed, identify the socio-economic profile of well owners and consumers, and patterns of domestic water usage in informal settlements in Kisumu, Kenya. Building on a previous study, 51 well owners and 137 well customers were interviewed about well water abstraction, water usage and handling patterns, asset ownership, and service access. An estimated 472 m^3 of groundwater per day was abstracted in two informal settlements, with most groundwater consumers using this water for purposes other than drinking or cooking. According to an asset index, well owners were significantly wealthier than both the customers purchasing their groundwater and those drinking or cooking with untreated groundwater. This suggests that shallow groundwater sources provide poorer urban households with a substantial volume of water for domestic purposes other than drinking and cooking. Ongoing challenges are thus to raise awareness of the health risks of such water among the minority of consumers who consume untreated groundwater and find means of working with well owners to manage well water quality.

Introduction

Between 2012 and 2050, the urban population of Sub-Saharan Africa (SSA) will increase from about 40% to nearly 60% and is projected to exceed 1.26 billion (United Nations, 2012). Rapid population growth in SSA is predicted for smaller towns with populations under 200,000, as well as large cities. More than 60% of SSA's urban population live in informal settlements and slums (UN-Habitat, 2010). Safe drinking-water from centralised distribution systems rarely meets demand in these settlements. Residents are forced to 'self-supply' from wells, surface waters, vendors, and illegal connections to the mains distribution system (Grönwall, Mulenga, & McGranahan, 2010). For many slum residents, groundwater is a vital domestic water source because of its affordability and availability, but rapid population growth, unplanned land development and climate change are putting it under increasing strain. Urban groundwater quality may be poor due to contamination from adjacent pit latrines, surface waste, and other hazards. Use of such poor quality groundwater could contribute to diarrhoeal disease and infant mortality (Bartram & Cairncross, 2010). The magnitude and locations of those affected remain unclear, but an estimated 41.4 million people in urban SSA use non-piped 'improved' sources, a source class that includes protected wells and boreholes (WHO-UNICEF., 2014). Safe water provision to the urban poor remains an international priority, given the emphasis on reducing inequality in safe water access in post-2015 monitoring (WHO-UNICEF., 2013), and a national goal in strategic plans across SSA.

Abbreviations: DHS, Demographic and Health Survey; GPS, Global Positioning System; NGO, Non-Governmental Organisation; PCA, Principal Components Analysis; SSA, Sub-Saharan Africa.

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Alongside formal water services installed and initiated by government, international donors and in some instances non-governmental organisations (NGOs), the water sources developed by households themselves may also play an important role in securing domestic water access. Such so-called ‘self supply’ water service solutions (Butterworth, Sutton, & Mekonta, 2013) include rainwater collection, shallow hand-dug wells (MacCarthy, Annis, & Mihelcic, 2013), home water treatment in some instances, and various community-led solutions to cope with the partial and often interrupted coverage of piped supplies. However, although the quantities of water vended through some of these systems has been documented (Sima, Kelner-Levine, Eckelman, McCarty, & Elimelech, 2013), the specific contribution of hand-dug wells to urban water supply remains unclear.

There is increasing recognition that households use a variety of water sources for a range of different purposes, a perspective embodied in the multiple use water services approach to water provision (Van Koppen, Moriarty, & Boelee, 2006). To date, this concept has largely been applied in rural areas (Katsi, Siwadi, Guzha, Makoni, & Smits, 2007), although urban residents may also use water from multiple sources for multiple purposes. Many household surveys and censuses continue to focus on the main water source, and thereby may miss the complexities of multiple source use, including population exposure to contaminants from subsidiary water sources and the economic contribution of such sources.

There are some interventions that specifically target hand-dug wells and springs, most notably spring and well upgrading programmes (Kremer, Leino, Miguel, & Zwane, 2011; Philip & Stevens, 2013). Given the growing policy emphasis on reducing inequalities relating to water and sanitation, an important question is the extent to which such interventions can be considered pro-poor and how the incidence of benefits from well upgrading might vary across different socio-economic groups. With urban hand-dug well upgrading, the analysis of benefits is often complicated by the presence of a supply chain (Ayalew et al., 2014), through which well owners may supply vendors who in turn sell groundwater on to consumers lacking reliable piped water connections.

This paper seeks to quantify the contribution of one particular self-supply solution, namely shallow hand-dug wells, within an urban Kenyan setting. The study examines the contribution of shallow hand-dug wells to the city's domestic water supply, alongside other types of water source. In particular, the study aims to quantify the contribution of groundwater from hand-dug wells to water supply in two neighbourhoods and quantify patterns of groundwater vending. It also aims to assess how urban water consumers use the generally cheaper and lower quality groundwater alongside more expensive, higher quality piped water and rainwater. Finally, it examines the socio-economic profile of those consuming vended groundwater, relative to hand-dug well owners and assesses whether contamination risks are greater for poorer owners' wells.

