Effect of land area on average annual suburban water demand

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ABSTRACT

Current guidelines for estimating the average annual residential water demand (AADD) in South Africa are based on residential plot size. This paper presents a novel, robust method for estimating suburban water demand as a function of the suburb area. Seventy suburbs, identified as being predominantly residential, were selected for analysis from the largest urban metropolitan area in South Africa. A linear relationship was noted between the total suburb water demand and two land cover areas, namely, the total suburb area and total residential plot area. The average demand for the 70 suburbs based on suburb area was 6.6 kℓ·d⁻¹·ha⁻¹, with 90% of the values in the range between 4.4 kℓ·d⁻¹·ha⁻¹ and 8.7 kℓ·d⁻¹·ha⁻¹. The average demand was 10.4 kℓ·d⁻¹·ha⁻¹ for calculation based on the residential area. The results are useful when crude estimates of AADD are required for planning new land developments.

Keywords: urban water demand, suburb area, residential

SYMBOLS

A_{PLOT}	-	Individual residential plot area (m²)
A_{RES}	-	Total residential plot area in a suburb (ha)
A_{SUB}	-	Total suburb area (ha)
$AADD$	-	Average annual daily water demand (kℓ·d⁻¹)
$AADD_{SUB}$	-	Average annual daily water demand of an entire suburb (kℓ·d⁻¹)
x	-	Area parameter for linear fit (ha)
α	-	Linear slope
α_{SUB}	-	Linear slope in relation to A_{SUB}
α_{RES}	-	Linear slope in relation to A_{RES}
β	-	Linear intercept

INTRODUCTION

Land development and water demand

Guidelines for residential average annual water demand (AADD) based on plot size were introduced to the South African Civil Engineering fraternity before 1960. The AADD still forms the basis of calculations performed during the design and analysis of water distribution systems. Jacobs (2007) provided a chronological review of South African AADD guidelines used between 1950 and 2007 and noted that only two guidelines were employed for relatively long periods at a time, namely those of the Department of Water Affairs prior to 1965 (DWA, 1975) and various CSIR guidelines thereafter (Van Duuren, 1965; CSIR, 1983).

One of the first steps in planning water services for land development is to obtain an estimate of the water requirement of the potential future land users, both in terms of the expected AADD and peak flows. This research project focused on residential land use and the AADD, which is still applied in South African practice as a basis for estimating residential peak flows.

Estimating residential water demand in South Africa

Various methods are available for estimating residential AADD in South Africa, but this is the first investigation into demand at a relatively large spatial scale. The most recent methods for estimating residential AADD in South Africa use individual plot size (m²) as an independent variable to provide an estimate of AADD (in kℓ·d⁻¹) for the particular property (Van Zyl et al., 2008; Jacobs et al., 2004).

Research problem

The problem in applying local guidelines for AADD to new land developments is that the residential plot size remains undetermined at the early stage of urban planning and the planner needs to make crude assumptions in order to apply the available methods. The spatial resolution could be increased with end-use modelling (Buchberger and Wu, 1995), where each property needs to be described in more detail by considering individual water use events. Application of end-use modelling has also been illustrated in South Africa (Jacobs and Haarhoff 2004; Van Zyl et al., 2003). However, end-use modelling poses no solution to the problem of estimating water demand for new land developments, because an increased number of parameters are needed for end-use models.

The approach presented in this paper was to decrease the spatial resolution to investigate the AADD of suburbs as a function of the total land area, a parameter that is easy to obtain at an early stage of urban planning. The entire suburban area would ultimately include the roads, parks and public open spaces in addition to the residential properties, despite much of this not requiring water supply per se.

Objectives

Suburban AADD in terms of the water demand per hectare was reported by Vorster et al. (1995) for what was then called the East Rand region, now known as Ekurhuleni Metropolitan Municipality in Gauteng Province, South Africa. Stephenson and Turner (1996) also reported AADD per hectare for '14 varied areas' in Gauteng Province. These publications

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hinted towards further research into AADD on a 'per hectare' basis, but no publication ever followed to address this topic.

