Research Paper

Assessing the impact of property size on residential water use for selected neighbourhoods in Lilongwe, Malawi

Chikondi Makwiza and Heinz Erasmus Jacobs

ABSTRACT

Malawi has one of the highest urbanisation rates in Africa, with an urban housing approach that favours large residential plot sizes. The impact of plot size on residential water use was evaluated by examining water use records, obtained for the period between January 2009 and December 2014, for formal residential properties in the city of Lilongwe. Water use increased with plot size in line with other reported research, but the dataset contained a considerable proportion of large plots, which were also associated with higher residential water use than presented in similar studies. The findings of this study point to the need for collaboration between water managers and urban planners to promote increased access of urban water supplies by appropriately managing future residential plot sizes.

Key words | equitable water use, residential plot size, urban water use

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INTRODUCTION

Malawi is a relatively small landlocked country in southern Africa with an area of 118,484 km^2 and a subtropical climate. The population is estimated at 13 million and continues to grow at an estimated rate of 4.8% per annum (National Statistical Office 2008). A more recent and rather pressing situation with regard to urban water supply is the significant relocation from rural areas to urban centres. At an urban influx rate of 5.2% per annum, Malawi has one of the highest urbanisation rates in Africa (Government of Malawi 2013). Along with urban population growth has come an urgent need for new housing developments and the necessity to expand and upgrade infrastructure for effective service delivery (UN-HABITAT 2010). The population of Lilongwe, the capital and administrative city of Malawi, has more than doubled since 2000 (Brown 2011).

The Lilongwe Water Board is already under increasing pressure to raise its production to meet the progressively rising residential, commercial and industrial water demands. Currently, new residential water connections are considered the main factor driving up water use (Lilongwe Water Board 2012). Lilongwe Water Board (2015) estimated residential water use in Lilongwe at about 60% of the total supply in 2010 and projected disproportionately rising water use in the subsequent years where the residential sector becomes more dominant through population growth. In 2014, the Lilongwe Water Board reported a 5.6% deficit in water supply, following which plans were made to expand one of its main reservoirs, Kamuzu Dam I, to achieve a daily yield increase of 28.9%. However, at the current trend of population growth in the city of Lilongwe, water demand will outstrip the newly proposed daily minimum reservoir yield by 2025 (Lilongwe Water Board 2015).

Strategies for managing residential water use at the household level can therefore play an important role in curbing present demands and reducing the impact of future supply shortages. Residential water use results from indoor use, which comprises water used for food preparation and basic hygiene, and outdoor use, which comprises water used for gardening, car washing and the like. Indoor use remains fairly constant throughout the year, whereas outdoor use is

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more responsive to changes in climatic factors. Access to sufficient quantities of water for indoor use is known to improve public health and hygiene, particularly where water connections are made to houses (Howard & Bartram 2003). Since outdoor water use is more elastic than indoor use, curtailment of this water use component is the primary way in which utilities manage short-term climate-related shortages (Jacobs *et al.* 2007). With regard to outdoor use, long-term conservation measures are aimed at reducing the responsiveness of water use to changes in climatic factors (Breyer & Chang 2014).

With improved management of customer water billing information at the Lilongwe Water Board and capabilities for retrieving datasets for substantially large numbers of customers spanning relatively long time periods, it is now possible to perform demand-side residential water use analyses for the city of Lilongwe. However, lack of readily available household-level socio-economic information precludes a detailed residential water use analysis. For single family houses, plot size has been reported to be the single most important factor affecting water use elsewhere (Jacobs *et al.* 2004; Van Zyl *et al.* 2008; Breyer & Chang 2014). Van Zyl *et al.* (2008) observed that plot size gave reliable water use estimates even when other significant determinants of water use were disregarded. Patterns of residential water use in relation to plot size can therefore provide useful insights into water use in the city of Lilongwe.

In this paper, patterns of water use for residential plots in selected neighbourhoods in the city of Lilongwe were examined using monthly customer billing records for the period 2009 to 2014. Annual averaged and monthly averaged daily water use were explored to derive patterns of water use in relation to residential plot size. In addition, the peak water use period and the minimum water use period were identified in order to examine the influence of seasonal factors on water use in distinct plot size categories. This analysis is of key interest, since residential plot sizes specified in the prevailing housing standards and guidelines (Government of Malawi 1987) are generally quite large, and considered unsustainable in meeting future housing demands (Brown 2011). The results are an important input for consideration in framing policy and strategies for both urban land use planning and water supply management.