Material and methods

Study area

Kisumu is Kenya's third largest city, with an estimated population in its urban core of 259,258 at the time of the 2009 census (Kenya Open Data Project, 2014). Within the city, there are eight informal settlement areas that generally lack access to sewered sanitation and reliable piped water, which surround higher income, more centrally located neighbourhoods such as Milimani (UN-Habitat., 2005). These informal settlements are Bandani, Kaloleni, Manyatta A,Manyatta B, Nyalenda A, Nyalenda B, Nyamasaria and Obunga. In informal settlements, rainwater and groundwater are used to supplement piped water. Alongside these informal settlements, there are other settlements (e.g. Migosi) that were originally formally planned but which have subsequently been subject to unplanned infill development. In the informal settlements, pit latrines are the dominant form of sanitation. Groundwater is obtained either through shallow hand-dug wells, which are typically privately owned, or through springs, which are communal. The groundwater abstracted from wells is sometimes sold on to others, though the extent of groundwater vending is unclear. However, springs and wells are both known to be microbially contaminated, with *E. coli* densities often over 1000 cfu/100 ml (Opisa, Odiere, Karanja, & Mwinzi, 2012). Whilst the domestic tariff for a piped utility connection is the cheapest source of water at US\$0.49/m^3, for those without such connections, well water is cheaper than all other alternatives. Well water has a median price of \$1.15/m^3, standpipe water \$2.23 m^3, whilst piped water vended from handcarts costs \$6.72 m^3 (Ayalew et al., 2010).

The study areas were Manyatta A and Migosi, the focus of an earlier study (Wright et al., 2012) but extended to Obunga, Nyalenda A and B, and Bandani where groundwater use is also common (Fig. 1). According to the 2009 census (Kenya Open Data Project, 2014), population density in Manyatta A and Migosi was 203 and 103 people per Ha respectively. Thirty nine percent of households in Manyatta A and 24% in Migosi used groundwater as their main domestic water source, with 31% and 23% respectively using piped water sources. 29% of households in Manyatta A and 50% in Migosi purchased water from vendors. The proportion of vended water originating from piped supplies versus groundwater is unclear. Ninety one percent of households in Manyatta A and 38% in Migosi used pit latrines. Mains sewerage was common in Migosi (32%) but rare in Manyatta A (5%) and in both areas, maintenance issues lead to frequent episodes of sewage overflowing into open storm drainages and low lying areas. A further 4% in Migosi and 29% in Manyatta were using septic tanks as a main means of sanitation. For all sanitation facilities, construction quality can impact on well water quality and consequently human health.

Both settlements have fractured basalt geology, overlaid with pyroclastic deposits that become deeper to the east. The old weathered surfaces between successive lava flows and older formations hold groundwater and perched aquifers are common, with their recharge often localised. Interconnected fractures are often intersected by pit latrines, soak pits, and sometimes cracked septic tanks and so act as pathways not only for groundwater movement and recharge, but also fecal contamination. Most groundwater is extracted from perched aquifers via hand-dug wells, with a mean depth of approximately 6 m and diameters of 1–1.5 m (Okotto-Okotto, 1999). The shallow depth and presence of both fractures and onsite sanitation mean that the hand-dug wells draw on a highly vulnerable aquifer system. Although several donor-funded boreholes have previously been drilled into the deeper second aquifer and been found to be free from microbial contamination (Wright et al., 2012), these boreholes were no longer functioning by 2014.

Preliminary analysis

To enable assessment of socio-economic status in a manner that would facilitate comparison with a nationally representative population, we examined household asset ownership in the 2008–9 Demographic and Health Survey (DHS). Since urban and rural households sometimes have very different sets of assets, making use of a single asset index for both types of household problematic (Menon, Ruel, & Morris, 2000), we examined asset ownership among the 2910 urban DHS households only. We undertook a Principal Components Analysis (PCA) of 17 assets and services

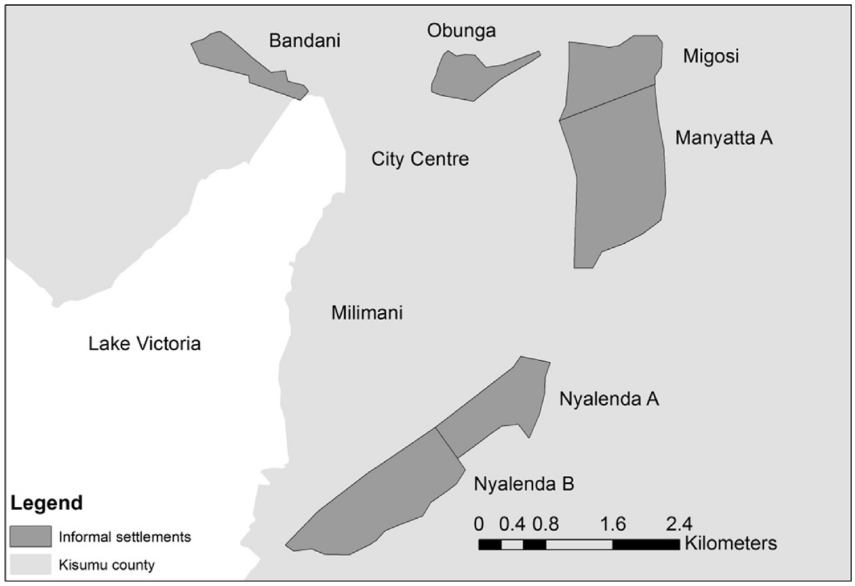

Fig. 1. Informal settlements in Kisumu selected for well owner and well water consumer survey.

