Small area population estimation: Estimating population size at ward level in 2014 in South Africa

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ABSTRACT

The census is the traditional source of population figures at various levels. Census figures however are technically outdated immediately they are released because planners require figures for the present and possibly for future dates. In an attempt to meet this demand different organisations and researchers produce population estimates and projections. These estimates however are usually at higher geographical levels and often do not meet the planning needs of administrators at lower geographical levels. In view of this, this study provides small area population estimation for 2014 at ward levels in South Africa.

The study used the 2011 South Africa Census to estimate current levels of fertility, mortality as well as current trends in net migration at a higher geographical level. Historical trends in fertility and mortality were based on the 1996 Census, 1997 and 1998 October Household Surveys as well as the 2007 Community Survey data. A top down hierarchical demographic modelling approach was used in the estimation. The results indicate that that 20 of the largest wards as at mid-2014 were located in South Africa's metropolitan areas. Nineteen of the 20 largest wards are currently growing at a rate of over 4% per annum and if this trend continues, eighteen of these wards will double their current population size in less than 15 years.

Keywords: Small area estimation; population estimates; hierarchical demographic modelling; South Africa.

INTRODUCTION

Statement of the Problem

There is increasing demand for small geographical areas population figures by policy makers, planners, provincial and local administrators as well as market researchers. In the case of South small geographical areas may be considered as including district and local municipalities as well as electoral wards. The traditional source of population figures at low geographical levels is the census as sample sizes in surveys are usually not large enough to produce population figures at very low geographical levels. Furthermore, from the perspective of planning, census figures are technically outdated immediately they are released because planners require population figures for the present and possibly for future dates.

In an attempt to meet the demand for current population figures many organisations produce population estimates and projections. These estimates however, are usually at higher geographical levels. In the case of South Africa, Statistics South Africa (the official agency that provides official statistics), produces mid-year population at two geographical levels – national and provincial levels (see Statistics South Africa: 2014). However, population estimates for higher geographical levels often do not meet the needs of local administrators for spatial planning or planning for provision of services. The lowest administrative unit in South Africa is the ward. The ultimate locations of services such as housing, electricity, sewage disposal, supermarkets, shops and basic infrastructures is at the lowest geographical unit and in the case of South Africa, are wards within local municipalities, within district municipalities and within provinces in the country although the decision as to where to locate such services and infrastructure may be taken higher administrative levels. Population figures are required to gauge current and future demand and need for such services and infrastructure for efficient allocation of scarce resources.

Objective

The objective of this study therefore, is to provide population estimates as at 2014 at ward level for South Africa based to aid planning by local administrators and decision makers in various sectors. There are currently 4,277 wards in South Africa in the nine provinces of South Africa based on the 2011 provincial boundaries. The number of wards varies from one province to the other in the country.

LITERATURE REVIEW ON SMALL AREA ESTIMATION

The population of a small area such as an electoral ward, *w* at a given point in time is determined by its previous population size, fertility and mortality levels in the ward, in- and out-migration into the ward. This may be expressed algebraically as:

$$p^w_{(t+n)} = p^w_t + b^w_{(t, t+n)} - d^w_{(t,t+n)} + i^w_{(t,t+n)} - o^w_{(t,t+n)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:
w denotes the ward
p^w_t is the base population of the ward at time t,
$b^w_{(t, t+n)}$ is the number of births in the ward during the period t, t+n,
$d^w_{(t,t+n)}$ is the number of deaths in the ward during the period t, t+n,
$i^w_{(t,t+n)}$ is the number of in-migrants into the ward during the period t, t+n,
$o^w_{(t,t+n)}$ is the number of out-migrants from the ward during the period t, t+n.