METHODS

Datasets

Household-level water billing records for the period between January 2009 and December 2014 were obtained from the Lilongwe Water Board in February 2015. A query was run to extract billing records from the customer database for six neighbourhoods identified as predominantly residential out of the 58 neighbourhoods in the city of Lilongwe. Neighbourhoods closest to the city centre were selected, because these were known to be least affected by pressure drops during peak demand periods and experienced the fewest water supply outages. These neighbourhoods also happen to be among the oldest formal residential developments in the city of Lilongwe. Most of the plots in the six selected neighbourhoods were developed from the 1970s and can therefore be assumed to have minimal use of piped water for construction purposes, with few vacant plots.

The original dataset contained a total of 681,797 meter readings for 11,378 customers. Aggregating repeated readings taken at meter replacements resulted in 666,476 unique monthly records. The dataset was retrieved by customer water account numbers to protect customer personal information. The attributes included were meter reading, meter read date, plot number, neighbourhood code, tariff code and actual billed monthly consumption.

The Lilongwe Water Board provides a single metered connection per residential plot. Semi-detached houses are normally built on adjacent plots that have separate lease agreements and are also furnished with separate water meter connections. Larger sized plots have a single water meter, although it is common to have a second smaller dwelling unit meant to be a guest wing or servants' quarters. Plots that have swimming pools are provided with an additional water meter that is charged at a commercial tariff.

Residential plot layout maps on hard copies and a few in GIS format were obtained from the Lilongwe City Assembly, the Malawi Housing Cooperation and the Lands and Surveys Department. The Lilongwe City Assembly is a local government authority that undertakes town planning, including allocation of serviced plots for private housing development. The Malawi Housing Corporation is a parastatal responsible for the development and provision of housing in urban areas. The Malawi Housing Corporation has become a major housing provider in cities since its establishment in 1964. The Lands and Surveys Department coordinates all land survey tasks and is the custodian of nationwide mapping information from various land use sectors.

Weather data for the city of Lilongwe was obtained from Chitedze Research Station. The city of Lilongwe lacks a broad network of weather stations (Department of Climate Change & Meteorological Services n.d.). Although the selected weather station lies about 20 to 30 km away from the study sites, it was the preferred station because it has the most complete and consistent record of historic weather in Lilongwe. Daily weather records were aggregated at monthly intervals to correspond with water meter read intervals in the water use data. These weather data were used to determine average monthly temperature and rainfall for the six-year study period.

Water use data processing and screening

The plot layouts acquired were used to obtain plot sizes and to identify single family detached or semi-detached residential plots. At various points during analysis, the plot layouts were checked against high resolution aerial photographs available at the Lands and Surveys Department to verify whether the originally-planned plot layout matched the existing site plot layout. The hard copy layout maps were scanned, imported into Quantum GIS software, geo-referenced and digitised. The digitised file was combined with the available GIS-based residential plot layouts to form a single shape file. Plot sizes were extracted by plot number from the attributes of the combined GIS file. The table of plot sizes created was joined to the customer water use table using the plot numbers field available in both data tables. Not all customer water accounts could be matched to corresponding plot size information because some customer records did not have plot numbers. Likewise, plot numbers were missing for some plots in the layout maps. The plot sizes were used to group all customers into plot sizes categories at 500 m^2 class intervals ranging from 0–500 m^2 to 7,000–7,500 m^2.

A series of filter criteria were applied to remove customer records that were not relevant to the study and records that contained irregularities. Table 1 shows the number of customers and monthly records retained at each processing stage. Non-residential customers were removed using an appropriate tariff code provided in the data. All customers whose plot sizes could not be found were removed. Customers with plot sizes exceeding 8,000 m^2 were also removed from the data. Wherever more than five monthly records were missing for a customer in a particular year, the entire yearly record of that customer was discarded. It was observed that long meter read intervals usually gave water use readings that were not consistent with the rest of the customers' water use records, mostly being too low for the given period. A plausible reason could be readings taken after a period of vacancy of dwelling units. There were also a few extraordinarily large records taken over very short periods. It was decided to discard all

Table 1 | Number of customers and monthly records retained at each processing stage