(ownership or access to a flush toilet; electricity; TV; fridge; radio; bicycle, motorbike; car or truck; landline phone; cell phone; watch; agricultural land; a separate kitchen for cooking; livestock; use of charcoal for cooking; use of coal, gas or electricity for cooking; and house walls of finished materials such as brick or cement). After examining factor loadings onto the first component, we dropped radio, bicycle, motorbike, cell phone, agricultural land, and livestock from these assets, since these had weak loadings, and undertook a second PCA. The PCA scores derived from this restricted set of assets remained strongly correlated with pre-calculated asset index scores provided with the DHS ($r = 0.83$; $p < 0.001$). We subsequently asked about ownership of this restricted set of assets and services in our fieldwork, drawing on the same question and response wording as those used in the DHS. We then used the PCA factor loadings derived from the national DHS sample of households to create an asset index for households in our study, drawing on an identical set of questions. In this way, we were able to relate asset index values for households in our survey and position these households in terms of socio-economic status relative to a nationally representative Kenyan urban population.

Survey of wells, well owners and groundwater consumers

Ethical approval for the human subjects part of the study was obtained from the Faculty of Social and Human Sciences, University of Southampton (reference: 8350) and the University of Surrey (EC/2014/19/FEPS). Fieldwork drew on a previous study of groundwater sources in the Manyatta A and Migosi informal settlements, which took place between 2002 and 2004 (see Wright et al., 2012). As part of this earlier study, the location of all 438 wells in both neighbourhoods was initially mapped from aerial photography and GPS-based ground survey in 1999. In this earlier study, a sample of 46 wells was selected from this full inventory of wells in Manyatta A and Migosi, so as to be representatively distributed across the two neighbourhoods. Well water from these 46 wells was tested for contamination on at least two occasions. In March–April 2014, these 46 wells were revisited and well owners interviewed where available. The sample from this earlier study was further extended to include 21 further wells from four other informal settlements, namely Obunga, Nyalanda A and B, and Bandani. Households in these additional settlements were recruited by generating random locations within each settlement's perimeter and selecting the well closest to these locations.

Questionnaires were initially piloted in a neighbouring area to the study sites. After piloting and then seeking informed consent from participants, questionnaire-based interviews with well owners and their customers were conducted by locally recruited enumerators under the supervision of a researcher (LG). Well owners were asked for the total amount of water abstracted from their well on the previous day (including water abstracted for selling and for personal use). Answers were given in 20 L jerry cans which is the most familiar water unit for the local population. Well owners were also asked about the subsequent use, handling and treatment of well water and water from other sources, drawing on the wording of existing questions and closed-ended responses (e.g. from the DHS) wherever possible. Each owner was asked to describe their reasons for using a given water source for a particular purpose and all the reasons mentioned were recorded, but not ranked. Well owners were also asked about access to the restricted set of services and ownership of durable goods from the earlier PCA analysis of the DHS, using identical question and answer wording as the DHS questionnaire. At each well, owners were asked whether they sold groundwater, and groundwater customers were then identified. Customers were identified either as they approached the well to purchase groundwater at the time of interview, or else were identified by the well owner. Groundwater customers were then asked the same questions about water use and ownership of assets and services as well owners.

A sanitary risk assessment was conducted at each well. These assessments consist of a standard observation checklist to identify potential pathways of water contamination at the well itself (e.g. lack of well lining; a missing, insufficiently wide, or cracked concrete wellhead cover) and in the immediately surrounding area (e.g. presence of pit latrines or uncollected waste). Following our earlier study (Wright et al., 2012), a standard World Health Organization inspection protocol was used (WHO, 1997).

Transect survey

To rapidly update the 1999 map of wells and enable subsequent estimation of total domestic groundwater abstraction, a transect survey was carried out in August 2014, with a belt of 0.1 by 1.7 km being used in Migosi and a 0.1 by 2.4 km belt in Manyatta. The start and end points of each transect were randomly generated. Within each transect belt, the locations of shallow wells were identified and any changes noted in comparison to the 1999 1:2500 basemap. This transect enabled us to update the 1999 estimate of the total number of wells in the study area.

Analysis of survey data

To estimate the amount of water consumed by well owners and sold on to customers, we calculated the mean quantity of water abstracted for household use and sold per day in the Manyatta A and Migosi neighbourhoods where we had additional data on the total number of wells. Average amounts abstracted for the two neighbourhoods were then multiplied by the number of wells in the two neighbourhoods to estimate the total volume abstracted. To account for the difference in well distribution between the creation of the well distribution map (1999) and the situation in 2014, the results were scaled on the basis of the 2014 transect survey.

We applied the factor loadings from our preliminary DHS analysis to the well owners, their customers, and owners or customers drinking or cooking with untreated well water in our own field survey. In this way, we generated an asset index that could be compared to a nationally representative population. The non-parametric Mann–Whitney test was used to compare socio-economic status between well owners and well customers using SPSS (IBM, version 21). We also compared matched asset scores for well owners and consumers using the same wells, calculating the correlation coefficient between the paired owner and consumer scores. Finally, based on the sanitary risk inspection, we calculated the proportion of observable contamination risks that were present at each well (e.g. cracked concrete well covers) and therefore potentially controllable by the owner. We separately calculated the percentage of such risks in the immediately surrounding area (e.g. presence of pit latrines) that could only be controlled through community action or planning controls. We used Spearman's correlation coefficient to compare the proportion of both types of risk present at each well to the asset score for the well's owner.