This relationship is often referred to as the basic demographic equation or balancing equation (Preston, Heuviline & Guillot: 2001). The relationship is a deterministic model of population change to the extent that it is the parameters on the right hand side of the equation that ultimately determine directly the population size of an are at a given point in time. Other extraneous factors may have impact on the magnitude of each of the parameters in the model - these are indirect determinants. For example, push and pull factors may have impact on the volume of in- and out-migration from an area. Given the above relationship, the problem in estimating the population of small area is lack of reliable data on each of parameters on the right side of the equation. For example, the traditional source of direct information on births and deaths is vital registration but in many African countries this is non-existent at country level let alone at small area levels. Where vital registration exists, there is often incomplete coverage. In population size estimation, migration data are the most problematic information to yet, in small areas, migration may be a more important determinant of population growth than natural increase (births and deaths). A number of approaches have therefore been adopted in estimating the population size of small areas. These may be classified as survey, regression and demographic approaches.

Survey approach: This entails various methods of re-weighting survey data to a number of known totals for small areas to estimate the population size (or other indicators) of small areas (Rao: 2008, Tanton et al.: 2011). One of the problems with this approach is operational cost – it is usually not possible to have a large enough overall sample to provide direct estimates for all the small areas (Rao: 2008). Consequently, the standard errors from direct small area survey estimates are generally too high rendering the estimates usually unreliable (Datta & Ghosh: 2012).

Regression approach: This approach is an indirect estimation of the population of small areas based on linking models using census, administrative and other auxiliary data sources associated with the small areas (Rao: 2008). In the methods, indirect drivers (Chi et al: 2011) or symptomatic indicators (Howe: 1999, Smith: 2002) or co-variates (Chambers & Tzavidis: 2006) that are related to population change are identified and used to estimate variation among the small areas.

One of the problems with this approach is that because the models depend on the assumed linearity of the estimators of the small area means (Chaudhuri & Ghosh: 2011) or strong distributional assumptions, and require formal specification of the random part, they do not easily allow for outlier-robust inference (Chambers & Tzavidis: 2006). Sinha and Rao (2009) have observed that the presence of outliers in the data can have a high influence on the estimates. A number of studies have attempted to overcome these issues by proposing alternative regression approaches. For example, (Chambers & Tzavidis: 2006) proposed an M-quantile modelling approach while Sinha and Rao (2009) have adopted a parametric bootstrap approach. Chaudhuri & Ghosh (2011) used empirical likelihood-based Bayesian approach. Datta and Ghosh (2012) have used shrinkage estimation approach motivated from both Bayesian and frequentist point of view. These regression approaches have been applied in different contexts. Although there is no over-riding criterion to judge the accuracy of a set of small-area population (Howe: 1999) a recurring concern in regression methods includes among others, the availability, choice and accuracy of the symptomatic indicators related to the small areas.

Demographic Approach: Symptomatic indicators related to the small areas in regression approaches are not needed in demographic approach of estimating population of small areas. The housing unit method is the most commonly used demographic method in small area population estimation. In this approach, the population of the small area is estimated using the following equation:

$$P_t = (HH_t * PPH_t) + GQ_t \quad \ldots\ldots\ldots\ldots..(2)$$

Where P_t is the population of the small area at time $_t$, H_t is the number of occupied housing units (i.e. households) at time t, PH_t is the average number of persons per household at time t, and GQ_t is the group quarters population which includes homeless population at time $_t$ (Smith et al.: 2002; Smith & Cody: 2004; Cai: 2007; Baker et al.: 2012; Deng & Wu: 2013).

Several issues have been pointed out regarding the demographic approach: the effect of census undercount (Murdock & Hoque: 1995), instability of migration may affect the accuracy of the small area estimates (Cameron & Poot: 2011), incompleteness of and biases in geocoded data sources (Baker et al.: 2012). Additionally, the following also need to be noted. The housing unit approach requires estimates of households using data sources such as building permits, certificates of occupancy, electric customers, telephone customers, property tax records (Smith & Cody: 2000). All of these sources may have varying degree of completeness. In the case of South Africa, illegal dwelling units (known locally as shacks) will not be included in building permits or electricity customers. Incompleteness of data sources will bias the estimates of small area populations (or other indicators).

Another issue that researchers often do not consider is the use of average household size as input in the estimation. Household size is partly influenced by household formation (which is age-distribution related) and which among others, is influenced by cultural factors such as marriage practices, rules of residence and so on. Average household size cannot capture these cultural dynamics, thus even within a small area, the size of some households may lie at the extreme ends of the average household size. In view of these issues, this study uses a 'top down hierarchical demographic modelling approach" in the estimation the population size of wards in South Africa.