The main aim of the research was to investigate the effects of residential suburb size, in terms of the total suburban land area and also the total residential plot area, on the suburban AADD. After identification of a suitable study region the research project had 5 key objectives, namely:

- Spatial description of suburbs: identify and describe suitable homogeneous residential areas (suburbs) spatially, including the cadastral information for individual plots contained within the suburb
- Water demand: identify and describe suitable individual residential properties' AADD for the same geographical region
- Verification and filtering: marry the suburb names in the different databases, conduct verification checks and filter the data to achieve the desired scope
- Results: investigate the relationship between the appropriate variables
- Conclusion: compare the results to previous work and draw conclusions

Selection of study site

The Ekurhuleni Metropolitan Municipality, situated in the Gauteng Province of South Africa, was chosen as an appropriate study area for this research, mainly because it is one of the largest metropolitan municipal areas in the country and contains a large number of different suburbs, many of which are predominantly residential. Prior research outputs from 2 studies (Vorster et al., 1995; Stephenson and Turner, 1996) were also available from this region to serve as comparison. Spatial data of suburbs and individual properties, with corresponding water use information for the year 2004, could be obtained for all individual properties in the area, making it an ideal study area. At the time of publication Ekurhuleni Metropolitan Municipality comprised 9 Service Delivery Areas: Alberton, Benoni, Edenvale, Germiston, Kempton Park, Nigel, Springs, Tembisa and Vosloorus.

Scope and limitations

The research was based on data for the particular study site in the summer rainfall region of South Africa, and for the particular period. Extending the work to a larger geographical region – such as the country – would add the complexity of different climatic regions, which would affect water use patterns, as noted by Jacobs et al. (2004). The data analysis was limited to a cross section of data for the year 2004; time-series analysis was considered to be beyond the scope of this research, thus neglecting the impacts of climate change and climatic variations.

Incorrect interpretations of the results could be drawn if climatic data for the year 2004 were compared to averages in the region, because water distribution systems are not designed for an average year. For this reason it was considered appropriate to focus on the research problem at hand under these spatial and temporal limitations.

The findings should be read with these limitations in mind and should not be interpreted as design guidelines per se. Further research could extend the work in future to other geographic regions and validate the outcomes against typical climatic variables.

METHODS

Spatial description of suburbs

GIS-application and software tools

According to Du et al. (2009) the analysis capabilities of a geographic information system (GIS) make it an ideal tool to model and synthesise all decision-making information pertaining to water supply management. Beuken et al. (2010) also researched the potential of using GIS for the analysis and management of a water distribution system (WDS) and found GIS as an excellent integrated platform to capture, analyse and view water network data. As part of this research GIS was used to identify and obtain the required spatial information. GIS was used by Sinske and Jacobs (2013) to spatially extract, analyse, display and summarise all data pertaining to suburbs. In that process the GIS environment was used to delineate suburbs by means of triangulated irregular network modelling. Boundaries for suburbs with predominantly residential land use were created that included all residential properties according to the suburb name field as recorded in the treasury system, given certain filter criteria.

Suburb selection and description

South African urban areas are sub-divided into relatively homogeneous neighbourhoods, called suburbs. A suburb could incorporate any type of land use category, and would in fact typically include a mix of different land uses with one type being predominant. The first step was to obtain the GIS shape files for the suburbs and also the cadastral data base with individual properties' information in order to select appropriate suburbs for this research. The following GIS layers were available for this research:

- Suburb boundaries of the year 2010, as a single polygon shape for each suburb
- Cadastral layout of plots with individual parcel polygons for the year 2004
- Verified water consumption data of the year 2004 for individual properties
- Parcel centroid layer of the year 2004, giving the centroid of each individual parcel polygon

The suburb polygons were created in 2010. Unfortunately these polygons were not available for the year 2004, for it would have been less complicated to match this to the water consumption data of 2004. A key challenge was to merge the various databases to ensure a match between suburbs and the individual plots in each suburb, despite the mismatch in terms of the date as well as possible mismatches between suburb name strings in the different databases.

The second step was to extract from these general suburbs only those that have predominantly residential land use, based on pre-defined criteria as addressed in the following section. In order to assess the land use in each suburb it was necessary to evaluate the individual parcels, for which a land use description was available in the GIS database. Various fields were joined to the suburbs layer in GIS, based on the suburb name text string as common join field. The parcel layer from 2004 could be imported into the project. This parcel layer has fields for each plot containing information on the land use and the suburb name in which the plot is located.

