Spatial inequality in water access and water use in South Africa

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Abstract

The importance of measuring inequalities in sustainable development is reflected in the requirement to disaggregate national data for the Sustainable Development Goals (SDGs). In this paper, piped water access, water use and water stress are mapped and reported at national, provincial, district, municipal, town and ward levels, and urban and rural areas. The results show that although 45% of the population has water access in their dwelling this ranges from 0.07% to 100% at ward level, with a high level of inequality (Gini index of 0.36). National per capita water use is 208 litres per person per day (l/c/d) but ranges from 8 l/c/d to 2,414 l/c/d at town level, with a Gini index of 0.27. The analysis shows that social factors, such as water access and income, and not natural factors, such as rainfall or runoff, have the greatest influence on per capita water use. The paper provides the first in-depth analysis of per capita water use at the local level across South Africa and suggests new water indicators that could support equitable allocation of water resources and SDG reporting.

Keywords: Data disaggregation; Non-income inequality; Per capita water use; SDGs; South Africa; Water access; Water stress

Introduction

The United Nations (UN) '2030 Agenda for Sustainable Development' and its 17 Sustainable Development Goals (SDGs), adopted in September 2015 (UN General Assembly, 2015) provide a global vision to end poverty and hunger, protect the planet from degradation, ensure prosperity for all, and foster peaceful, just and inclusive societies by 2030. Equality is at the heart of the SDGs. In addition to Goal 5 on

gender inequality and Goal 10 on income inequality, national data across the goals must be disaggregated by income, gender, age, race, ethnicity, migratory status, disability, geographic location and other characteristics relevant in national contexts to measure inequality (UN General Assembly, 2015).

Data disaggregation by geographic location is useful for social and environmental indicators as the data can support policy implementation at sub-national levels. Spatial disaggregation of social data, such as income and water access, is particularly useful in South Africa as spatial inequality was entrenched in the 1900s by the very limited service delivery to the 'homelands' (territories set aside for black inhabitants as part of the apartheid agenda of racial segregation) and low-income urban and peri-urban areas. At the end of white minority rule in 1994, 20% of households had no access to piped water but this varied from 1% to 98% across municipalities (StatsSA, 2013). South Africa has extreme income inequality, with a Gini index of 0.65 (DPME, 2015) compared to Sweden, with a Gini index of 0.22, the least unequal country (Solt, 2009).

Spatial disaggregation of environmental data, such as water stress, is useful in South Africa as the limited water resources are very unevenly distributed across the country (see Figure 1). More than 60% of its river flow arises from only 20% of the land area requiring large-scale inter-basin transfers (DWA, 2013). South Africa is the 30th driest country in the world with low and highly variable rainfall (both inter- and intra-annually), erratic runoff, high evaporation and shallow dam basins (DWA, 2013). With a current population of 55.91 million people (StatsSA, 2016) and total annual renewable resources of 51,350 Mm^3/a, South Africa is a water-scarce country with a Falkenmark index of 918 m^3/c/a.

Water was enshrined as a basic human right in South Africa's 1996 Constitution (Republic of South Africa, 2012), 14 years before the UN explicitly recognised the human right to water (UN General
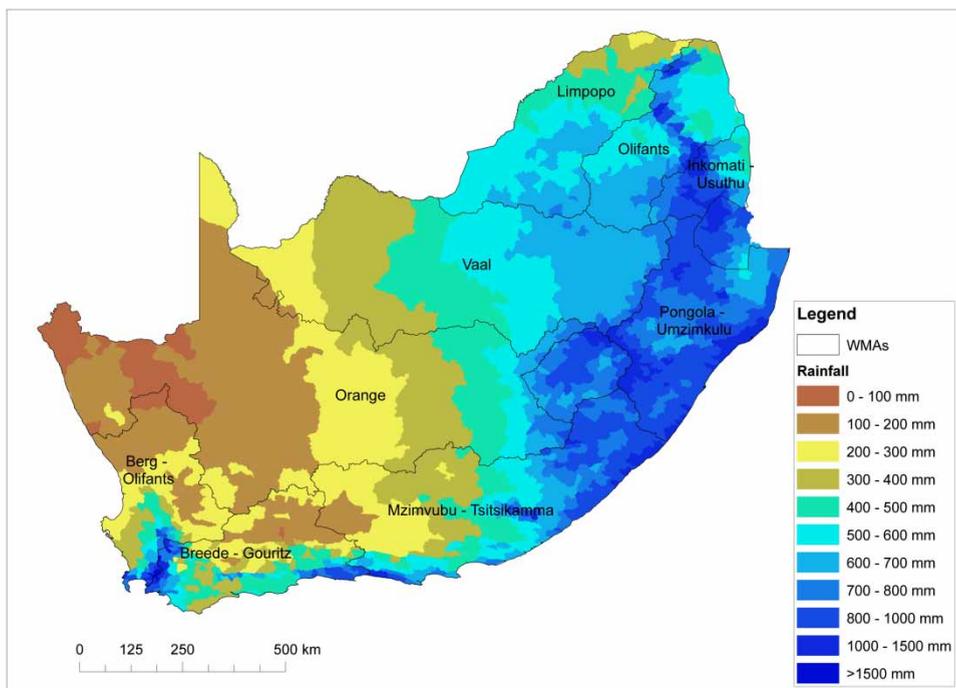

Fig. 1. Map of South Africa's annual rainfall across Water Management Areas (WMAs).