DATA

For the cohort component projections, historical trends in fertility and mortality were based in part, on estimates provided by Udjo (2005a, 2005b, 2008), that utilised the 1996 Census (Statistics South Africa: 1998), 1997 and 1998 October Household Survey as well as the 2007 Community Survey data. The estimations of current levels of fertility, mortality as well as current trends in net migration were based on the 2011 South Africa Census (Statistics South Africa: 2012).

The estimates at the lower geographical hierarchies utilised information from the 2001 and 2011 censuses (Statistics South Africa: 2003, 2012) being the last two post-apartheid. The estimates were based on the census population figures adjusted for undercount. The overall undercount in the 2001 census increased to 18% from 11% in the 1996 census but decreased to 14.6% in the 2011 Census (Statistics South Africa: 2003, 2012). The tabulations of the relevant variables for analysis in this study were based on the 2011 provincial boundaries. The adjustment of the 2001 provincial boundaries to the 2011 provincial boundaries was carried out by Statistics South Africa (described in another section). South Africa's post-apartheid censuses are controversial as seen in several studies. These include Dorrington (1999), Sadie (1999), Shell (1999), Phillips, Anderson & Tsebe (1999), Udjo (1999, 2004a, 2004b). Some of the controversies pertain to the reported age-sex distributions (especially the 0-4 years age group) and the overall adjusted census figures. A number of the limitations in the data relevant to the present study especially those pertaining to underreporting of fertility ad mortality were addressed in Udjo's (2005a, 2005b, 2008) studies and incorporated in this study.

METHODS

Definition

Small area in this study is defined as a sub-geographical region below an administrative local municipality area. In the context of South Africa, this comprises electoral wards which constitute the lowest administrative units. As administrative units, local municipalities are one hierarchy lower than district municipalities while district municipalities are one hierarchy lower than provinces. There are nine provinces in South Africa.

The Top-down Hierarchical Demographic Modelling

To estimate the population of the electoral wards, a top down approach was adopted as indicated above. This entails firstly, a cohort component projections at a high geographical level and secondly, the ratio methods of population projections at lower geographical. The cohort-component projections require estimation of levels and trends in fertility, mortality and net-migration at the high geographical level. The rationale for adopting this approach is that the quantity of data are usually richer at high geographical than at lower geographical levels, the estimates at the high geographical level provide controls for the estimates at lower geographical levels. The hierarchies in this study from top to bottom, are provinces, district municipalities, local municipalities and electoral wards. The stages in the estimation were therefore as follow. Firstly, a cohort component projections of provincial populations from 2011 to 2014. The results were part of the inputs for projecting the population of district municipalities. Secondly, projections of district municipalities' populations from 2011 to 2014. The results were part of the inputs for projecting the population of local municipalities. Thirdly, projections of local municipalities' populations from 2011 to 2014. The results were part of the inputs for projecting the population of electoral wards. Lastly, projections of the population of electoral wards' population from 2011 to 2014. The reason for using 2011 as the base is because it was the last census year in South Africa.

The Cohort Component Method Projections of the Provincial Populations

The cohort component method is an age-sex decomposition of the Basic Demographic Equation given above (equation 1) and involves projecting separately, the components of population change. In the context of this study, mortality for age groups higher than the 0-4 was estimated as:

$$ {}_nP^p{}_x{}^{(m,f)}{}_{(t+n)} = {}_nP^p{}_{x-n}{}^{(m,f)}\,(t).\ {}_nL^p{}_x/{}_nL^p{}_{x-n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3) $$

(See Preston et al.: 2001).

Where p is any province, ${}_nP_x{}^{(m,f)}$ (t+n) is the number of persons, males or females, in a specific age group x, in an age group interval n, at the end of the estimation interval, t+n,
${}_nP_{x-n}{}^{(m,f)}$ (t) is the number of persons, males or females, in a specific age group x, in an age group interval n, at the beginning of the estimation t,
${}_nL_x/{}_nL_{x-n}$ is the survivorship ratio (the proportion of persons aged x-n to x that will be alive n years later. HIV/AIDS was incorporated into the estimates through the use of the INDEPTH (2004) model life tables.