Results

Well owner and customer survey

Of the 46 Manyatta A and Migosi wells from the earlier study, 7were lost to follow-up. 4 wells had been built over, 2 had been abandoned (for example due to influx of sewage), and 1 was inaccessible within a private compound. A total of 51 well owners were interviewed from all informal settlements. The 9 owners not interviewed were not at home during the survey period and therefore could not be included. Of these well owners, 20 sold their well water to others (Table 1). 137 consumers of this vended well water were interviewed during the survey.

Table 1 shows the characteristics of well owners and customer water handling and usage practices, in addition to other household characteristics. Well water was most commonly used for washing clothes and cleaning. Drinking well water was less common, though well owners more often drank the water from their well (17.6%) than customers (11.7%). For the customers and owners that responded to the water storage question, a covered small container (for example a 20 l jerry can or smaller) was commonly used and 5.9% used a covered large container. Storing water in uncovered containers was less common, with 13.8% responding that they stored water in a small uncovered container (e.g. bucket) and 0.5% responding that they stored water in a large uncovered container.

Table 1
Water handling and use, service access and asset ownership for well owners and groundwater customers in six informal settlements in Kisumu (Bandani, Manyatta A, Migosi, Nyalenda A, Nyalenda B and Obunga).

Household characteristic	Owners	Customers	Total
Number of responses	51	137	188
Number of owners selling water			
Selling	20 (39.2%)		
Not selling	30 (58.8%)		
No response	1 (2.0%)		
Well water use			
Drinking	9 (17.6%)	16 (11.7%)	25 (13.3%)
Cooking	14 (27.5%)	35 (25.5%)	49 (26.1%)
Personal hygiene	26 (51.0%)	103 (75.2%)	129 (68.6%)
Washing clothes/cleaning	29 (56.9%)	105 (76.6%)	134 (71.3%)
Flushing toilet	24 (47.1%)	64 (46.7%)	88 (46.8%)
Well water treatment (for those drinking well water regularly)			
Boil	0 (0.0%)	1 (6.3%)	1 (4.0%)
Additive (e.g. chlorine, Waterguard)	4 (44.4%)	6 (37.5%)	10 (40.0%)
Water filter	0 (0.0%)	0 (0.0%)	0 (0.0%)
Solar disinfection	1 (11.1%)	0 (0.0%)	1 (4.0%)
No water treatment	3 (33.3%)	8 (50.0%)	11 (44.0%)
Other/don't know	1 (11.1%)	1 (6.3%)	2 (8.0%)
Household water storage			
Uncovered small container (e.g. bucket)	7 (13.7%)	19 (13.9%)	26 (13.8%)
Uncovered large container	1 (2.0%)	0 (0.0%)	1 (0.5%)
Covered small container (e.g. jerry can)	23 (45.1%)	56 (40.9%)	79 (42.0%)
Covered large container	4 (7.8%)	7 (5.1%)	11 (5.9%)
Don't store/No response/ Don't know	16 (31.4%)	55 (40.1%)	71 (51.8%)
Sanitation access			
Pit latrine	34 (66.7%)	109 (79.6%)	143 (76.1%)
Flush/pour toilet	13 (25.5%)	26 (19.0%)	39 (20.7%)
Composting	1 (2.0%)	1 (0.7%)	2 (1.1%)
Other	1 (2.0%)	0 (0.0%)	1 (0.5%)
No response	2 (3.9%)	1 (0.7%)	3 (1.6%)
Main cooking fuel			
Electricity	0 (0.0%)	1 (0.7%)	1 (0.5%)
LPG/natural gas	7 (13.7%)	24 (17.5%)	31 (16.5%)
Kerosene	5 (9.8%)	25 (18.2%)	30 (16.0%)
Charcoal	33 (64.7%)	78 (56.9%)	111 (59.0%)
Wood	3 (5.9%)	8 (5.8%)	11 (5.9%)
No answer/don't know	3 (5.9%)	1 (0.7%)	4 (2.1%)
Main housing wall material			
Brick	12 (23.5%)	9 (6.6%)	21 (11.2%)
Cement or cement block	16 (31.4%)	53 (38.7%)	69 (36.7%)
Stone with mud or lime/cement	7 (13.7%)	40 (29.2%)	47 (25.0%)
Dirt/mud	8 (15.7%)	16 (11.7%)	24 (12.8%)
Other/no response	8 (15.7%)	19 (13.9%)	27 (14.4%)
Owns a car/truck			
Yes	11 (21.6%)	25 (18.2%)	36 (19.1%)
No	33 (64.7%)	101 (73.7%)	134 (71.3%)
No answer	7 (13.7%)	11 (8.0%)	18 (9.6%)
Owns a television			
Yes	39 (76.5%)	84 (61.3%)	123 (65.4%)
No	12 (23.5%)	53 (38.7%)	65 (34.6%)

Transect survey

Table 2 shows the results of the transect survey of wells in Migosi and Manyatta A. Overall, although 15% of the wells present in 1999 had disappeared, a much larger number of new wells had been constructed in both settlements. As a result, the total number of wells had risen by 39% between 1999 and 2014.

Quantity of domestic groundwater consumed

Fig. 2 shows the spatial distribution of well water abstraction across Manyatta A and Migosi. Of the 39 Manyatta A and Migosi wells targeted, there were 27 wells for which both abstraction data and location data were available. The average reported daily

Table 2
Results of a transect survey of shallow wells in the Migosi and Manyatta A informal settlements within Kisumu.