Assembly, 2010). Since then significant progress has been made on access to water and sanitation, but inequalities remain. The primary goal of the National Water Resources Strategy of 2013 is equity and redistribution, and poverty eradication and equity are (in policy if not practice) prioritised over strategic uses (inter-basin transfers and electricity generation) and economic purposes in the allocation of water resources (DWA, 2013).

In this paper, the current state of water inequality in South Africa is assessed, providing a case study of SDG data disaggregation and reporting, and supporting more effective policy-making. Water access (SDG 6.1), water use and water stress (SDG 6.4) are mapped and reported at national, provincial, district, municipal, ward and town levels in South Africa (see details on administrative levels in Table 1). The Methods section describes how data were obtained from the national census and 843 town, village and metro water reconciliation strategies, and analysed using geographical information systems (GIS), distribution plots, scatter plots, multiple linear regression, descriptive statistics and Lorenz curves. The Results and discussion section provides maps, and measures of variability and inequality for water access, use and stress. Gini indexes and Palma ratios for inequality in piped water access and per capita water use are presented. Factors affecting the spatial distribution of water access and per capita water use are identified, new indicators for monitoring SDG 6 and measuring non-income inequality are suggested and policy recommendations are made.

Methods

Selecting water indicators

South Africa's official development indicator for sufficient water access is 'households with at least 25 litres of potable water per person per day within 200 m of a household, not interrupted for more than 7 days per year', termed the 'RDP[1] standard' (DPME, 2015). This level of access has steadily improved since the advent of democracy, increasing from 62% in 1994 to 86% in 2014 (DPME, 2015). However, this indicator focuses on extreme poverty and does not tell us much about overall inequality. Less than half of South Africa's population has piped water access in their dwelling, only increasing slightly from 44% in 1996 to 46% in 2011 (StatsSA, 2014). The UN Human Development Report 2006 and the World Health Organization (WHO) recommend that 50–100 litres per capita per day (l/c/d) of water should be piped into households for human development (Watkins *et al.*, 2006) and to maintain adequate health (Howard & Bartram, 2003). This is reflected in the government's unofficial target of 60 l/c/d. In this paper the indicators 'persons piped water access in the dwelling', 'town per capita water use' and 'town per capita water stress' are selected for analysis.

Sourcing the data

Data on piped water access are collected by Statistics South Africa (StatsSA) annually in the General Household Survey (GHS) and once a decade in the national census (StatsSA, 2012a). The GHS results are reported at the provincial level while the census results are reported at municipal level, but sub-municipal census data can be found in the SuperCross and SuperWeb databases. The Department

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[1] Reconstruction and Development Programme, the first democratic socio-economic policy framework.

Table 1. Hierarchy of government and water management scales in South Africa.

Water services			Water resources	
Administrative levels	Population in 2011	Area (km^2)	Management levels	Area (km^2)
National	51,770,560	1,220,813	National	1,220,813
Province (9)	1,145,861 to 12,272,263	18,178 to 372,889	Water Management Areas (9)	12,880 to 234,770
District (52)	71,011 to 4,434,827	1,645 to 126,836	Sub-Water Management Areas (86)	1,500 to 104,000
Municipality (234)	7,003 to 4,434,827	252 to 36,128	Quaternary catchments (1,855)	48 to 18,128
Ward (4,277)	360 to 91,717	0.15 to 29,838		

Notes: The number of administrative or management units are given in brackets. The ward boundaries used in the 2011 Census were defined in 2010. Eight metropolitan areas are classified as both districts and municipalities.
Data sources: Census 2011 (StatsSA, 2012b, 2014) and GIS shapefiles (DWA, 2012).

of Water and Sanitation (DWS) uses these figures to report households with water access 'at and above RDP standard' or 'below RDP standard' at the municipal level data. The most recent modelled and updated data are reported in the National Water Services Knowledge System (DWS, 2016a). As the census is the only source that provides data on piped water access in dwellings at the lowest spatial levels, it was used in this paper. Census data for all 4,277 wards were extracted from StatsSA's Super-Web database (StatsSA, 2014) and compiled by municipality, district and province and by urban and rural area (classified as traditional/tribal area[2] or commercial farm 'geotype').

Per capita water use is not regularly reported in South Africa, and although it could be calculated from municipal water accounts, these are not publically available. Supply and demand in the eight metropolitan areas (metros), home to 40% of the population (StatsSA, 2012a), were measured or estimated in DWS reconciliation strategies for the major water supply systems (WSS) (DWAF, 2007, 2009, 2011; DWA, 2009, 2011a, 2012). The different WSS studies were undertaken over an 8-year period so that the 'current' status varies from 2006 to 2011, but all except the most recent study (for Mangaung metro) has had regular status updates which are available on the DWS website. For this paper, the 2011 figures for demand and supply were extracted for the urban areas in the WSS reports to ensure that the per capita figures were as accurate as possible.