The fertility component was estimated as:

$$ {}_nP^p{}_{0\text{-}4} = {}_nF^p{}_x\ .\ \mathrm{n}\ .\ [\{{}_nP^p{}_x{}^{(f)}\,(t) + {}_nP^p{}_{x-n}{}^{(f)}\,(t)\ .\ {}_nL^p{}_x/{}_nL^p{}_{x-n}\}/2] \quad \ldots\ldots..(4) $$

(See Preston et al.: 2001).
Where p is any province, ${}_nP_{0\text{-}4}$ is the population aged 0-4 years at time t+n, ${}_nF_x$ is the age-specific fertility rate for a particular age group x, in the age group interval n.

Net provincial migration was estimated from the 2011 census data from the questions on province of birth (foreign born coded as outside South Africa, living in this place since October 2001, and province of previous residence (foreign born coded as outside South Africa). The tabulations produced migration matrixes and from which provincial net migration was estimated. The sum of the 2014 provincial projections constituted the national population estimate for 2014.

Projecting the District Municipalities Populations

The projections of the district municipalities' populations from 2011 to 2014 were done using the following expression:

$$ D(i,j,t) = P(j,t) * r(i,t) \quad \ldots\ldots\ldots..(5) $$

Where $D(i,j,t)$ is a projected district municipality i, population in a province j, in a specific time period t, $P(j,t)$ is a projected provincial j, population at time t and $r(i,t)$ is a projected ratio of district municipality population to its projected provincial population at time t.

Projecting the Local Municipalities Populations

The local municipalities' population projections from 2011 to 2014 were based on the expression:

$L(i,j,t) = D(j,t) * r2(i,t)$ ………..(6)

Where $L(i,j,t)$ is a projected local municipality i, population in a district municipality j, in a specific time period t, $D(j,t)$ is a projected district j, population at time t and $r2(i,t)$ is a projected ratio of local municipality population to its projected district population at time t.

Projecting the Electoral Wards Populations

Each electoral ward's population estimate for mid-2014 was based on the expression:

$W(i,j,t) = L(j,t) * r3(i,t)$ ………..(7)

Where $W(i,j,t)$ is a projected electoral ward i, population in a local municipality j, in a specific time period t, $L(j,t)$ is a projected local municipality j, population at time t and $r3(i,t)$ is a projected ratio of electoral ward population to its projected local municipality population at time t.

The ratios (r, $r2$, $r3$) in equations 5-7 were obtained as follows. Firstly, the ratios in the elements observed in the 2001 and 2011 census data were computed and those for the period 2002 and 2010 were obtained by linear interpolation. Secondly, the ratios for 2014 were obtained by linearly extrapolating the ratios for 2009-2011. One of the advantages of using the ratio method for the lower geographical level estimates is that it is not necessary to estimate and project trends in fertility, mortality and net migration at these levels where the data are more limited. Yet, the approach indirectly takes into account fertility, mortality and net migration because the growth (positive or negative) and hence the size of each lower geographical level population is due to fertility, mortality and net migration.

Linking the 2001 Boundaries to 2011 Boundaries

It was noted above that the estimates were based on the 2011 provincial boundaries. There were changes in provincial boundaries in South Africa in 2005, 2008 and 2011. Since one of the primary data sources in this study was the 2001 census data, it was essential that the data be comparable to the 2011 census data hence the 2001 census data adjusted to the 2011 census data. The adjustment was carried out by Statistics South Africa by Statistics South Africa as follows.

1) Calculate AREA of census Enumeration Area (EA) - using one geo database to maintain area calculation.
2) Run intersect between municipal 2011 and EA.
3) Group by EA Code in intersected shape file.
4) Count of 1 in grouping can be taken as EA completely within municipal file.
5) Delete Count 1 from Intersected shape file.
6) Calculate AREA of Intersected shape file so you have the ORIGINAL AREA of EA and AREA of intersected part.
7) Calculate percentage of intersected part to ORIGINAL.
8) AREA >= 85% to be taken.