Informal settlement	No. wells present in both 1999 baseline and 2014 survey	No. wells present in 1999 baseline but absent in 2014	No. wells present in 2014 that were not in 1999 baseline
Migosi	14	6	12
Manyatta A	46	3	24
Total	60	9	36

abstraction per well was 0.76 m^3 in Manyatta and 0.81 m^3 in Migosi. Daily abstraction rates were highly variable between wells and ranged from 0.02 m^3 to 3 m^3. No spatial pattern was identifiable in the data. On the basis of the transect survey results, we increased the number of wells in Manyatta A and Migosi by a factor of 1.43 and 1.30 respectively to account for the change in well numbers over time between the creation of the well map (1999) and the current survey (2014). The overall contribution of shallow well water to the domestic water supply in these two neighbourhoods was calculated as 472 m^3 per day (381 m^3 in Manyatta and 91 m^3 in Migosi).

Household domestic water use

Fig. 3 shows the proportions of well owners and customers using water for drinking versus washing clothes, broken down by the more widely accessible water source types. Most respondents avoided drinking borehole and hand-dug well water, but did use spring water for drinking. Piped water and to a lesser extent rainwater were preferred for drinking. In contrast, respondents were much more likely to use groundwater for washing clothes and less than half used piped water for the same purpose. The pattern of source use for cooking was similar to that for drinking. The proportion of households using groundwater sources for personal hygiene, flushing toilets/latrines, and irrigation was greater than those using piped water for each of these purposes (data not shown).

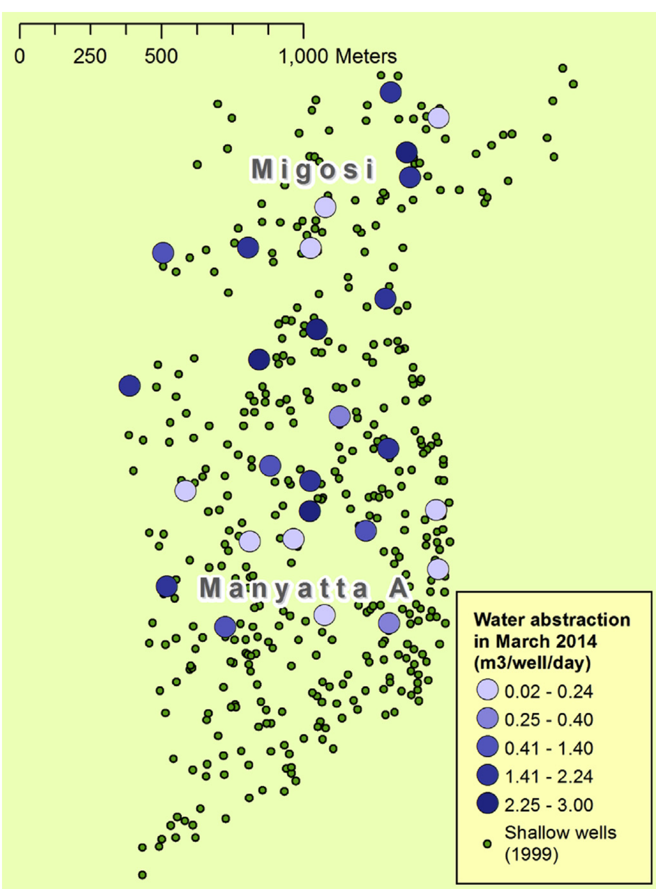

Fig. 2. Locations of Manyatta A and Migosi shallow wells mapped in 1999 (Wright et al., 2012) and the daily water abstraction (m^3) per well for 27 of those wells in 2014.

Fig. 4 shows the reasons given by respondents for their choice of water source for different domestic purposes. Water quality/safety was overwhelmingly cited as the reason for choosing a source for drinking or cooking, whilst other considerations such as quantity, constancy of supply, and ease of access and cost became increasingly important for other domestic uses.

Socio-economic status of well owners, their customers and those consuming untreated well water

Fig. 5 shows the distribution of wealth quintiles in five separate groups of urban households, with these quintiles being based on the same set of assets and services across all five groups. These groups are urban households nationally across Kenya; urban households in Nyanza province; well owners in our study settlements of Manyatta A and Migosi; those purchasing well water in our study settlements; and those well owners or customers drinking or cooking with untreated well water. The figures for Kenya nationally are taken from the 2008–9 DHS and show an even split, since this was the basis on which quintile boundaries were defined. For the DHS sample of urban households in Nyanza province, there are proportionately more households in the wealthiest and poorest quintiles and greater variation than among the national group. Among households participating in our study, of the 51 well owners interviewed in our survey, we were unable to calculate wealth quintiles for 9 of these, because of missing data on one or more of the 11 assets or services used to calculate the index. Similarly, among the 137 customers interviewed, we were unable to calculate wealth quintiles for 27, who lacked data on one or more assets or services. Fig. 5 shows the breakdown of wealth quintiles among the remaining 42 well owners and 110 customers. Whilst only 14% of well owners were from the two poorest quintiles, 42% of those purchasing well water were from the two poorest quintiles, suggesting that well owners were generally wealthier than those who purchased well water from them. This was confirmed using a Mann–Whitney test; well owners were significantly wealthier than well customers ($U = 1673$, $p < 0.01$, $r = -0.021$ [small-medium effect size]). Among the 25 well owners or customers who drank or cooked with untreated drinking-water, we were unable to calculate wealth quintiles for 4 of these households. The socio-economic profile of this final group of consumers exposed to untreated well water was broadly similar to that of those purchasing well water.