Step	Description	Number of customers remaining	Number of monthly records remaining
1	Total number of records extracted	11,328	681,797
2	Aggregate duplicate monthly meter readings	11,328	666,476
3	Remove non-residential connections	10,725	638,275
4	Remove customers whose plot sizes were not available	4,074	281,550
5	Remove customers with plots larger than 8,000 m^2	4,066	280,995
6	Remove yearly customer records with more than five gaps or zeros	4,005	274,067
7	Remove meter readings less than 20 days and greater than 40 days	4,005	245,743
8	Remove monthly consumption readings greater than 600 kL	4,004	245,418
9	Remove records with meter read dates falling outside study period	4,004	245,411

records with meter read intervals shorter than 20 days or longer than 40 days. Monthly records exceeding 600 kilolitres (kL) were considered too high for residential connections and these were excluded from the analysis. A few records were noted to have meter read dates that fell outside the data extraction period. Any records with such erroneous entries were removed from the dataset.

Computation of key variables

The average annual daily demand (AADD) and average monthly daily demand (AMDD) were calculated for each customer for each year. The AADD for each customer was obtained by dividing the total annual consumption by the number of days in that year. The AMDD was calculated by dividing the monthly consumption by the number of days between consecutive meter readings. Monthly consumption records typically span across consecutive months. The AMDD obtained from a given billed consumption was assigned to the month when the latter meter reading was taken.

In order to compare the interactive effect of seasonal weather changes and plot size on water use, monthly peak factors were calculated for each plot size category. Monthly peak factors were calculated by dividing the highest AMDD by the AADD for the whole six year period. Peak factors are conventionally used to calculate peak flow requirements for the design of water supply systems, and therefore provide a sound basis for comparison of summer peak water use with other studies.

RESULTS AND DISCUSSION

Plot size distribution

Table 2 gives the distribution by plot size category of the 4,004 customers that met the filter criteria presented in the previous section. The table also shows the spread of the customers in each of the six selected neighbourhoods. In all subsequent analyses, customers falling into each plot size category are lumped together irrespective of neighbourhood.

Water use patterns across customers

The AADD of all customers calculated for the period between 2009 and 2014 ranged from 1.2 to 1.5 kL/plot/day.

Table 2 | Plot size distribution

	Neighbourhood							
Plot size category (m^2)	A	B	C	D	E	F	Total number of customers	Percentage of the sample (%)
0–500	638	504					1,142	28.5
500–1,000	396	251		192			839	21.0
1,000–1,500	13	18	7	212		10	260	6.5
1,500–2,000	5		130	302		16	453	11.3
2,000–2,500			66	324		55	445	11.1
2,500–3,000			14	65	1	44	124	3.1
3,000–3,500				20	11	55	86	2.1
3,500–4,000				8	18	162	188	4.7
4,000–4,500				1	88	38	127	3.2
4,500–5,000					138	47	185	4.6
5,000–5,500				2	30	13	45	1.1
5,500–6,000					37	7	44	1.1
6,000–6,500				1	20	5	26	0.6
6,500–7,000	1			1	15	1	18	0.5
7,000–7,500					22		22	0.6

Figure 1 shows the frequency distribution and the cumulative frequency distribution of AADD for the year 2014. The household-level AADD had a positive skew that resembled the frequency distribution of plot sizes in the study sample. About 90% of the customers had AADD values below 2.5 kL/plot/day. The other 10% of customers accounted for at least 25% of the total consumption in the study sample. The highest water users were found among the top 2% of the customers, with AADD ranging from 5 to 10 kL/plot/day.

Water use by plot size category

The mean AADD values for the distinct plot size categories are plotted in Figure 2. Water use clearly increases with plot size up to about 5,000 m^2. The relationship between AADD and plot size is less clear for the larger plot size categories. The variance increases for the larger plots sizes, leading to larger standard errors, meaning that the mean water use estimates become less precise than in the smaller plot size categories as shown in Table 3.