9) For the balance determine the no of Eskom (the company responsible for electricity supply in South Africa) points in each portion (spatial join between intersected polygon and Eskom point, take the higher count (Marlanie Moodley: 2014).

RESULTS

Absolute Population Size

The estimated population at the highest geographical hierarchy in this study as at mid-2014 is shown in Table 1. The table indicates that Gauteng Province had the largest population as of mid-2014 (12,740,510) constituting about 23.9% of the national population while the Northern Cape had the smallest population, constituting about 2.2% of the national population

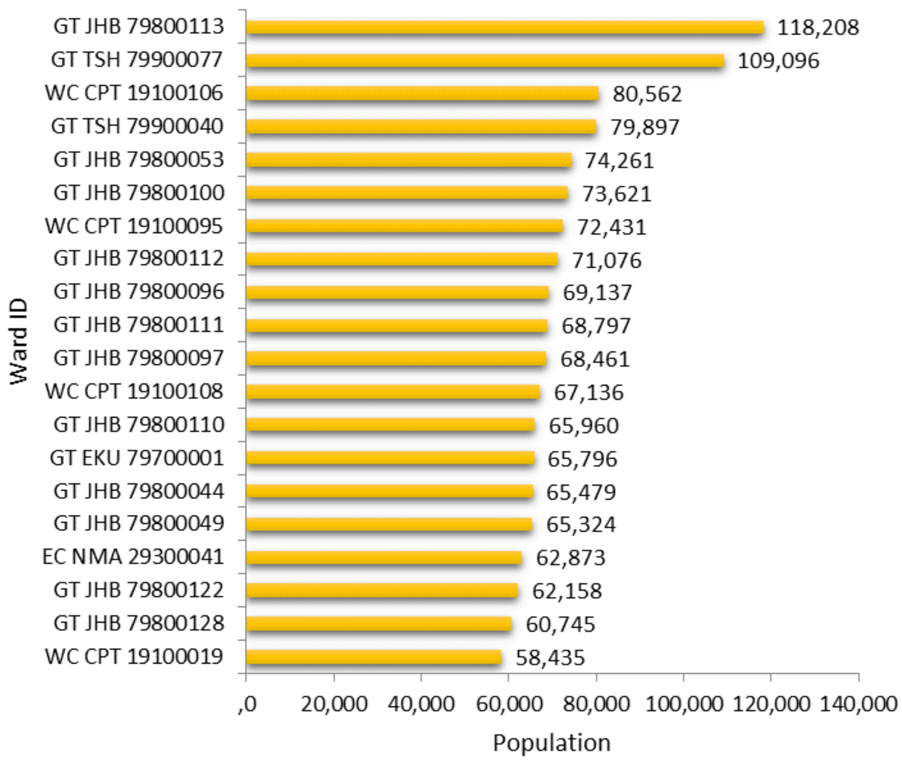
Table 1: Estimated mid-2014 Provincial Population

Province	Estimated population	% of total population
Eastern Cape	6,661,373	12.48
Free State	2,808,232	5.26
Gauteng	12,740,510	23.88
KwaZulu-Natal	10,507,713	19.69
Limpopo	5,626,065	10.54
Mpumalanga	4,184,020	7.84
Northern Cape	1,181,783	2.21
North West	3,631,113	6.81
Western Cape	6,017,300	11.28
Total	**53,358,109**	**100.0**

Source: Author's estimates

For brevity of presentation (as it is not practicable to present results for all 4,277 wards), the estimated 20 largest ward populations in South Africa as of mid-2014 are illustrated in Figure 1. The acronym following each of the Ward ID indicates the province and municipality in which the ward is located. As seen in the graph, 15 of the 20 largest wards are located in Gauteng (GT) province, 4 in the Western Cape (CPT) and 1 in the Eastern Cape (EC). As can also be seen from the graph, the 20 largest wards are located in metropolitan cities: 12 in the City of Johannesburg (Gauteng province), two in city of Tshwane (Gauteng Province), 1 in Ekhuruleni (Gauteng Province), 4 in the City of Cape Town (Western Cape province) and 1 in Nelson Mandela Metro (Eastern Cape Province).