We matched well owner and customer asset index scores for 20 wells (Fig. 6). For 65% of the matches, asset score of the owner was higher than the asset score of the customer, meaning that the owner was wealthier than the customer. There was a statistically significant positive correlation between asset scores for owners and customers (Spearman's rank correlation coefficient = 0.66, sig. at $p < 0.01$). This suggests that poorer customers bought water from poorer owners and that wealthier customers bought water from wealthier owners.

When asset scores for well owners were compared to sanitary risk scores at the well itself (Fig. 7), there was no apparent relationship between the two ($n = 35$; Spearman's $r = -0.22$; $p = 0.21$). However, there was an inverse relationship between the sanitary risk score for contamination hazards in the surrounding area and

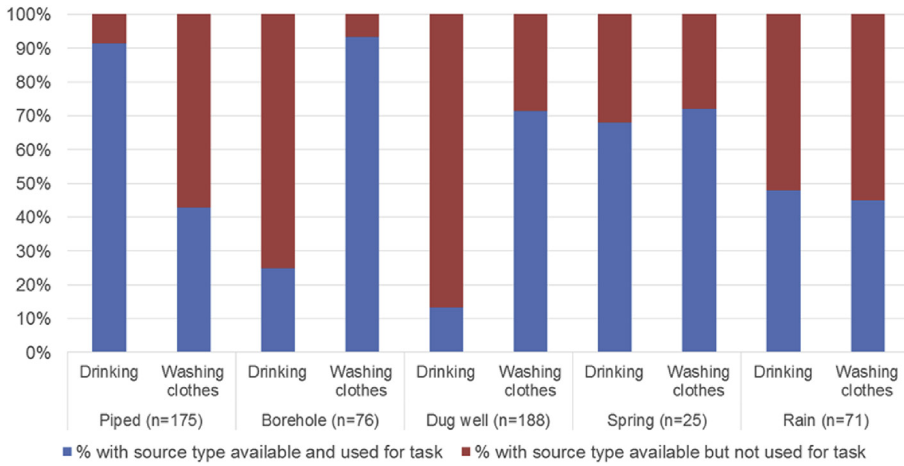

Fig. 3. Proportion of well owners and customers using more widespread, accessible water sources types for drinking versus washing clothes.

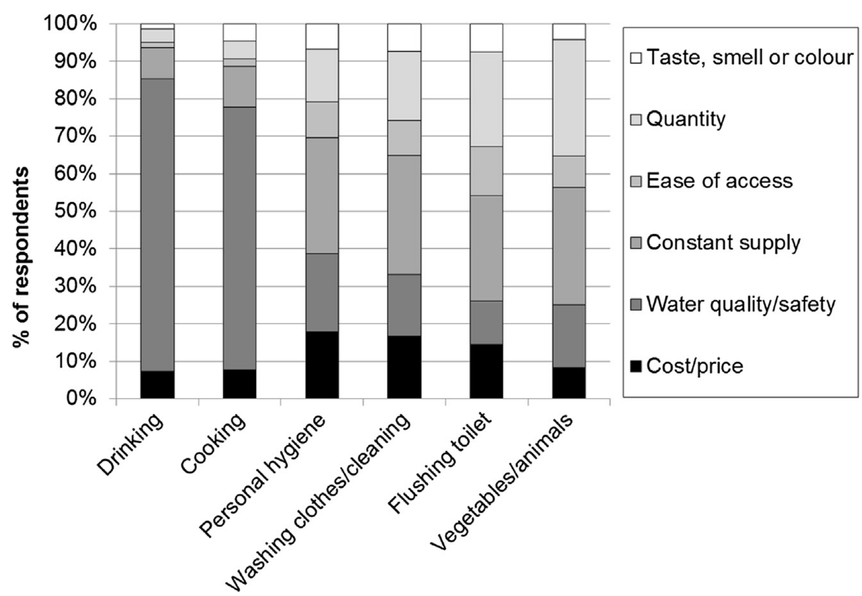

Fig. 4. Reasons for making choices about which water source to use for which task. Data are shown for well owners and well customers combined ($n = 188$). Where respondents gave multiple reasons, all were included.

the asset score for the owner that was significant ($n = 35$; Spearman's $r = -0.48$; $p = 0.003$).

Discussion

Interpretation of findings

Our findings suggest most well water consumers appear aware of the health risks of shallow well water and do not drink such water untreated, in accordance with other studies of Kisumu's informal settlements (Philip & Stevens, 2013). Residents' decisions about which water to use for drinking and cooking appear driven by a recognition of the importance of water quality. In contrast, the ease of access, affordability and constancy of supply of water from shallow wells mean it is commonly used for purposes other than consumption, such as washing clothes. However, despite limited borehole availability in these neighbourhoods, many respondents reported using borehole water, suggesting that they may be mistaking enclosed hand-dug wells for boreholes and presuming such wells to be safer. Similarly, although households appear well aware of the health risks of water from hand-dug wells, water from springs was frequently used for drinking and cooking. Given reported high levels of microbial contamination in Kisumu's springs (Opisa et al., 2012), any belief in the safety of such sources may be misplaced. Similarly, although most households are aware of the health risks from hand-dug wells, a minority continue to consume untreated well water. In Kenya nationally, the predominant form of home water treatment is boiling, practiced by 38% of households in 2008–9, with chlorination practiced by 21.5% (Kenya National Bureau of Statistics and ICF Macro, 2010). In our study households, those who did treat water overwhelmingly used home chlorination rather than boiling. Boiling may be a more acceptable alternative to chlorination for those not currently treating their water.