In 2007/8, the DWS published water reconciliation strategies for all towns and rural villages in South Africa to inform water resource investment and management decisions (DWA, 2013), providing the first comprehensive water use information at the local level across South Africa. The so-called 'All Town Studies' grouped towns and rural villages into 838 logical clusters based on their water supply. The studies reported 'current' (2007/8) and projected (2010 to 2035) water requirements including losses (demand) and yields (supply) based on population growth scenarios, reconciliation options (e.g., water conservation) and augmentation measures (e.g., groundwater). In many cases, insufficient data of actual water consumption and water supply were available, and estimates and assumptions had to be made. Demand estimates were based on water allocations reported in the Water Authorisation and Registration Management System (WARMS) database (DWA, 2014) and/or population, type of housing/settlement and level of basic services (see details in the Supplementary information, Section S1 and Tables S1 to S5; the Supplementary information is available with the online version of this paper). Supply estimates were based on mean annual runoff (MAR), 98% assurance of supply, existing

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[2] Communally owned land under the jurisdiction of a traditional/tribal leader, and rural informal settlements (StatsSA, 2012b).

infrastructure, return flows, allocation in WARMS and the sustainability of groundwater resources. They did not make provision for the ecological reserve, the minimum requirement for ecological functioning in rivers, which varies significantly at the local scale and when aggregated is 19% of total MAR at the national scale (DWAF, 2004).

Apart from two provincial summaries for the Western Cape (DWA, 2011b) and Eastern Cape (DWA, 2011c), there is no summary report of the All Town Studies. The 838 town reports are, however, available on the DWS website (DWS, 2016b). For this paper, the 'current' demand, supply and population data were extracted from each report and compiled at the ward, town, municipal, district, province and national levels (see Supplementary information, Section S2: provincial data in Tables S6 and S7, ward data mapped in Figure S1, town data plotted in distributions in Figure S2 and Excel spreadsheets). In addition, the residential per capita water use reported in 74 town studies in KwaZulu-Natal province was extracted to investigate the purely residential component of town use. Also, the end-user per capita use (which excludes bulk transmission losses and internal network losses) was reported in 278 town studies in the Eastern Cape and Western Cape, and this was also extracted for analysis.

Calculations

Using demand, supply and population in the WSS reports and All Town Studies, the per capita water use and per capita water stress (supply less demand divided by population) of each metro, town and village cluster was calculated. They were weighted by population so that small towns with high per capita figures did not skew the results.

The descriptive statistical properties (mean, range, standard deviation, coefficient of variation) of the three indicators (water access, water use, water stress) were calculated at municipal, district, provincial and national levels using the ward and town data sets. The results were plotted on maps using the 2011 administrative boundaries provided online by the Municipal Demarcation Board (MDB, 2015). It would have been preferable to plot the water use and water stress data at the town scale but no GIS data files were available for this.

Using the ward and town data sets, a Gini index and Palma ratio for piped water access in dwellings and per capita water use were calculated for South Africa (Supplementary information Table S8), its nine provinces (Supplementary information Tables S6 and S7) and 52 districts (Supplementary information Figure S3). Gini indexes and Palma ratios were not calculated for per capita water stress as many of the figures are negative. The detailed calculation method is provided in the Supplementary information, Section 3. The same properties were calculated at national level using aggregated municipal, district and provincial data to assess the effect that the scale of the data set used had on the result (see Figure S4).

The Gini index, the most widely used inequality index, is a measure of the distribution of income inequality across the whole of society (plotted on a Lorenz curve) with a natural benchmark of pure equality of zero (Palma, 2011; Cobham *et al.*, 2015). Although the Gini index is normally used for income inequality, it has been used to measure inequality in the distribution of land and water resources (e.g., Carter, 2000; Erickson & Vollrath, 2004; Cullis & van Koppen, 2007; Wang *et al.*, 2011), and by Bhorat *et al.* (2009) to measure changes in non-income inequality in South Africa. The Palma ratio is a new measure of inequality based on Palma's (2011) evidence that in most countries there is great heterogeneity between the top 10% (the tenth decile, D10) and the bottom 40% (the first decile, D1 to the fourth decile, D4) of the population. The Palma ratio measures the ratio of D10 to D1–D4; the ideal Palma ratio for income inequality is 0.25, although the global average is 1.8 and South Africa's is

11.6 (Cobham & Sumner, 2013). The SDG target 10.1 on reducing income inequality uses language similar to the Palma ratio (IAEG-SDG, 2015).

Analysis

To interrogate the variation in the town per capita water use results, 18 possible explanatory variables were identified and 14 (those with available data) were plotted in scatter plots (see Supplementary information, Section 4, Figures S5 and S6). Eight variables related to water supply were assessed: mean annual precipitation (MAP), mean annual evaporation and MAR[3], total supply, percentage groundwater in total supply, household main water source, overall water balance[4] and piped water access in the dwelling[5]. Six variables related to water demand were assessed: household size, household access to flush toilets, household ownership of a washing machine, annual household income, formal housing and urban location. Factors that affect per capita water use but could not be included due to lack of available data were physical losses, water price, property size (identified by Van Zyl *et al.* (2008) as the best parameter for municipal water-demand estimations in South Africa), and consumers' knowledge about their water use (identified by Smith & Visser (2013) as the most influential behavioural factor in water use in Cape Town). The six demand-related variables showed a correlation to per capita water use and were used in multiple linear regression to determine their effects on use. Full details are provided in the Supplementary information, Section 4. To interrogate per capita water stress, the results were compared with the water balances reported in the first National Water Resource Strategy (DWAF, 2004).