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GIS models were specially developed in this study to:

- Obtain a suburb selection with predominant residential land use
- Retain only the suburbs with boundaries from 2010 that coincide with the underlying parcels' suburb names from 2004
- Retain only the suburbs where the AADD was available from the water demand data base
- Determine the water consumption and residential density per suburb

Suburban water demand

Water meter readings with corresponding date stamps were available for consumer meters in the study area on a monthly basis. The data used in this study was derived from the meter readings with a software programme called Swift. Jacobs and Fair (2012) provided a detailed description of the procedures used in Swift, and application of Swift in research projects. An account of the procedure is beyond the scope of this text.

The AADD values for about 2.5 million consumers in South Africa, extracted by means of Swift, were recorded in the National Water Consumption Archive (NWCA) compiled by Van Zyl and Geustyn (2007). The consumption data were aggregated to suburb level in a parallel study (Scheepers, 2009), without consideration of the suburb land areas in that study. The same data were used as the basis for deriving suburban AADD values in this research project.

The first step in terms of water demand was to isolate the study area and residential land-use category, leaving 377 suburbs and 345 807 plots in the database. Thereafter each stand's identity code, suburb name, land use type and AADD values were extracted from the comprehensive NWCA database. The AADD was expressed in kilolitres per day per plot (kℓ·d^{-1}·plot^{-1}). Suburbs that contained water consumption data for less than 10 plots were removed from the database to ensure that relatively small suburbs were not included in the analyses, in line with the objectives to assess water use on a relatively large spatial scale. The number of suburbs and individual plots was reduced to 323 and 345 620, respectively, after the filtering process.

In each suburb the AADD for all plots was summed to determine the total AADD per suburb. The total AADD for each suburb was subsequently married to the corresponding suburb's land cover area, as derived via the GIS methods described earlier.

Verification and filtering

Three peripheral models were developed with the embedded ModelBuilder application of ArcGIS to perform certain tasks during the analysis, including verification checks on the suburb names and also to attain only the predominately residential suburbs that comply with the desired criteria. The model was a typical binary model with a logical expression to select features from a feature layer, with 1 (true) for features that meet the selection criteria and 0 (false) for features that do not comply. Sinske and Jacobs (2013) provided a comprehensive flow diagram of the suburb delineation procedure. In the absence of a former definition for what would constitute a residential suburb, the following threshold percentages were specified in the input boxes for the filtering process:

- Percentage parcels of type 'residential' in a suburb > 70%, to ensure predominantly residential suburbs in terms of the number of properties
- Residential area as percentage of the total suburb area > 50%, to ensure predominantly residential suburbs in terms of the total area with this land use
- Percentage of combined residential area, public open space and institutional areas in the suburb > 60%, to remove suburbs that included relatively large expanses of unrelated land uses such as agricultural smallholdings or undeveloped land
- Percentage of parcels with type 'business' < 5%, to ensure that suburbs with predominantly residential land use based on area and property counts, but with notable clusters of business properties, were not included
- Percentage business area in the suburb < 5%, to ensure that suburbs with predominantly residential land use based on area and property counts, but with notable business properties in terms of area, were not included
- Percentage of parcels with type 'industrial' must be 0%, to exclude all industrial land uses that could easily skew the results
- Based on the verification check for the suburb name, more than 95% of parcels in any suburb must have matching suburb names
- Percentage difference between the number of residential plots counted in the suburb based on the spatial analysis and the number of plots counted in the AADD data base < 15%

The criteria were set with the aim of selecting only those suburbs which were considered to be predominantly residential from various perspectives. Sensitivity analyses in terms of parameter selection and the subsequent filter values were not conducted. Instead, the final selection was achieved by successively adding complexity in terms of the number of parameters, while increasing the level of fitness so that fewer and fewer suburbs were selected that better represented true residential areas. After each step the selection was reviewed subjectively by adjusting the filter until a sufficient number of suburbs were selected that were considered to be mainly residential in nature. After processing the filter a final list was compiled containing the suburbs (i) that were predominantly residential and (ii) for which a reasonably good match could be obtained between the different databases. Thus, their corresponding per area water demand and residential density values could be calculated as part of the model procedure. The GIS model was used to export the results as a dBASE table, which was imported in MS Excel for further analysis.