We estimated that 472 m^3 of groundwater was abstracted per day in the two informal settlements of Mnayatta A and Migosi. This compares with an estimated 18,700 m^3/day leaving Kisumu's two piped water treatment plants in 2008 and an estimated total water demand of 12,520 m^3/day in 2011 for an area including both these settlements (Maoulidi, 2010). Although this figure is small in

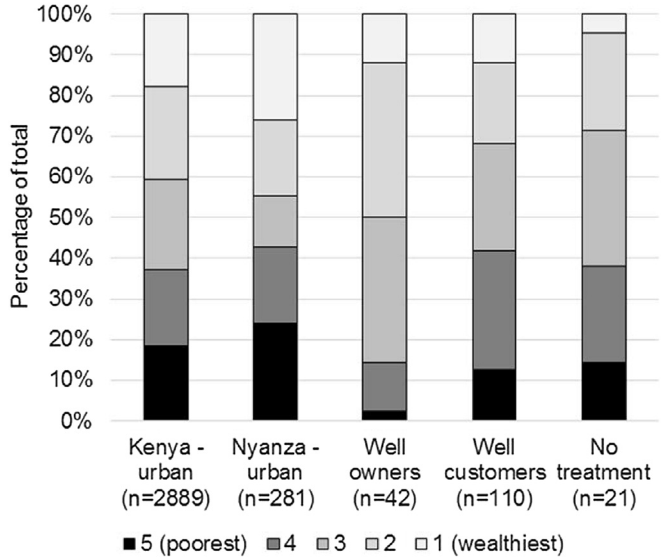

Fig. 5. Distribution of wealth quintiles for urban households in Kenya and Nyanza Province (from the 2008–9 Demographic and Health Survey), compared to well owners, their customers, and those drinking or cooking with untreated well water in Manyatta A and Migosi.

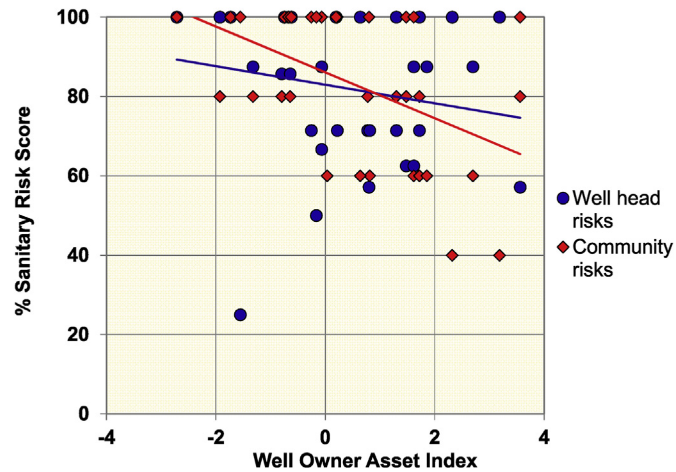

Fig. 7. Scatter plot of wellhead sanitary risk scores and neighbourhood (community) sanitary risk scores versus well owner asset index values for 35 wells in Kisumu.

proportion to estimates of the volume of piped water leaving Kisumu's treatment plants and demand in such settlements, it suggests such wells form an affordable source of domestic water for poorer households in the city.

The daily average amount of water abstracted per well seems plausible from a hydrogeological standpoint, given that evidence suggests that yields upwards of 5 m^3/day are often encountered in fractured basement geology of the type present in Manyatta and Migosi (MacDonald & Davies, 2000). In a study of the urban core of Kisumu that incorporated Manyatta, Migosi and several other surrounding neighbourhoods, Sima et al. (2013) found that 109 m^3/day of groundwater was abstracted for subsequent vending through kiosks for subsequent sale to both households and businesses. This study largely focussed on water vending through kiosks and therefore did not measure groundwater directly abstracted from wells for subsequent consumption by households or directly abstracted from wells by vendors using water carts, who by-passed kiosks. Our estimate of the amount of daily abstracted groundwater, which incorporates such direct groundwater abstraction, suggests that groundwater contributes a higher proportion of the city's domestic water supply. Given recent efforts to mobilise inhabitants to map and provide information about their own communities (e.g. Karanja, 2010), there may be potential to quantify the contribution of hand-dug wells in a greater number of informal settlements by combining mapping of groundwater sources with household-based abstraction estimates.