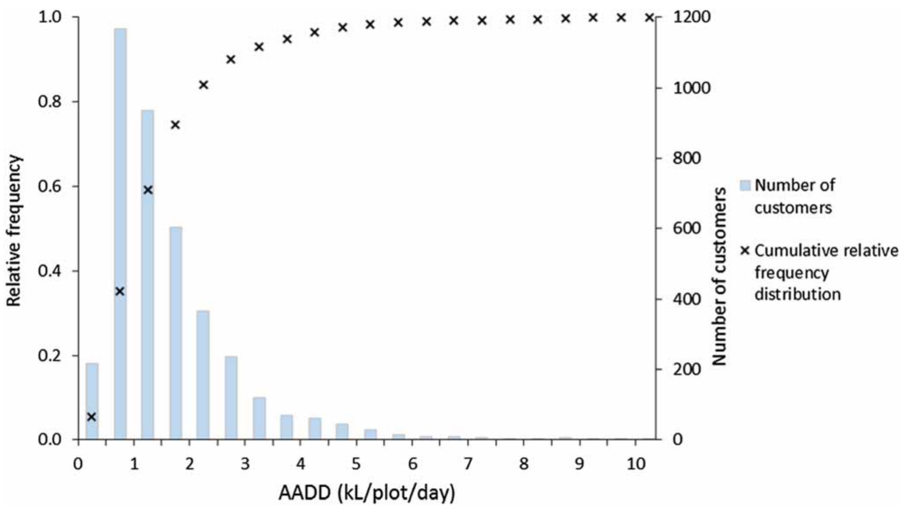

Figure 1 | Frequency distribution of AADD.

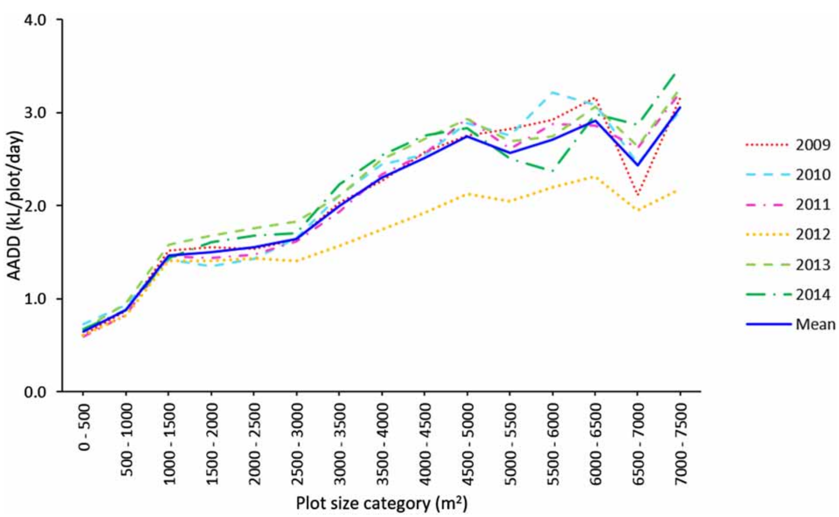

Figure 2 | Water use variation with plot size.

Table 3 | Summary statistics for AADD by plot size category averaged over the period 2009 to 2014

	AADD (kL/plot/day)		
Plot size category (m^2)	Mean	Standard deviation	Standard error
0–500	0.648	0.367	0.004
500–1,000	0.878	0.655	0.009
1,000–1,500	1.470	0.820	0.022
1,500–2,000	1.506	0.886	0.017
2,000–2,500	1.554	0.972	0.019
2,500–3,000	1.642	1.025	0.038
3,000–3,500	2.000	1.299	0.058
3,500–4,000	2.306	1.640	0.049
4,000–4,500	2.513	1.846	0.068
4,500–5,000	2.748	1.837	0.056
5,000–5,500	2.570	1.758	0.109
5,500–6,000	2.713	2.116	0.133
6,000–6,500	2.915	2.398	0.198
6,500–7,000	2.435	1.949	0.189
7,000–7,500	3.055	1.961	0.171

Water use was notably lower in 2012 than for the other years. A follow-up with the Lilongwe Water Board revealed that major rehabilitation works were carried out at their water treatment facilities, including the replacement of intake pumps between March and December in that year (Lilongwe Water Board 2012). Delivery pressure was affected and water supply rationing was introduced. The Electricity Supply Commission of Malawi coincidentally happened to carry out maintenance works at their main power generation plant in the same period. Extensive load shedding was introduced which further disrupted pumping and water supply.

The mean AADD in 2012 was 12% lower than that calculated for the entire six-year study period. As would be expected, AADD dropped considerably in the larger plot size categories, while the smallest plot size categories barely showed any reduction in water use. Substantial water use reductions were observed in plot sizes larger than 2,500 m^2. The average daily use for the period 2009 to 2014 was used to calculate the percentage reduction in water use in each plot size category in 2012. The percentage water use reduction was 5.6% in the smallest plot size category (0–500 m^2), while at least 14.2% reduction occurred in the plot size categories larger than 2,500 m^2. The largest plot size category (7,000–7,500 m^2) had a water use reduction of 28.6%.