RESULTS

Number of selected suburbs passing the filter

Ultimately 82 of the 468 suburbs in the 2010 GIS database (and 377 suburbs in the water demand database) met the criteria described above. The different total number of suburbs was due to changes in the Ekurhuleni Metropolitan Municipality boundaries between 2004 and 2010. This relatively small selection of 82 could be explained by the fact that many suburbs actually include other land-use types that prevent them from passing the stringent filter for residential suburbs applied in this study. The selection also excluded some suburbs simply due to inconsistencies in the database entries; suburb names (or spelling of names) may have changed between 2004 and 2010, or were inconsistently reported in the different databases.

Calculation method and initial results for 82 suburbs

The residential plot density, expressed in units of plots·ha⁻¹, was calculated for the 82 suburbs by dividing the total number of residential plots in each suburb by the total suburb area (ha). It was immediately apparent that 12 of the suburbs meeting the criteria for selection set out above were atypical and skewed the results, as discussed below.

Additional filter for plot density

An additional filter was added and employed in MS Excel to limit the residential plot density to less than 10 plots·ha⁻¹. This filter subsequently excluded 12 suburbs with relatively high residential plot densities ranging from 13.7 to 23.7 plots·ha⁻¹, thus representing relatively small plots.

In addition 10 of these 12 suburbs resulted in the highest water use per unit area of all suburbs in the selected set, with another being one of the remaining highest values. In contrast, the last of the 12 presented the 4th-lowest value for water demand per unit area of all 82 suburbs. These 12 suburbs were subsequently inspected on an individual basis. All 12 were identified as being extremely low-income, high density areas often referred to locally as being previously disadvantaged communities from a socio-economic perspective. A characteristic of these areas in terms of water use is that the infrastructure leakage index (ILI) for such areas is typically high (Still et al., 2008; Seago et al., 2004). Another characteristic of such areas is poor metering and payment, which could have led to low water use readings. This provided possible explanations for the atypical nature of results from these suburbs. For the purpose of this research it was considered appropriate to thus limit the residential plot density to 10 plots·ha⁻¹. The results presented in this paper are for the remaining 70 suburbs that meet all criteria for selection.

Water demand per unit area

Presenting suburban AADD in units of kℓ·d⁻¹·ha⁻¹ of suburb area, in addition to the more common units of ℓ·d⁻¹·m⁻² (CSIR, 1983; Jacobs et al., 2004) of property area, has the advantage that estimates of the AADD for any proposed suburb development can quickly and easily be estimated in a robust way. Most former methods of this nature were based on per capita demand, but valid estimates of population are often hard to come by. In contrast, urban planners preferentially describe a proposed development in terms of the total suburb land area (in ha). The only South African report on suburban water demand per hectare in terms of typified residential suburbs to date was by Vorster et al. (1995), who reported 8 to 11 kℓ·d⁻¹·ha⁻¹ for low-density residential areas and 11 to 15 kℓ·d⁻¹·ha⁻¹ for medium density residential areas. Unfortunately no definition was provided in that publication as to what low- and medium density meant and the values cited were presented without an explanation of how they were derived.

Similar results to those by Vorster et al. (1995) and Stephenson and Turner (1996) were derived as part of this research and it was thus possible to directly compare the findings to their work, particularly since all three studies were conducted in the same study area. The AADD per unit area for any suburb could be presented with one of the following

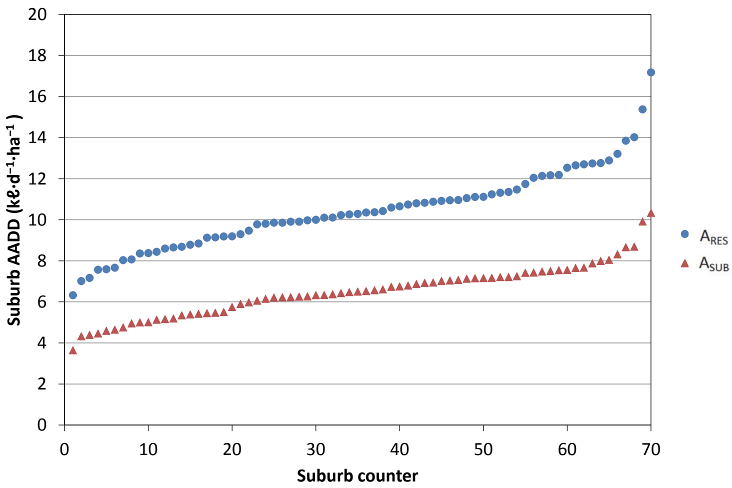

Figure 1
Ranked suburban water demand for the 70 selected suburbs

denominators:

