INTEGRATING LAND-COVER DATA WITH DATA ON POPULATION AND HOUSEHOLD CHARACTERISTICS TO ASSESS DENSIFICATION ALONG THE BRT ROUTE IN THE CITY OF TSHWANE

N DUDENI-TLHONE, E PETZER, A GXUMISA, JP HOLLOWAY, S KHULUSE-MAKHANYA

Spatial Planning and Systems, Council for Scientific and Industrial Research (CSIR), PO Box 395, Pretoria

Tel: 012 841 2958; Email: NDudenitlhone@csir.co.za, Tel: 012 841 4380, Email: EPetzer@csir.co.za, Tel: 012 841 3058, Email: AGxumisa@csir.co.za, Tel: 0128413305, Email: JHollowa@csir.co.za, SMakhanya@csir.co.za, Tel: 012 841 4942

ABSTRACT

This paper is centred on an investigation of whether the integrating earth observation and census data can result in useful information to support transport planning and monitoring. In particular circular buffers with radii of 500 m were created covering the current City of Tshwane's Bus Rapid Transit (BRT) service areas in order to estimate the proportion of population with convenient access to BRT; and to assess densities in terms of both population and relevant land use characteristics. A combination of data sets were used, namely, the 2011 census, GPS locations of the BRT stops and BRT routes, the satellite-derived urban land-cover and the building land use data. The results indicate that 5% of the population in the City of Tshwane has convenient access to the BRT service. Population densities along the BRT service area range from 2 351 to about 37 518 people per 0.79 km^2. Some of the BRT service buffers have low population densities and low building densities; while others have moderate to high population densities and high proportions of residential and commercial properties. Routes from Pretoria central towards Sunnyside vary from medium to high densities with respect to population and residential (cluster type residences, flats and student accommodation) and commercial buildings. It can be deduced from these results that there is potential to proceed with proposed densification strategies along BRT routes given that current densities are lower than desired at specific parts of the route. This could subsequently promote public transport accessibility and usage. In conclusion, publically available data that were used in this study and further enhancements of the methodology can be used as a tool for monitoring the implementation of the densification strategy along the BRT route.

1 INTRODUCTION

In an era where there is an increase in the availability and variety of public data, it is critical that we understand how to use it in order to create valuable information for the benefit of decision makers and beneficiaries in the public sector. Valuable information in an urban context can support transport and town planners to better understand the challenges of the city and to monitor the impact of interventions.

Census data represent human population as *"a continuous variable across the entire land area".* The smallest spatial unit for disseminating these data is the small area, which implies that the data are aggregated and therefore other data are needed to understand the spatial distribution of the population within a small area (Holt et al in Pena, 2012). Further, to gain a better understanding of the complex inter-dependency between land use and transport, different aspects need to be considered, including the absolute numbers of the population, the socio-economic profile of the population and the concentration (or density) of people and buildings in certain areas (Pozzi and Small, 2005). This implies that one needs more than census data for analyses that address questions at the interface of urban settlement and transport planning.

Systematic efforts to map and monitor land use and land cover changes using remotely sensed observations have been documented extensively. The investigation in this paper concerns the integration of earth observation data with administrative data and whether the result of this integration can provide useful information for transport and land use planning and monitoring. Multiple publically available data sets are co-investigated for the purpose of characterising an urban area with respect to public transport accessibility. This is in line with recent efforts in earth observation research (Gamba et al., 2012) where multiple data sets are used to improve characterisation of human settlements.

The City of Tshwane's Bus Rapid Transit (BRT) system is a recent intervention aspiring to, among other goals, *"stitch the city together"* by serving as a catalyst for spatial transformation through mixed use, density and value capturing (City of Tshwane, 2017). Looking at circular areas of 500 m radius around the BRT stations along, land-cover data and the latest census data are used to understand both the generic spatial patterns and the structure of the city in terms of land cover, demographic and socio-economic characteristics. Next, densification with respect to the built-up area, the population distribution and household characteristics is assessed. Finally, an assessment of how these characteristics change as the distance increases outwardly from the BRT route is done.