Results and discussion

Persons with piped water access in dwellings, town per capita water use, and town per capita water stress, are mapped at municipal, district and provincial level in Figure 2. Piped water access in wards is mapped in the Supplementary information, Figure S1 (the Supplementary information is available with the online version of this paper). The maps are powerful communication tools, highlighting the spatial nature of poverty, inequality and access to resources, and supporting effective 'geographical targeting' – focusing efforts on key areas (Henninger, 1998) – which has the potential to be a more efficient system of allocation of scarce resources than means testing[6] (Bigman & Fofack, 2000; Cullis & O'Regan, 2004). The efficiency of geographical targeting improves as the resolution improves, i.e., more of the poorer households are included at lower scales (Cullis & O'Regan, 2004) and therefore the ward and municipal level maps are the most useful.

Table 2 summarises the results of the analysis of sub-national variability and inequality in water access, use and stress. Distribution plots for all three indicators are provided in the Supplementary information, Figure S2. Figure 3 plots the Lorenz curves used to determine the national and provincial Gini indexes and Palma ratios for piped water access and town per capita water use. The results for each indicator are discussed below.

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[3] For the quaternary catchment the town/village is located in.
[4] For the towns/villages.
[5] For the municipality the town/village is located in.
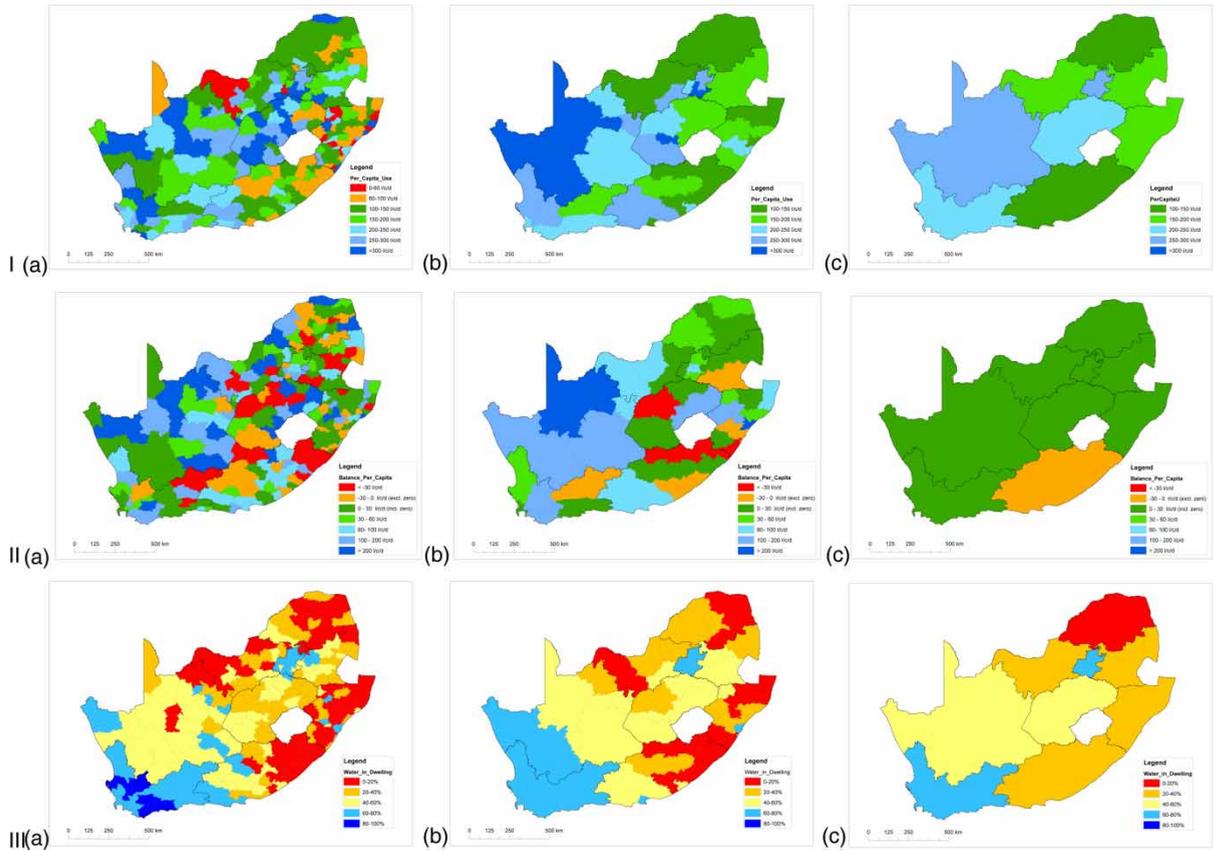[6] Usually based on income and savings.

Fig. 2. Municipal (a), district (b) and provincial (c) maps of I. per capita water use and II. town per capita water stress, and III. persons with piped water access in the dwelling in 2011.