- The total suburb area, A_{SUB} (thus including all open space, roads, and the limited non-residential land use areas in what is deemed a predominantly residential suburb based on the filter employed)
- The total residential plot area, A_{RES} (equal to the sum of all individual residential plot areas in the suburb)

Both results were calculated for the 70 suburbs and compared to the values presented earlier. Subsequent discussion with two of the authors of the former work (Geustyn and Loubser, 2012) suggested that A_{SUB} was used in their analysis and also that the residential land use and description of the density (low or medium density) was based on subjective judgement at the time. Both former studies stopped short of providing detail of the parameters used for deriving the *AADD* per unit area.

The ranked values of suburb water demand per unit area for the 70 suburbs in the selected data set in terms of A_{SUB} and A_{RES} are shown in Fig. 1. The range shown and the average value of 10.4 kℓ·d⁻¹·ha⁻¹ based on A_{RES} agrees well with the values of 8 kℓ·d⁻¹·ha⁻¹, 11 kℓ·d⁻¹·ha⁻¹ and 15 kℓ·d⁻¹·ha⁻¹ put forward by Vorster et al. (1995), despite those authors recalling that A_{SUB} was used in their analysis. Stephenson and Turner (1996) noted that water consumption per unit area for 'normal residential areas' was 'about 10 kℓ·d⁻¹·ha⁻¹', but reported 5 kℓ·d⁻¹·ha⁻¹ in regions with lower levels of supply (such as yard taps or stand pipes) and up to to 20 kℓ·d⁻¹·ha⁻¹ for cluster housing and apartments. It is not clear whether these values compare to those from this study based on A_{SUB} or $A_{RES.}$ The suburb unit water demand based on A_{SUB} is notably lower, because the residential cover is less than 100%. The average water demand based on A_{SUB} was 6.6 kℓ·d⁻¹·ha⁻¹, with 90% of all values between 4.4 kℓ·d⁻¹·ha⁻¹ and 8.7 kℓ·d⁻¹·ha⁻¹. In addition to uncertainties in results from the former study, the implementation of water demand management (WDM) initiatives over the past decade (McKenzie and Wegelin, 2009; Still et al., 2008) provides a plausible explanation for a reduced demand, as indicated by the results of this research compared to that reported in 1995. Also, the level of service may have changed since the previous study due to the fact that some homes had aged, while new homes were also added to the study region over time. It should be recalled that the effects of climate and climate change on results were not assessed.

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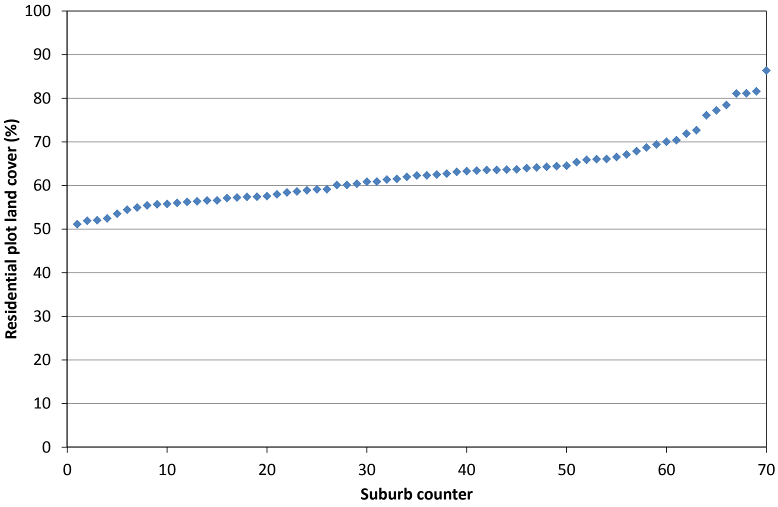