Through the assessment, a view on the optimality of the current route is obtained and this can be used for future evaluations to determine whether densification increased. Ultimately, if the combination of proposed data and methodology yield informative results, these can be refined and used for monitoring development patterns and forecasting growth within public transport service areas in different cities in South Africa.

2 BACKGROUND

2.1 Policy and approaches

In 2005 the City of Tshwane argued: *"Cities are inconvenient and dysfunctional for the majority of citizens as they generate enormous amounts of movement with great costs in terms of time, money, energy and pollution"* and *"the provision of efficient and viable public transportation is almost impossible, because of the low densities and the dispersed location of activities"* (City of Tshwane, 2005).

Post-1994 South African planning legislation and policy documents routinely promote higher densities, mixed use, a different kind of built form, a mix of residents and transit oriented development (Grey and Behrens, 2013). This is in line with global approaches to creating sustainable cities. The 2015 Sustainable Development Goal (SDG) 11 aims to *"Make cities and human settlements inclusive, safe, resilient and sustainable"* and emphasises that access to public transport needs to be monitored. More detail on these commitments is provided in the New Urban Agenda of 2017 and locally in documents such as the Integrated Urban Development Framework (IUDF) of 2015.

Concentrating growth along high density activity spines is one of the approaches promoted to effect much-needed spatial transformation in South African cities. Integrated Rapid Public Transport Networks (IRPTNs) are increasingly targeted for this type of development (Browning, 2017). The South African Public Transport Strategy of 2007 planned for the phased implementation of IRPTNs. The longer-term vision for 2020 was to develop a system that would place over 85% of a city's population within 1 km of an IRPTN trunk (road and rail) or feeder (road) corridor (Browning, 2017). The implementation of the strategy has been slow and the City of Tshwane's BRT system became operational in 2016 with the first line of 8 km linking the Hatfield transport hub with the CBD (Browning, 2017).

2.2 Tshwane

The City of Tshwane had to upgrade their public transport systems to a level that is car-competitive in line with the approved Public Transport Action Plan of March 2007 (Matlawe and Swanepoel, 2017). This gave rise to the planning and construction of a high quality road-based BRT system. In tandem with the planning for the BRT, land use planning was done through spatial development frameworks along major transit corridors that would promote transit oriented development (TOD) along these corridors, densification closer to the city core, mixed use development and the creation of job opportunities closer to where people are living (Vorster, 2015). The frameworks promote intensification of land uses along public transport corridors through the development of Greenfield sites as well as redevelopment of existing residential sites (City of Tshwane, 2015).

The Tshwane Rapid Transit (TRT) Densification and Intensification Guidelines of 2014 provides very specific directives for development along the various routes. The areas around the BRT stations have been earmarked for higher density promotion zones. Densification should take place within a 700 m walking radius of a station. Densities in excess of 200 units/ha in nodes around the station will be applicable for the first 500 m walking distance and up to 120 units/ha for the area between 500 m and 700 m (City of Tshwane, 2014). The walking radius around the BRT station is depicted in Figure 1. This is in line with international practice, as reflected in the targets that are set to support the realisation of the SDGs. According to Target 11.2 of Goal 11, a public transport mode is considered to be accessible and convenient if stops are within a 500 m radius from a variety of facilities such as schools, places of work and dwellings.

In addition to the proposed densities around stations, the City of Tshwane Compaction and Densification Strategy promotes linear density zones of high activity areas that are located along major mobility routes (City of Tshwane, 2005). The development along the BRT route typically represents an activity spine, as defined by the City of Tshwane (2005) where a mix of public and private transport is prevalent and a mix of land uses is the dominant trend. The concentration zones and linear zones effectively introduce a radical change in the built environment in terms of densities, typologies, built form and urban design, *"moving away from suburban typologies in these areas toward a more urban fabric and typologies"* (City of

Tshwane, 2014). The densification proposals along the BRT routes should achieve a range of goals, including increasing accessibility to public transport facilities, creating the necessary population thresholds for economic growth and business development in specific areas, minimising distances between home and work and containing outward expansion of the urban footprint (City of Tshwane 2014).