Piped water access

Although 45% of the national population has piped water access in their dwelling, this ranges from 0.07% in ward 19 in rural Umzimbuvu, Eastern Cape to 100% in ward 9 in urban Midvaal and ward 19 in urban Merafong City, Gauteng. Across the provinces, piped water access in dwellings ranges from 18% in Limpopo to 78% in Gauteng (see Supplementary information, Table S6). The national Gini index for piped water access in dwellings is 0.36 but varies across provinces, from 0.06 in the Western Cape (least unequal) to 0.57 in the Eastern Cape (most unequal), and across districts, from 0.05 in the Cape Winelands to 0.72 in O.R. Tambo.

The wards with the lowest access (<2%) are almost all in traditional/tribal areas in the Eastern Cape and KwaZulu-Natal. There is a stark difference between urban, traditional/tribal and commercial farm areas, which make up 63%, 32% and 5% of the total population, respectively. While 65% of urban dwellers have piped water in their dwelling, 34% of those living on farms and only 8% of those living in traditional/tribal areas have this level of access. Ninety per cent of people with piped water in their dwelling live in urban areas, indicating that the type of housing is not the main barrier to water access, but rather the geographic location. Combining census data with GIS provides a powerful

Table 2 . Summary of variability and inequality in water access, water use and water stress.

Indicator	Access People with piped water access in their dwelling (%)	Use Town per capita water use (l/c/d)	Stress Town per capita water balance (l/c/d)
Weighted mean	45	208	24
Minimum	0.07	8	−303
Maximum	100	2,414	4,949
Range	99.93	2,406	5,252
Standard deviation	33	182	402
Coefficient of variation	0.72	0.88	16.87
Gini index	0.36	0.27	
D1–D4 share (bottom 40%)	11.3%	20%	
D5–D8 share (middle 40%)	52.5%	46%	
D9–D10 share (top 20%)	36.2%	34%	
D10 share (top 10%)	19.3%	19%	
Palma ratio (D10/D1–D4)	1.71	0.95	

tool to identify the most deprived areas in the country and support geographical targeting for service delivery. The results show that these maps should be at as fine a resolution as logistics allow, and make a case for additional data capture beyond the census (undertaken once a decade) and the GHS (which only gives provincial resolution). Administrative data collected as piped water is provided to new households could be used to update the census figures, while satellite imagery could be used to identify households with communal taps or taps in their yard.

Lack of service delivery in South Africa is largely due to logistics, cost and affordability, and national policy being to upgrade or replace informal settlements with formal settlements, which is a slow process. Other challenges to achieving universal service delivery are the growth in number of households (from 8.7 million in 1994 to 14.5 million in 2011) and internal migration between provinces and urban/rural areas (Nnadozie, 2011). The government aims to increase the percentage of households with access to 'a functional water service' to 90% by 2019. This is still a long way off from achieving piped water in all dwellings, the optimal type of water access for human development and health. Cost-effective ways need to be found to provide piped water access to rural households and to keep track of the changing demand for water access. One low-cost data collection method would be mobile phone surveys and crowd sourcing.

Per capita water use

Although the analysis shows that national per capita water use (including water losses) for towns is 208 l/c/d, this ranges from 8 l/c/d in rural Kokomeng, North West to 2,414 l/c/d in the mining town Aggeneys, Northern Cape. Across the provinces, per capita water use ranges from 1,14 l/c/d in Limpopo to 295 l/c/d in the Northern Cape with a coefficient of variation of 0.29. The national Gini index is 0.27 but varies across provinces, from 0.07 in the Western Cape (least unequal) to 0.35 in the Northern Cape (most unequal).