Figure 2
Ranked values for residential cover as percentage of total suburb area

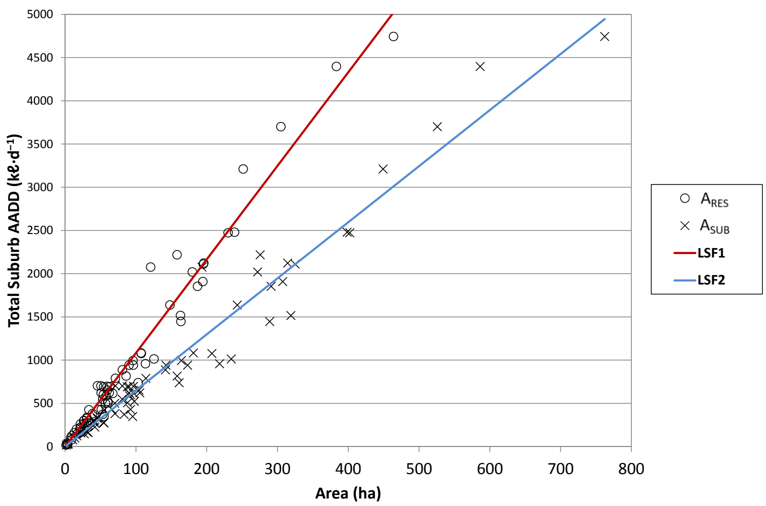

Figure 3
Suburb water demand as function of suburb areas A_{SUB} and A_{RES}

Residential plot cover

The fraction of ground covered by residential plots was calculated for each suburb to investigate its impact on the water use per unit area, but no correlation between these variables was apparent. The ranked values of land cover for all 70 suburbs are shown in Fig. 2. The average residential cover for all suburbs was 63%, meaning that, on average, 63% of the land area in a suburb would be filled with residential plots. The remaining 37% of land area in this case would be a mix of roads, public open spaces, parks, and the limited other land use types that were allowed to pass through the filter, bar industrial (which was set to 0% in the filter procedure). This makes sense when referring back to the average water demand values of 10.4 kℓ·d⁻¹·ha⁻¹ based on A_{RES}, and 6.6 kℓ·d⁻¹·ha⁻¹ based on A_{SUB}, with the latter being 63% of the former.

Suburban area as independent variable

A key objective of this research was to investigate the effect of A_{SUB} and A_{RES} on the suburban AADD. The total suburban

TABLE 1
Linear equation parameters to describe the suburb AADD

Parameter	LSF1	LSF2
$AADD_{SUB}$	Suburb $AADD$ (kℓ·d⁻¹)	
x	A_{RES} (ha)	A_{SUB} (ha)
β	0	0
α	10.824	6.487
R^2	0.9667	0.9561

AADD was found to increase linearly with both these areas, as shown in Fig. 3. The difference between abscissa for each suburb's A_{SUB} and corresponding A_{RES} value is due to the percentage residential cover.

Linear equations of the form $AADD_{SUB} = \alpha{\cdot}x + \beta$ were fitted to both series by means of least squares fit (LSF) and by fixing the origin in each case to (0;0), thus setting β=0. The appropriate parameters for the lines LSF1 and LSF2 as shown in Fig. 3 are summarised in Table 1.

DISCUSSION

The slope α is of particular interest, because it was also possible to derive slopes of similar lines from previous plot-based guidelines for AADD by making some assumptions. The results of this study make provision for the water consumed within a suburb boundary by individual residential consumers. Non-revenue water is thus excluded per definition, as was the case with previous plot-based guidelines by Jacobs et al. (2004) and Van Zyl et al. (2008). Both the cited studies provided estimates for AADD based on the plot size of individual residential properties. By assuming a constant 63% residential cover in all suburbs, equal to the average of all suburbs in this study, the plot size could be varied and a total suburban demand could be derived from both the former guidelines for entire suburbs as part of this study. The individual plot size was varied from 500 m² to 2 000 m² to compare typical residential plot sizes addressed by the former studies. In each case the derived lines were linear and passed through the origin, so only the slope for each line was needed for comparison with results from this study, as shown in Table 2. The process was repeated to find the linear slopes α_{SUB} and α_{RES}, respectively, in terms of A_{SUB} and A_{RES}.