It is claimed that since the BRT came into operation there has been an increase in the rental demand in the area when compared to 2013. According to recent statistics cited by the City of Tshwane there is a vacancy rate of less than one month along Line 2A (City of Tshwane, 2017). The City of Tshwane has also recorded an increased number of rezoning applications along Line 2A (City of Tshwane, 2017).

However, Grey and Behrens (2013) caution that achieving the goals set for the BRT as a spatial structuring instrument is a long-term challenge. Intensification of land use is unlikely to occur instantaneously upon the construction of a public transport line. Detecting land-cover and population changes over the span of several years requires reliable information.

In this study, we seek to estimate the proportion of the population within the City of Tshwane that has convenient access to the BRT (a walking distance of 500 m to the bus stop). We use population and building land use to estimate densities at the BRT service buffers.

3 METHODS AND MATERIALS

3.1 Study site

The City of Tshwane BRT service runs from the north-eastern townships around Mabopane through the CBD to the eastern township of Mamelodi; covering a distance of approximately 80 km and 76 bus stops. The BRT route was selected as a specific study area due to efforts by the City to implement a densification strategy along this bus route. It is understood that the City of Tshwane's population density is low when compared to international cities and that densities in the city centre are even lower (Pienaar et al, 2007). In 2015, new residential buildings were already erected and specific plans were made for areas around this route which include Menlyn, Brooklyn and others. Densification along this route is one of the mechanisms to restructure future growth patterns of Tshwane as such restructuring does not usually occur instantaneously.

3.2 Data and pre-processing

Multiple data sets were used to estimate the proportion of the population with convenient access to the BRT service in Tshwane as well as in determining current densification patterns along the BRT (Areyeng) service. To create circular buffers with 500 m radii for all the existing BRT stops, a geocoded inventory was used consisting of 76 stops including trunk and feeder stops. The corresponding area for each circular buffer is approximately 0.79 km^2.

Population estimates, relevant demographic and socio-economic variables, and variables involving general health and functioning (disability) of the population, were extracted from the Small Area Layer (SAL) of the 2011 South African Population Census. A SAL is the finest spatial resolution at which the 2011 census data were disseminated and consists of parcels referred to as small areas. These SALs were overlaid onto the buffers and GIS analysis was performed to extract population and relevant characteristics, some of which are shown in

Table 1. Out of the total of 4524 SALs, 233 (5%) of them were spatially located within the BRT service buffers. For simplification, all the statistics from overlapping SALs (regardless of the extent of overlap), were used. It may also be important to note that most of the service buffers around the stations from the CBD through to Hatfield were themselves overlapping, thereby sharing and possibly servicing the same population. Such duplications were proportioned and smoothed within a GIS framework in order to obtain sound estimates of densities at each service buffer.

The 2013/2014 National land-cover and land use data set as well as the GTI spot building count were used to estimate built-up characteristics which can be associated with population densities at the buffer zones. These data sets were also linked to the buffer zones in order to (1) extract relevant characteristics, particularly residential and commercial footprints and (2) present an integrated view of current density patterns (within certain limitations) using publicly available data sources.

Once these various data sets had been linked within a GIS platform, they were imported into statistical software for further analysis. The following section gives an overview of the results obtained.

4 ANALYSIS, RESULTS and DISCUSSIONS

4.1 Proportion of Tshwane population with convenient access to BRT service

The proportion of the population with convenient access to the BRT service can be approximated as follows:- $\hat{p} = \frac{x}{N}$, where $x =$ 138 056, is the number of Tshwane residents with convenient access to BRT service (they are within the 500 m radius BRT service buffers) and $N =$ 2 921 364, is the total population in the Tshwane metro based on the census 2011. Therefore, the proportion of the Tshwane population with convenient access to BRT service ($\hat{p}$) is approximately 5%.

The BRT service buffers had a total of nearly 53 000 households, constituting about 6% of the total number of 911 514 households in Tshwane as a whole.