Results showed that 75 towns and village clusters are at or below the government minimum threshold of 60 l/c/d. Of the 32 towns/clusters using less than 40 l/c/d, almost all of them rely solely on
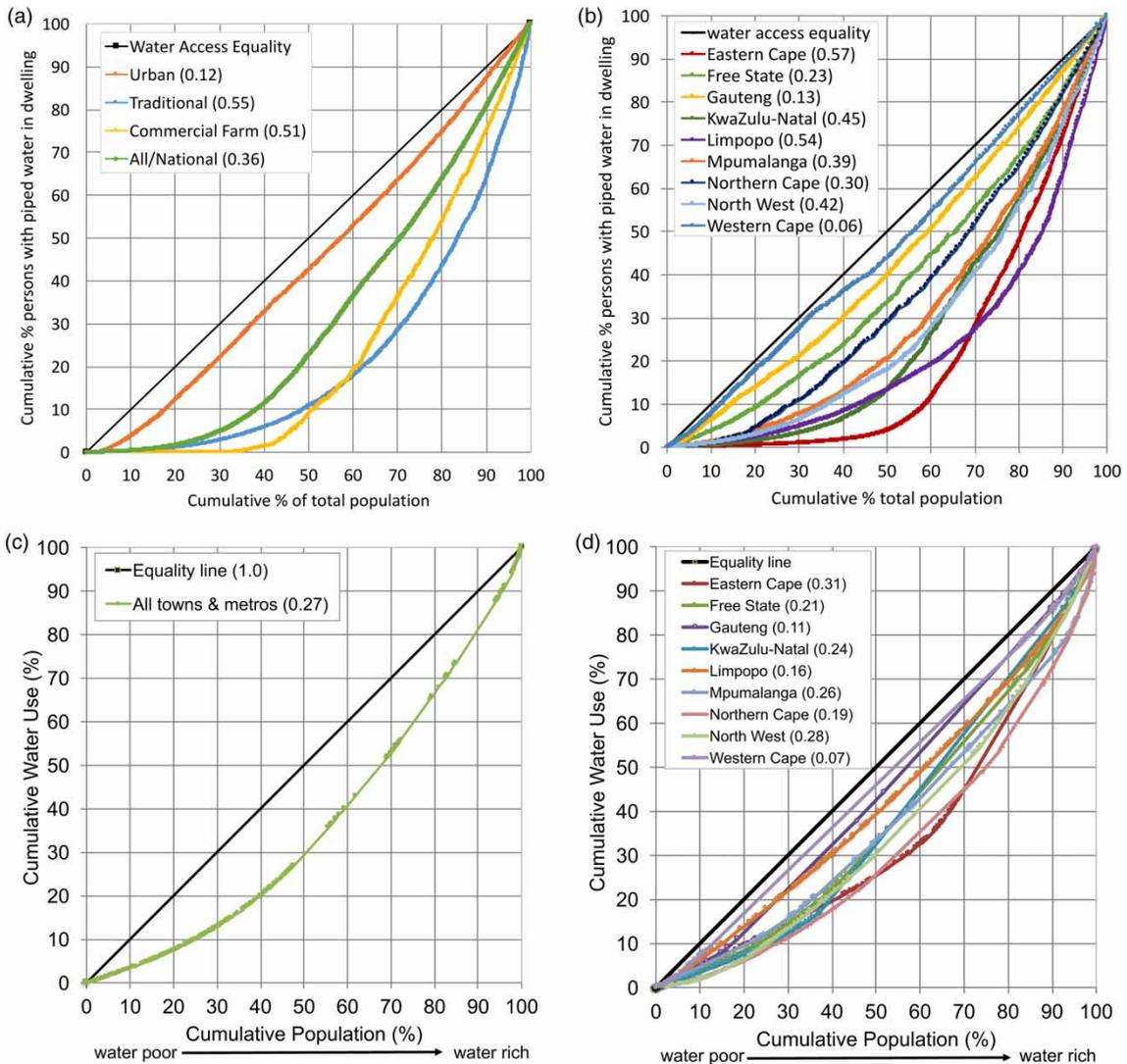
Fig. 3. Lorenz curves for (a) piped water access in dwellings in all urban, traditional and commercial farm areas, (b) provincial piped water access in dwellings, (c) per capita water use in all towns, villages and metros and (d) provincial per capita water use.

groundwater with relatively low borehole yields. At the opposite end of the spectrum, 28 towns use more than 500 l/c/d and seven towns use more than 1,000 l/c/d. Four of these are small mining towns in the Northern Cape – Aggeneys (2,414 l/c/d), Kleinsee (1,719 l/c/d), Hotazel (1,509 l/c/d), Kommagas (1,015 l/c/d) – and two are coastal holiday town clusters – Cape St Francis and St Francis (1,262 l/c/d) in the Eastern Cape and Betty's Bay, Rooi Els and Pringle Bay (1,196 l/c/d) in the Western Cape. The latter have high non-resident holiday populations that are not reflected in the per capita figures. There is greater variation in per capita use among the smaller populations (the smallest being 33 people in Cape Infanta) whereas there is an averaging effect for the larger towns and cities (the

largest being 4,434,827 people in the city of Johannesburg) and therefore a smaller range. The metros and large towns should therefore be disaggregated to reveal a more accurate picture of the distribution within these areas. The range between municipalities is also significant, however, ranging from 29 l/c/d to 1,037 l/c/d.

The residential per capita use in 74 town reports in KwaZulu-Natal ranges from 50% to 100% of total demand, with an average of 80%. The town per capita end-use (which excludes losses) for 278 town reports in the Western Cape and Eastern Cape ranges from 20% to 96% of total demand, with an average of 75%. The town per capita use figures are therefore overestimates of residential end-use, which would be the ideal inequality indicator. The large ranges in these figures mean that average residential percentages or losses cannot be applied to the other All Town Studies to assess residential end-use. This is an area for future research.

The scatter plots (Supplementary information, Figures S5 and S6) show no correlation between water use and supply-related variables (e.g., rainfall) but some correlation (R-squared greater than 0.1) between water use and the demand-related variables (household size, piped water access, access to flush toilets, washing machine ownership, income and urban location). A stepwise regression (see Supplementary information, Section 4) shows that only three of these variables – income, access to flush toilets and ownership of a washing machine – should be included in the model. In this model, R-squared is 0.26, therefore it only explains 26% of the variation in per capita water use. Also, all three variables have imperfect collinearity, i.e., they correlate with each other, so it is difficult to precisely estimate the individual effects of the variables. Although more than 20% correlation is considered good when predicting human behaviour (Van Zyl *et al.*, 2008), the variables that could not be included due to lack of data (price, property size, physical losses, consumer knowledge) are clearly important ones. Comparing water use to income for only those households with piped water access in their dwellings produces a lower correlation therefore the level of access is more influential than the level of income.

These findings are supported by Howard & Bartram (2003) who showed that if off-site water (100–1,000 m away) was moved on-site, consumption would increase from 20 l/c/d to 50 l/c/d per day. This indicates that the government should change its official target from the RDP standard (piped water within 200 m of the dwelling) – which was very reasonable in the early years of democracy when water access was so low in historically disadvantaged areas – to a more ambitious target (piped water in dwelling) that better suits the current focus on equity. Using the RDP standard hides the significant inequality that still exists in the country.