The derived slopes and thus water demand for a particular suburb size increased in all cases with decreased individual plot size. This may seem like a paradox, because the AADD-guidelines based on plot-size (Jacobs et al., 2004; Van Zyl et al., 2008) provide an increased demand per plot with increased plot area. However, the smaller plots result in an increased density of plots per hectare. The results from this study suggest a constant slope when considering an entire suburban area. This is explained by the fact that a particular suburb typically comprises a mix of different plot sizes.

Any change in the assumed cover percentage of 63% in the above procedure would only impact the slope α_{SUB} , because α_{RES} is based on a 100% cover percentage in the first place. The

TABLE 2 Comparison of results to former plot-based AADD-guidelines				
Slope	α_{SUB}		α_{RES}	
LSF to data	**6.5**		**10.8**	
Linear slopes derived from AADD-guidelines as function of individual plot-size				
Plot size (m^2)	Jacobs et al. (2004)	Van Zyl et al. (2008)	Jacobs et al. (2004)	Van Zyl et al. (2008)
500	8.6	16.0	13.7	25.3
750	7.0	12.0	11.1	19.0
1 000	6.1	9.8	9.8	15.6
1 250	5.6	8.4	9.0	13.3
1 500	5.3	7.4	8.4	11.7
1 750	5.1	6.6	8.1	10.5
2 000	4.9	6.0	7.8	9.6

results for suburban AADD presented here agree better with those of Jacobs et al. (2004) than Van Zyl et al. (2008), because the AADD-guideline presented by Van Zyl comprised a country-wide analysis while that of Jacobs et al. (2004) provided estimates for 4 different geographical regions. It was thus possible to select the equation from Jacobs et al. (2004) for estimating AADD for the study area located in the inland summer rainfall region specifically.

CONCLUSION

Suburban water demand per unit area

This paper presented the first comprehensive analysis of annual average suburban water demand on an area-wide scale in South Africa. The AADD was expressed in units of kℓ·d⁻¹·ha⁻¹ to provide a robust method for estimating AADD when only the suburb size is available. Stringent filtering of various databases led to the ultimate selection of 70 suburbs for detailed analysis. The average AADD for all 70 suburbs, based on the suburb area A_{SUB}, was 6.6 $kℓ·d^{-1}·ha^{-1}$, with 90% of the values in the range between 4.4 $kℓ·d^{-1}·ha^{-1}$ and 8.7 $kℓ·d^{-1}·ha^{-1}$. The average unit demand was 10.4 $kℓ·d^{-1}·ha^{-1}$ for the calculation based on A_{RES}. The difference between the suburban AADD results based on A_{SUB} and A_{RES} was due to the percentage of residential cover in a suburb; an average of 63% cover was found for all suburbs. The total suburb AADD was explained in terms of the total suburb area A_{SUB} and the total residential area A_{RES} in each suburb. Linear equations were fitted for estimating the suburb water demand $AADD_{SUB}$ ($kℓ·d^{-1}$) in terms of A_{RES} (ha) and A_{SUB} (ha), resulting in R^2 values above 0.95:

- $AADD_{SUB} = 10.824·(A_{RES})$
- $AADD_{SUB} = 6.487·(A_{SUB})$

Recent research into water demand per area (Jacobs et al., 2004; Husselmann and Van Zyl, 2006; Van Zyl et al., 2008) focused exclusively on the individual residential plot size A_{PLOT} (called stand size in those publications) as independent variable. No attempt was made to spatially aggregate the demand in those studies to suburb level. A possible explanation for the lack of published suburb-scale results may lie in the fact that suburb polygons and corresponding water use data for predominantly residential suburbs was not readily available. A notable portion of the work in this research project involved procedures for defining, identifying and mapping the suburbs spatially, with corresponding water use of individual plots in each suburb.

Future research needs

The project could be extended to include other regions of the country, but this would require an improved method for suburb selection. A spatial tool was subsequently developed for this purpose to automatically delineate suburb boundaries in the ArcGIS environment (Sinske and Jacobs, 2013). A comprehensive data set of suburbs from all over the country would enable the analyses to be performed for different geographical regions, as was the case with the AADD guideline presented by Jacobs et al. (2004) based on individual plot size.

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