Table 1: Characteristics of the Tshwane population and at the BRT service buffers

		Rest of Tshwane		BRT Buffers	
Main variable	**Variable category**	**N**	**%**	**n**	**%**
Age	Age 0-14 years	2 921 278	23	138 048	12
	Age15-64 years		72		84
	Age 65- 120 years		5		4
Car ownership	Yes	911 477	44	45 973	37
	No		56		63
Hearing	No difficulty	2 630 268	97	112 058	98
	Some difficulty		3		2
Mobility	No difficulty	2 637 366	97	112 339	98
	Some difficulty		3		2
Sight	No difficulty	2 638 669	91	112 604	92
	Some difficulty		9		8
Employment status	Employed	2 101 205	51	116 252	47
	Unemployed		16		13
	Economically Inactive		29		40
Migration	Gauteng	2 826 874	86	118 665	63
	Other Provinces		10		27
	Outside SA		3		10

***Table notes**: N represents the total estimates for the entire City of Tshwane in each relevant variable category while n represents the number of responses within the service buffers.*

Table 1 provides summary statistics of the demographic, socio-economic, general health and functioning and migration characteristics of the entire Tshwane Metro and those of the segment of Tshwane with convenient access to the BRT service. It is important to indicate that most of the variables presented in this table relate to individuals while only car ownership and race were measured at a household-level.

In the previous sections we mention that convenient access to public transport is also determined in respect of the personal characteristics of such a population. The UN-Habitat specifically highlights that convenient public transport service should cater for disabled (including physically, hearing and/or visually impaired) individuals, the elderly, and children. Hence, such characteristics are presented in this table. Factors including vehicle ownership and migration are also important in informing transport planning and estimating of trends over time.

This table broadly indicates that the overall proportional distributions observed in the larger Tshwane population or households; appear to be similarly represented within the buffer zones, which represent the population with convenient access to the BRT service. This is not to say that this sub-population is statistically representative of the Tshwane population, but to rather indicate that there is inclusion of the key characteristics that exist at a bigger scale and that generic patterns observed in the whole of Tshwane are not reversed in the sub-population. For instance, 44% of Tshwane households own vehicles while 56% do not. Similarly, a slightly larger proportion (63%) of households within the buffers does not own a vehicle(s). Perhaps it may be important to note that even though households with vehicles could be potential users of reliable and convenient public transport facility; those without vehicles in these areas potentially rely on one or more forms of public transport including the BRT service. Also, the number of employed residents also increases population thresholds for economic growth and employment related mobility, which has an impact on both private and public transport usage.

With respect to disability or impairment involving sight, hearing and mobility, the table shows that a subset of the population with convenient access has a number of individuals with these kinds of disabilities.

4.2 Estimation of population density along BRT service buffers

From the previous 2011 census, a generic population density estimate for the whole Tshwane metro was approximately 464 people per square kilometre. Investigating population density patterns at the service buffers is of interest as service buffers are comparatively smaller (0.79 km^2) than normal spatial scales at which such estimates are usually produced. An assumption made in this study was to consider the population density as the quotient of the total population from all SALs whose centroids fall within a buffer area divided by a fixed area of 0.79 km2 which corresponds to the area of a buffer circle. This assumption disregards the fact that the area covered by the SALs whose centroids are in a particular buffer would not equal 0.79 km^2 in most cases. Therefore, a different assumption would lead to different population density figures. A deeper analysis to find a solution to this problem of misalignment was beyond the scope of this paper, but it will be a subject of further research. Figure 1 shows the mapped estimates of the population densities across each of the BRT service buffers.