Monthly variation in water use

The monthly variation in water use is depicted by AMDD in Figure 3. The average monthly maximum temperature and average monthly rainfall for 2009 to 2014 are shown in Figure 4. Water use generally follows the seasonal trend of temperature and rainfall. Minimum water use was observed in March, one month after the period of highest rainfall in February.

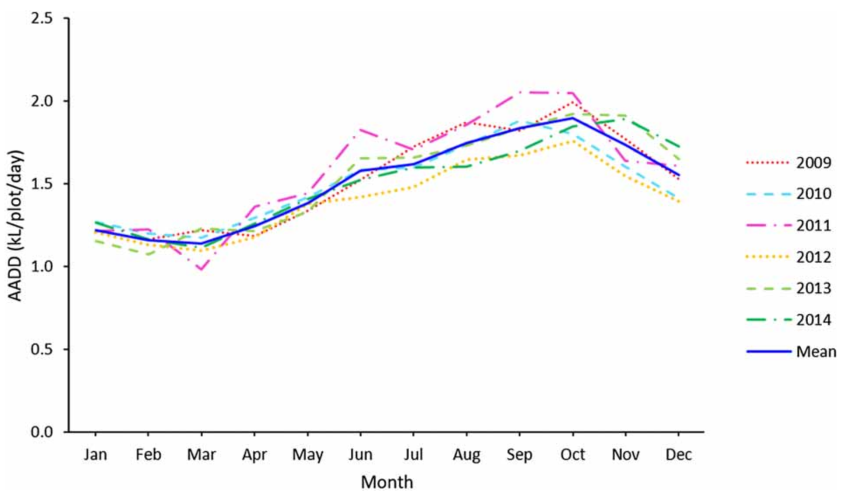

Figure 3 | Overall annual variation in AMDD.

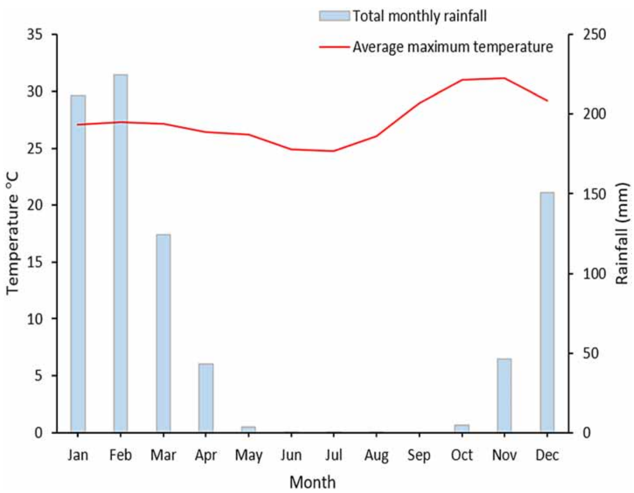

Figure 4 | Seasonal variation in temperature and rainfall.

Temperatures remain relatively moderate throughout the rainy season but reach the annual minimum later during the cool dry season between June and August. As expected, water use began to increase towards the end of the rainy season. It is likely that watering of landscapes is resumed around this time as evapotranspiration losses can no longer be replenished by rainfall. Water use, however, continued to increase as temperatures dropped from May throughout the cool dry season. Seasonal horticultural crops in backyard gardens, a common practice in Malawi, are planted during this time. The cool season is conducive to the establishment of certain leaf vegetables that are difficult to grow in hot weather.

Peak water use corresponded with maximum temperatures in October. Peak month water use in October was, on average, 70% higher than the minimum winter water use in March. Water use subsequently dropped at the start of the rainy season, which was also accompanied by a decrease in temperatures.

Monthly patterns of water use in relation to plot size

Monthly variation in AMDD within each plot size category is given in Figure 5. The small plot size categories maintained nearly constant AMDD throughout the year, implying predominant indoor water use. This observation suggests that indoor water use responded negligibly to seasonal weather variations.