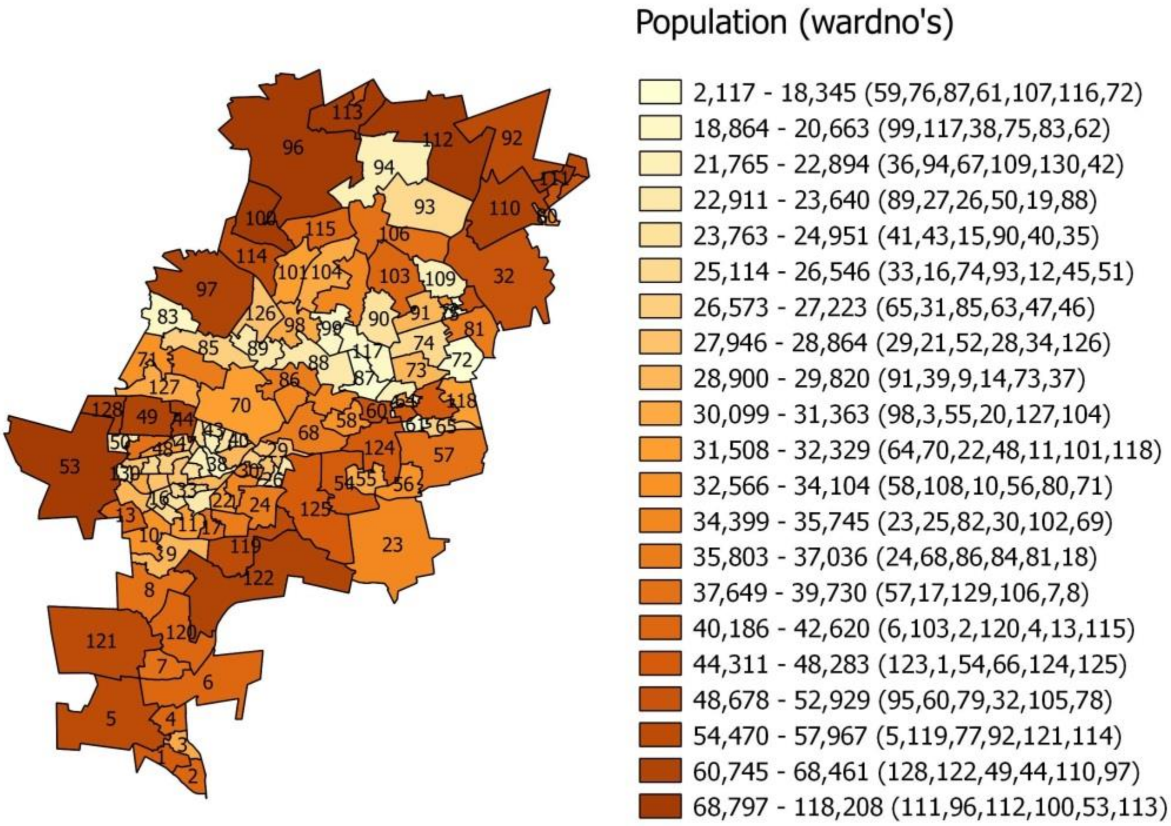
Figure 1: The 20 Largest Wards in South Africa, mid-2014



Source: Authors' estimates

The mapping of the estimated ward populations in the local municipality that has the largest population in South Africa - City of Johannesburg in Gauteng Province - is shown in Figure 2 for illustrative purpose. The estimated ward populations in the municipality ranged between 2,117 persons and 118,208 persons as at mid-2014.

Figure 2: Estimated Ward Population mid-2014, City of Johannesburg Municipality*



Source: Mapping based on author's estimates
*Numbers in the map are last digits of Ward ID

Table 2 shows the statistical summary of the estimated population size of all the wards in South Africa as at mid-2014. The figures show that KwaZulu-Natal has the highest number of wards (19.4% of the total wards) in the country.