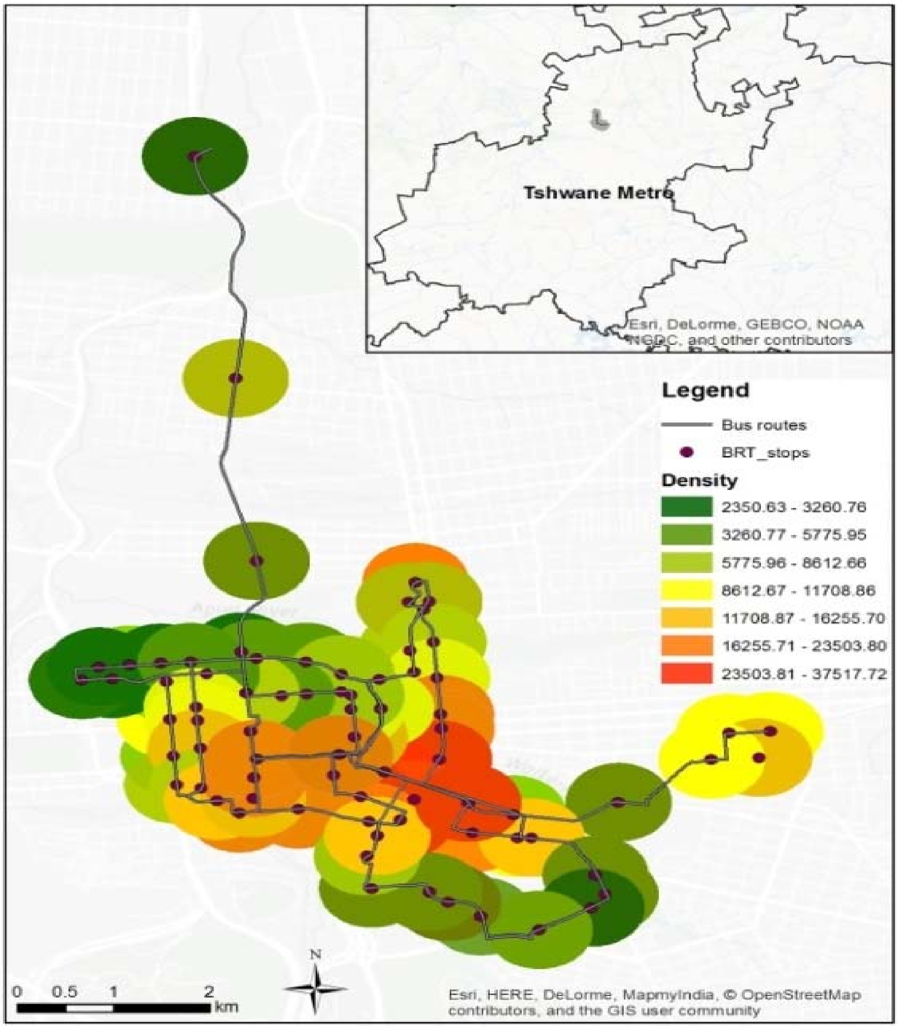

Figure 1: Population densities per 0.79 km^2 circular area around BRT bus stops

Within buffer zones, densities varied from a minimum of 2 351 to a maximum of 37 518 people per buffer area of roughly 0.79 km^2. The medium to high population densities were observed from the CBD towards Sunnyside and a part of Muckleneuk. The less dense parts of the route included areas such as Annlin, Pretoria North, Capital Park, Mayville and Hatfield.

4.3 Building footprint along the BRT route

4.3.1 BRT service buffer building types

The GeoTerra Image (GTI) building-based land use data set is a spatial point pattern data set of facilities or buildings which are categorised by land use activities such as residential, commercial, education, institutional and agriculture. A summary of the main building land use types in the BRT buffer areas is provided in Figure 2. A total of 43 928 facilities are located within the BRT service zones and the majority (37%) of these are commercial, followed by residential at 28%. Transport facilities including public transport terminals, parking spaces or vehicle storage facilities constitute about 14%. There are comparably smaller proportions of facilities that include educational, public or semi-public institutions, as well smaller proportions of industrial buildings.