The importance of income on water use has been recognised by the South African government through the introduction of a free basic water allowance in 2001. It commits to supplying every household with 6,000 litres of water per month for free, which equates to 50 l/c/d for a household of four. It is not always easy to implement due to varying household sizes and means of access; in poor communities, the installation of pre-paid water meters for communal taps has in some cases forced people to drink from polluted rivers (Smith, 2012). Another existing mechanism to address water poverty in South Africa is the increasing block tariff structure for municipal water pricing, which charges below cost for low consumption and charges higher rates for higher consumption. However, Burger & Jansen (2014) found that the premium paid by the richest households is redistributed to middle income rather than poor households because of the lack of access, while the poor often purchase from water vendors or other households. Providing on-site access to piped water therefore should be the highest water service delivery priority for the government.

Town water stress

Although the analysis shows that national per capita water stress is 24 l/c/d per person, this ranges from a deficit of −303 l/c/d per person in Dullstroom, Mpumalanga to 4,949 l/c/d per person in Grootpan, North West. Over 16 million people living in 280 towns/village clusters had negative water balances in 2007/8. A further 18.5 million people in 148 towns/village clusters were within 10% of deficit and over 200 towns/village clusters were expected to experience a deficit by 2017/18. Of the metros, eThekwini and Nelson Mandela Bay, home to 4.6 million people, experienced water deficits. More than 70% of South Africa's population is therefore in a vulnerable position with respect to water supply. Deficits do not necessarily mean the town experiences water shortages and water restrictions but can also mean that the town is using more water than it is allocated. This may have a negative impact on other water users who cannot use their full allocation as a result. In these towns, the allocations need to be reviewed against the official allocation priorities and future supply and demand projections.

The per capita water stress highlights both first order water scarcity (physical water shortage) and second order water scarcity (lack of social adaptive capacity), common in rural towns and villages. For example, despite relatively high rainfall and runoff in the Eastern Cape, demand exceeds supply due to limited infrastructure because of low levels of economic activity or dysfunctional town water supply schemes (DWA, 2011c). Capacity building and cost-effective solutions need to be found to ensure communities are given access to piped water so that they can benefit from their local water resource.

Half of the settlements in deficit were located in sub-Water Management Areas with water deficits in 2000 (DWAF, 2004), although it is not a direct comparison as the All Town Studies and WSS reports did not include non-town uses such as irrigation, or the ecological reserve. As the ecological reserve is implemented over the next decade, about a fifth of existing supply must be allocated to the environment and new supply sources must be developed to meet the growing demand required for socio-economic development. Supply options include building new dams, raising existing dam walls, water transfers between catchments and from neighbouring countries, groundwater abstraction, reuse of effluent and irrigation return flows, use of treated acid mine drainage, and desalination of seawater (Basson *et al.*, 2010). Sufficient water can be made available to meet future development needs, but at steeply increasing costs (ranging from R3.18 to R72.27 per cubic metre of potable water in 2009 Rand terms) and with increasingly inter-dependent water resources (Basson *et al.*, 2010). The government needs to budget for these increasing costs and review existing pricing for heavy water users. Climate change is projected to affect rainfall across South Africa, with a risk of drier conditions to the west and south and wetter conditions over the east of the country (DEA, 2013). These projected changes need to be factored into water resource planning at national and local level.

Indicators for the SDGs

The three indicators described in this paper could be used as national indicators in SDG 6 target 6.1 (achieve universal and equitable access to safe and affordable drinking water for all) and target 6.4 (substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity). It is likely that the South African government will use the official development indicator for piped water access (households with piped water within 200 m of the dwelling) for target 6.1.

However, using 'persons with piped water in the dwelling' better suits the ambition of the SDGs and is a better measure of inequality. We suggest that it is also used in SDG 6.1. Using persons rather than households produces a higher Gini index revealing greater, and more accurate inequality, and is therefore preferable. The target would not need to be 100% by 2030, as there are significant barriers to this in informal settlements and traditional/tribal areas. Perhaps 75% is reasonable as 34% of the population currently lives in traditional/tribal areas or informal settlements (StatsSA, 2014). Plotting trends in this indicator would measure progress on service delivery to achieve sustainable development.

An ideal indicator for target 6.4 would be 'residential per capita water end use' (i.e., town use excluding water losses and other municipal uses). The national figure for South Africa would be roughly 113 l/c/d; the town average of 205 l/c/d minus 25% for physical water losses and 20% for non-residential use. To obtain an accurate figure, data would have to be obtained from local municipalities. The target could be a minimum of 60 l/c/d, the current government target or 100 l/c/d, recommended by the WHO. A maximum target could also be defined. The Rand Water Board, which manages the city of Johannesburg's water supply, put forward examples of 'inefficient' and 'efficient' residential end-user water use of 194 l/c/d and 71 l/c/d, respectively, as part of their Water Wise campaign (Rand Water, 2016). Additional indicators for SDG 6.4 could include non-residential use to enable sectoral analysis, which is important for determining the socio-economic value of water, which in turn guides water allocation decisions. This is an area for further research.