Monthly peak factors for the highest usage month (October) were 1.2 and 1.5, respectively, for 0–500 m^2 and 1,500–2,000 m^2 plot size categories. Peak factors approached a maximum of 1.6 in the larger plot size categories. The seasonal water use component of the study sample was estimated at 24% by deducting the minimum winter water use recorded in March from water use in the

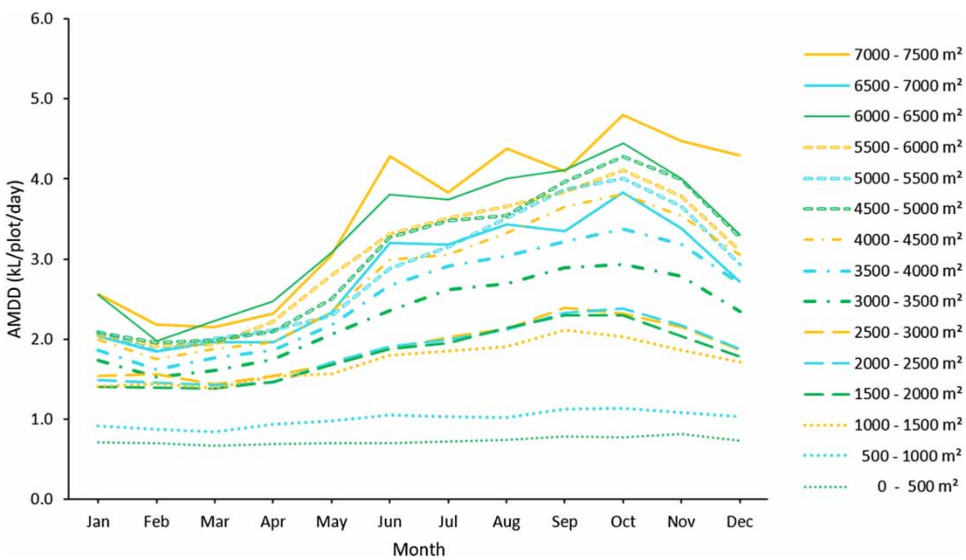

Figure 5 | Variability of AMDD by plot size.

rest of the months, and expressing the result as a fraction of total annual use.

Comparison of water use in this study with findings from similar studies

For the purpose of comparison with similar studies, AADD values obtained in this study for Lilongwe are presented in Figure 6 together with guideline curves for estimating AADD presented by Jacobs *et al.* (2004) and Van Zyl *et al.* (2008). The water use results show good agreement with the findings by Jacobs *et al.* (2004) for plot sizes between 0 and 2,050 m^2 reported for three different regions of South Africa and Windhoek in Namibia. Van Zyl *et al.* (2008) provided estimates of water use in South African towns and cities for up to 4,000 m^2 plots, although only 2.7% of the plots in their sample were classified in the range between 2,000 and 4,000 m^2. The AADD guideline curve recommended by Van Zyl *et al.* (2008), represented by the 50% confidence limit, overestimates water use of smaller plot sizes in Lilongwe but matches the results of this study for plots in the 3,500 to 4,000 m^2 category. For the purpose of comparison, per capita water use values for Lilongwe, some selected towns in Western Cape, South Africa and Windhoek in Namibia are given in Table 4.

Plot size and neighbourhood water use

The results presented in the preceding sections show that smaller plot sizes are related to low water use per household while at the same time being less sensitive to seasonal weather variation. Reducing plot sizes increases both housing density and the number of people in a neighbourhood. Jacobs *et al.* (2013) and Griffioen & Van Zyl (2014) reported relatively constant water use of about 10 kL/ha for residential neighbourhoods irrespective of the development density. Their findings suggest that plot density does not necessarily increase water use per unit area in a neighbourhood. However, the increase in the number of people causes a corresponding decrease in the water use per capita (Balling *et al.* 2008). Breyer & Chang (2014) have actually reported an overall reduced per capita water use attributed to increase in residential area density in Oregon. They argue that increased density of residential areas is a form of 'retrofitting of the landscape' that reduces the potential for outdoor water use.