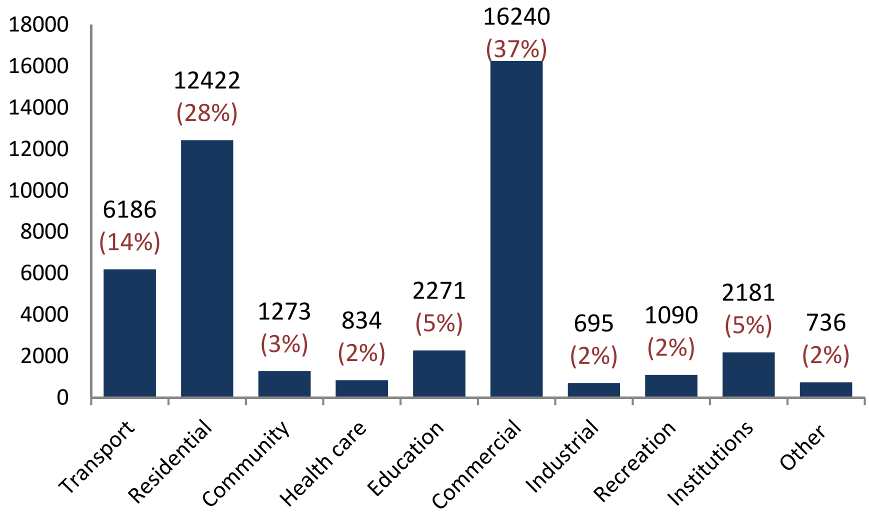

Figure 2: Building types across BRT services buffers

When these building point data are linked to the buffers, they validate the results mapped in Figure 1. For instance, service buffers; including Mahatma Gandhi, Ruth Mompati and General G.L. Pitso; which are located within the Sunnyside sub-place, contain the majority of residential buildings as well as a fair share of commercial buildings and transport facilities. The Nana Sitha buffer, which is located in a denser part of the CBD, also has a relatively large number of residential buildings. The Enoch Sontonga buffer also has a large proportion of residential buildings but is one of the less dense BRT service buffers. This could be explained by the fact that buffers like Enoch Sontonga are made of free-standing houses as opposed to the relatively large proportions of cluster type houses or complexes (including flats, student residences, etc.) around Sunnyside and the CBD, which cater for a large number of residents.

4.3.2 BRT buffer building density from national land-cover data

The latest national land-cover data set is satellite derived classified image with a ground sampling spatial resolution of 30 m by 30 m. Each pixel is classified into one of the built-up classes (like residences, places of work, schools and sport facilities), natural characteristics like grasslands, wetlands, bushes and water-bodies. In this analysis, we only present classes which are of relevance to our density estimation and they are shown in Table 2.

Table 2: Summary statistics of the land use classes within service buffers

	Number of pixel	% of Pixels
Urban built-up	16883	67
Urban commercial	4546	18
Urban industrial	635	3
Urban residential	1981	8
Urban school and sports ground	980	4
Urban smallholding	6	0
Urban sports and golf (bare)	351	1
Total	**25382**	

Over 25 000 pixels within the BRT service buffers, belong to one of the man-made land use types. Commercial areas constitute about 18%, with residential areas making up 8% of the urban footprint. Even though it is difficult to directly relate this table to the building count percentages in Figure 2, similar patterns are observed with respect to the broader distribution patterns (number) of the commercial vs residential areas or points. Further, service buffers like Sunnyside, which had the highest population densities, appear to have the highest proportions of urban residential areas and or combination of both residential and commercial areas.

5 CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to investigate the feasibility of integrating census, transport and earth observation datasets, in order to develop transport related indicators which can be used to produce useful planning information. Within the scope of this study we determined the current spatial density patterns in terms of public transport use, considering both population distribution and built-up area characteristics. The results showed that parts of Tshwane, through which the BRT service runs, have varying densities, some of which may not be dense enough to support optimal usage of BRT and possibly other public transport modes. The analysis confirms that areas such as Sunnyside are dense and this can be viewed favourably in terms of reliability of our method. Further, the method can potentially be extended to simultaneously model a variety of public transport modes and develop associated indicators.

One of the gaps in this study, however, was that no target density values (or a range thereof), which would be considered sufficient to support a bus transit such as the Tshwane BRT service, were available to use as a benchmark to assess current levels of accessibility. Further information about targets with respect to BRT accessibility and in general densification in the City of Tshwane will be sought. It would also be of interest to determine the estimates of the population that is serviced by the BRT in order to have a broader and nearly complete understanding of the current usage and possible future growth patterns.

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