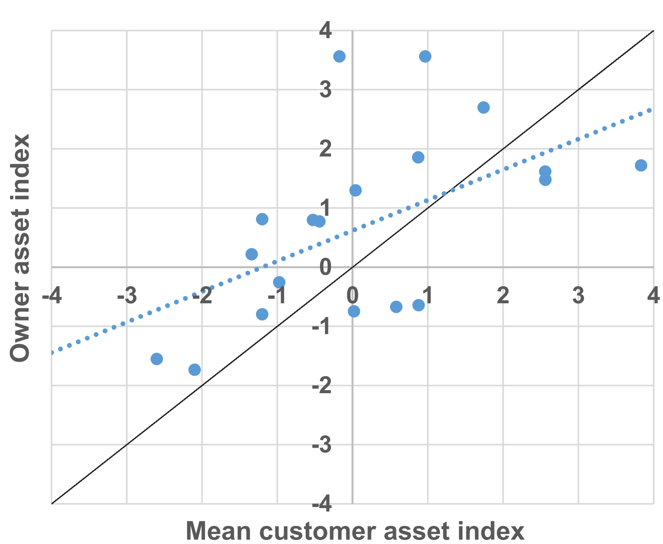

Fig. 6. Scatter plot of matched well owner and well customer asset index scores for 20 wells (customer asset indices are averaged for between 1 and 6 customers per well). The solid line shows a 1:1 relationship, while the dotted line is a linear trendline fitted to the data.

Our findings also suggest that whilst well owners are seldom among the poorest of urban households, those who purchased well water are largely from the poorest three quintiles, as are those consuming untreated well water. Thus, interventions to improve hand-dug well water, such as well protection and lining, may bring benefits to poorer households purchasing such water, provided consideration is given to issues such as post-collection contamination (Wright, Gundry, & Conroy, 2004) and subsequent use. This is because other studies have shown that the quality of water deteriorates significantly in the household storage containers (Okotto, 2010). More generally, water vending is now a widespread practice in many urban settings and any interventions targeting the poor and points along water supply chains need to be informed by an understanding of the socio-economic characteristics of all actors in such chains. Many nationally representative household surveys now document selling of domestic water as well as its consumption. It should thus be possible to adapt the small-scale socio-economic profiling of actors at different points in the urban water supply chain that we present here and apply it to a much larger group of nationally representative households.

We examined the relationship between well owners' socio-economic status and sanitary risk scores, distinguishing between observed hazards at the well itself (controllable by the owner) versus observed hazards like pit latrines and uncollected refuse in the well's vicinity (controllable through planning and regulation but not by the owner). Analysis of the latter sanitary risk scores suggested that poorer well owners and poorer well consumers were living in neighbourhoods where there was a greater concentration of contamination hazards such as pit latrines immediately around wells. However, in terms of observed hazards that could be controlled by owners, there was no significant evidence from sanitary risk scores that the wells of poorer owners were less well maintained. Wells owned by wealthier households were just as likely to have poor sanitary risk scores for potential hazards at the wellhead and from inadequate well lining, so there was no evidence that poorer well owners lacked the finances to invest in protecting their wells. More generally in an urban setting, it seems valuable to separate sanitary risk inspection checklist items (WHO, 1997) into those controllable by well owners and those only controllable through community action and/or formal improved planning and regulation. If more widely adopted, this separation could provide insights into the underlying causes of contamination hazards in other, similar urban settlements.

Study limitations

Our estimate of the amount of groundwater abstracted is based on a typical weekday during February or March, which would fail to capture annual and weekly variation in abstraction. We have relied on well owners to estimate the amount of water abstracted from their wells in the previous day and these estimates may be subject to recall bias. There is growing interest in using automated water level loggers and other forms of sensor to estimate abstraction directly, thereby overcoming this difficulty (Thomson, Hope, & Foster, 2012). However, the field use of such devices remains experimental.

Since our sample drew on a set of wells that were selected in a baseline study in 2002, our finding may be biased towards longer term residents, given that our transect survey suggested widespread subsequent well construction in both Manyatta A and Migosi. Similarly, we were unable to interview absentee well owners, who may have different socio-economic characteristics and whose wells may experience different usage patterns. In developing our measure of SES, although we used the same question and response wording as the DHS in our survey, several methodological issues may have produced differences in question responses between our survey and the DHS. For example, responses to questions can be influenced by questionnaire length and question sequence (McColl et al., 2001) and by differences in survey implementation and enumerator training. Similarly, the DHS represents historic conditions in 2008–9 rather than 2014.

Conclusion

Our conclusions from the above findings are that shallow hand-dug wells and springs are an affordable source of water for washing clothes, flushing toilets/latrines and irrigation among informal settlements in Kisumu. It is also clear that most residents are aware of the health risks from microbial contamination of such water and use it for purposes other than drinking and cooking. However, a minority of residents continue to drink untreated well water, and there is some evidence that some may mistake hand-dug wells for boreholes and mistakenly consider spring water to be safer than well water. Whilst well owners are wealthy relative to those who purchase well water, both their customers and those drinking untreated well water are drawn from the poorest three quintiles of urban Kenyan households. Thus, interventions that seek to improve well water quality, such as wellhead chlorine dispensers and well protection and lining programmes, may still benefit the poorest households, provided attention is given to post-collection contamination of groundwater and its subsequent use.

Although the public health risks from shallow hand-dug wells are well documented, they provide a means of increasing the quantity of water available to poorer households for purposes other than consumption. However, poorer households do require an alternative, affordable means of securing safe water for drinking and cooking alongside such well water, such as through effective home water treatment or hygienically vended piped water. It may thus be premature to consider closure of such wells before there is an affordable alternative for poorer households to use for purposes such as washing clothes and irrigation. Until affordable safe water becomes accessible to all urban households, the interim challenge remains to manage the contamination risks to urban shallow wells and springs as far as possible, and promote safer handling, storage, and treatment by groundwater consumers.

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