Table 2: Statistical Summary of Estimated Ward Population by Province, 2014

Province	Number of Wards	Average Ward Population	Minimum Ward Population	Maximum Ward Population
Eastern Cape	715	9,317	830	62,873
Free State	317	8,859	1,798	44,807
Gauteng	508	25,079	866	118,208
KwaZulu-Natal	828	12,690	120	52,595
Limpopo	543	10,364	2,265	52,712
Mpumalanga	402	10,408	934	25,735
Northern Cape	194	6,090	516	16,039
North West	383	9,481	1,437	43,087
Western Cape	387	1,5549	342	80,562
TOTAL	**4,277**	**12,476**	**120**	**118,208**

Source: Author's estimates except number of wards

The estimated ward population as of 2014 ranged between a minimum of 120 persons in KwaZulu-Natal and 118,208 persons in Gauteng with an average ward population ranging between 6,090 persons in the Northern Cape and 25,079 persons in Gauteng.

Growth Rates and Doubling Time

Table 3 shows the estimated percent average annual growth rates of the ward population for wards that have positive growth rates during the period 2011-2014. Of the 4,277 wards, 2,386 were estimated to have positive growth rates during the period with an average growth rate in ward population ranging between 1.8% per annum in the Eastern Cape and 2.7% per annum in the North West. It can be seen also from the table that the estimated annual population growth rates during the period in some wards exceeded 8% in all the provinces.

Table 3: Statistical Summary of Estimated Growth Rates of Ward Population & Doubling Time by Province, 2011-2014

Province	Number of Wards	Average Annual Growth of Wards Population	Minimum Average Annual Growth of Wards Population	Maximum Average Annual Growth of Wards Population	Average Doubling Time (Years)
Eastern Cape	341	1.8	0.001	8.5	693.3
Free State	181	2.2	0.009	9.0	146.8
Gauteng	271	2.6	0.003	10.5	253.0
KwaZulu-Natal	474	2.0	0.001	9.0	380.4
Limpopo	369	2.1	0.002	10.7	267.3
Mpumalanga	216	3.0	0.020	10.9	90.1
Northern Cape	119	2.4	0.048	8.3	105.3
North West	186	2.7	0.009	9.9	181.4
Western Cape	229	2.4	0.031	10.3	87.3
TOTAL	**2,386**	**2.3**	**0.001**	**10.9**	**291.8**

Source: Author's estimates except number of wards

The growth rates shown in Table 3 if the trends continue, average doubling time of the ward populations would range from about 87 years in the Western Cape to 693 years in the Eastern Cape. But, 20 of the largest wards in South Africa will double their current population size in less than 10 years, six of them in less than 15 years, and two of them in less than 30 years if current trends continue. These high growth rates have implications for planning for these wards.

DISCUSSION AND CONCLUSION

The ultimate spatial unit for location of services and infrastructure is the ward or similar geographical unit even when decisions about services and infrastructure development are made at higher administrative levels. A key consideration in service provision and spatial planning is the population size (an indicator of the potential demand), yet censuses do not provide this information for the current year at ward level. The information will at least one to three years out of date depending on when the census results are released.

This study provided an approach for estimating population size at ward level for the current year in South Africa that could also be used to project future population size at ward level. The results indicate that 20 of the largest wards as at mid-2014 are located in South Africa's metros. Nineteen of the 20 largest wards are currently growing at a rate of over 4% per annum and if this trend continues, eighteen of these wards will double their current population size in less than 15 years. These high growth rates and short doubling time have implications for social services provision and infrastructure development in the wards. Such high growth rates may present challenges for competing resources in spatial planning for the wards. Although the results of this study provide insights into 'hotspots' in growth, it should be noted that some of the growth rates may have been exaggerated in some wards and underestimated in some others due to the methodology in linking the 2001 boundaries to the 2011 boundaries. Although the population size and growth rates may not be exact, they are indicative of the population factors in spatial planning at ward level in the intercensal period.

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