The need for collaboration in urban planning

The results of this study agree with other studies in the sense that water use increases with residential plot size. As

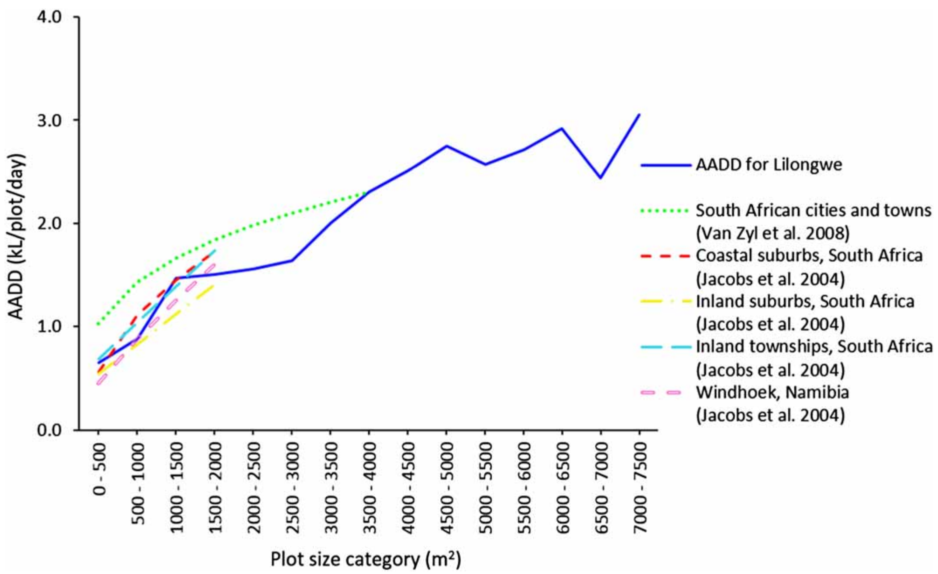

Figure 6 | Comparison of AADD for Lilongwe to similar studies.

Table 4 | Per capita water use for selected towns

Town/City and Country	Source	Per capita water use (litres/capita/day)
Lilongwe, Malawi	Lilongwe Water Board (2012)	64
Franschhoek, Western Cape, South Africa	Du Plessis (2007)	305
Paarl, Western Cape, South Africa	Du Plessis (2007)	325
Piketberg, Western Cape, South Africa	Du Plessis (2007)	180
Windhoek, Namibia	Uhlendahl *et al.* (2010)	200

temperatures increase in summer, water use increases more for larger plots, that is, summer peak factors are higher for large plot sizes than for smaller plot sizes. Formal residential plot sizes in Malawi have their origins in the early housing developments for government employees. The standard plot sizes were given in the planning standards and guidelines prepared then by the Ministry of Lands, Physical Planning and Surveys (Government of Malawi 1987). All plots were supposed to range from 300 m^2 to 4,000 m^2 depending on the designated density of the residential area, although these size limits appear to be occasionally ignored. These housing guidelines and standards favour the development of relatively large plot sizes that are inducing high seasonal peak factors and overall increase in water use at household level. The plot sizes in the standards have been criticised as taking too much urban space and being unsuitable for future climate-related challenges (UN-HABITAT 2010; Brown 2011). The determination of plot sizes is, however, beyond the control of water supply managers. Thus, collaboration is needed between the water supply sector, town planners and other stakeholders to achieve sustainable urban housing forms that take into account current and future water needs.

Study limitations

The total number of records used in the analyses was relatively smaller compared to similar studies conducted elsewhere in large metropolitan areas (Jacobs *et al.* 2004, 2007; Van Zyl *et al.* 2008). For this reason, the results were not separated by neighbourhood in all the analyses in spite of the distinct characteristic features of the six selected neighbourhoods. Non-homogeneous characteristics among the selected neighbourhoods that were not considered in the analyses, therefore, potentially introduced considerable variability in the results obtained from the combined dataset. Factors such as household size and socio-economic status are known to impact water use habits. Likewise, water pricing structure is a key factor influencing residential water use. Further research that incorporates detailed information on these factors would increase confidence in the observed results.

CONCLUSIONS

This study investigated the effects of plot size on water use of formal housing in the city of Lilongwe. Water billing records for 4,004 single-family customers, obtained through a series of screening criteria, were analysed. The AADD, AMDD and summer peaking factors were examined with respect to plot sizes. The AADD increased with plot size category. The results showed a substantial proportion of large plots, which were also associated with higher water use than reported in similar studies elsewhere. Summer peaking factors were higher for larger plot size categories, suggesting substantial water usage for outdoor purposes. The results obtained provide a benchmark that water managers can use to estimate expected water use for new residential neighbourhoods. Water managers can, therefore, use the results to advocate urban residential forms that improve the level of access of households to adequate quantities of water from the available supplies in Malawi.

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