The range, standard deviation and coefficient of variation are useful figures for measuring variability in water access, use and stress. However, they are not generally used in the policy discourse. Most policy-makers are familiar with their Gini index for income inequality, making it a better choice. A Gini index of water access could be used in SDG 6.1 and a Gini index of water use could be used in SDG 6.4. Adding the Lorenz curves and reporting by population decile provides further useful summary information and data visualisation, and both are easy to understand. The Palma ratio is still new and, although it is gaining traction, it remains to be seen whether it becomes a commonly used inequality measure and therefore whether it would be easy for decision-makers to relate to.

A Gini index could also be calculated for several other social dimensions in the SDGs, such as electricity access, sanitation, housing, etc. to ultimately provide a suite of Gini indexes which would be more representative of a country's inequality than the income Gini alone. This would be similar to Bhorat *et al.*'s (2009) Gini for their non-income welfare index constructed using six public assets (dwelling, roof, wall material, electricity, water source, sanitation) and four private assets (telecommunications, radio, car, television). Reporting multiple measures of inequality (i.e., not only income) would help to gain a broader understanding of inequality in a country in the same way that multiple deprivation measures provide a better understanding of poverty.

The Gini indexes in this paper are quite low (0.36 for water access and 0.27 for water use) compared to the income Gini index of 0.65 for South Africa. This is because unlike income, which has no upper limit, piped water access cannot exceed access within a dwelling and water use also has practical limitations, although not as strict. This means that wealthy households can be recorded as the same as those who are much less well-off, and the inequality in their living conditions are not reflected in the Gini index for water access. In addition, for water use the metros and large towns are reported as single observations, and the inequality remains hidden. For similar reasons, Bhorat *et al.*'s (2009) Gini index for non-income welfare in South Africa is 0.16. The Gini indexes may be most useful for comparing regions. In previous analyses of water use inequality in South Africa, Cullis & van Koppen (2007, 2008) calculated a Gini index of 0.96 in the Olifants Water Management Area (WMA) and values

ranging from 0.78 to 0.92 for the nine provinces. Their figures were much higher because they included all agriculture and industry and equated them to a single household to compare them to rural households to highlight the inequality in water allocation. When they measured a Gini index of water benefits by accounting for the jobs created by the water in industry and agriculture, the Gini index dropped to 0.64 in the Olifants WMA. Extending the water use inequality analysis described here to measure the inequality in water allocation would be a useful area of further research.

Geographic location is only one of many dimensions of data disaggregation that are part of the SDG global monitoring framework. The other dimensions (gender, age, race, ethnicity, migratory status, disability) have a geographical nature as the spatial distribution of, for example, gender equality, is important. The inequality measures tested in this paper could therefore be relevant across other dimensions of disaggregation.

Data collection is a significant challenge in tracking progress towards the SDGs. The results in this paper show that the scale of the data set used can have a large effect on the apparent levels of inequality (see Supplementary information, Figure S4); using local level data to calculate inequality indexes is much better than provincial or district level data at exposing the inequalities. Local data supports local action to address water access, use stress. The annual GHS, the main source of data between census years, only takes a sample of the population and is therefore only representative at national and provincial level. These surveys are likely to form the basis for annual SDG reports in South Africa (and other countries) and if inequality measures are included, then it will be important to note the hidden inequalities. These are important points for data disaggregation and the SDGs. If national data are disaggregated to the first sub-national level (in this case provinces), only some of the finer scale inequality will be revealed.

The two data sets used in this study are not annually updated – the Census is undertaken once every 10 years and the All Town Studies are only being updated for the towns facing water shortages. However, these could be used as the baseline data while other sources could be used to create an up-to-date dynamic national database. Administrative data collected as piped water is provided to new households could be used to update the figure on access to piped water in dwellings, while satellite imagery could be used for more accurately determining households with communal taps or taps in their yard. Smart meters would improve water use reporting and crowd-sourced citizen reporting could identify areas of water stress. The 'data revolution for sustainable development' that has been prompted by the SDGs, is a vibrant new field of research and is likely to produce several innovative approaches for collecting local level data necessary for effective policy- and decision-making.

Conclusion

This paper has exposed significant inequality in water access, water use and water stress across towns, municipalities, districts and provinces in South Africa. This has highlighted the importance of data disaggregation by geographical location, a requirement of the SDGs, and of reporting an inequality measure such as the Gini index along with the national average. The maps, indicators and inequality measures presented in this paper provide monitoring and communication tools that could be used for the SDGs and for geographical targeting for more effective decision-making. Policy recommendations include: (1) using more ambitious official indicators for water access; (2) reporting suburb level water use data by sector to identify high and low end users; (3) exploring innovative cost-effective solutions to

provide on-site piped water access to informal settlements and remote communities; (4) increasing the official minimum per capita water supply to 100 l/c/d to meet WHO guidelines; (5) introducing a maximum per capita water supply in line with supply and demand projections; and (6) use additional indicators of inequality in the SDGs based on disaggregated data. As South Africa's population grows and its climate changes, water scarcity and inequality is likely to worsen at national and local level. It is imperative that water resource policy, planning and management is informed by accurate, up-to-date data and analysis at the appropriate spatial scale, such as those provided in this paper.

Acknowledgements

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