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OCCASIONAL PAPER

04

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Department of Geography, Environmental Management and Energy Studies, University of Johannesburg

March 2013

GCRO Gauteng City-Region Observatory

UNIVERSITY OF JOHANNESBURG

ISBN Number: 978-0-620-56078-8

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The mission of the Gauteng City-Region Observatory (GCRO) is to help illuminate trends and dynamics shaping the region of towns and cities in and around Gauteng, and also enhance understanding of the idea of the Gauteng City-Region (GCR) as a project – a different way of thinking about and governing this space. While much of the data collection and analysis work of the GCRO is focused on the present, we also consider the city-region's past and its possible futures.

A 2030 National Development Plan, crafted by the National Planning Commission, has recently been adopted. In addition the Gauteng Provincial Government, working with municipal partners and business, civil society and labour stakeholders, is drafting a G2055 long-term development plan. As our society looks forward to what sort of country and region we need to become, it is also important to look backward. Understanding the past gives us insights into how we have come to be where we are now, and so in turn what paths we should tread into the future.

This Occasional Paper is one of two that GCRO has commissioned specifically to deepen our understanding of the past of the GCR. Both focus on aspects of the region's spatial past, and ought to be read together. This paper by Brian Mubiwa and Harold Annegarn explores the historical spatial evolution of the GCR. It examines key spatial changes that have shaped the region over a century and provides a remarkable picture, based on satellite imagery, of regional spatial growth in the last two decades. The companion paper by Alan Mabin asks the different but related question of how the idea of a city-region found expression in various statutory planning frameworks over the course of the last century, and how embryonic city-region concepts influenced spatial decisions and developments.

Disclaimer:

The views or opinions presented in this document are solely those of the author/s and do not necessarily represent those of the Gauteng City-Region Observatory or any of its partners.

Note: Revised version (31 October 2013) with corrections to Table 4, Figure 11 and related text.

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1. Introduction

The global urban population continues to grow at more than six percent per year (World Bank, 2002), resulting from rapid rural-urban migration and high birth-rates in developing world cities. If this trend continues, the number of *megacities* – cities or urban agglomerations with a population of over ten million inhabitants – is expected to reach thirty-seven (from a current total of twenty-three) by 2025 (ESA, 2011). Consequently, problems associated with an increasing urban population – including green house gas (GHG) emissions[1] (carbon dioxide, methane), other air pollutants, water pollutants, urban heat island, increased pressure on resources, suburban sprawl, traffic congestion, housing and water shortages – will be exacerbated (World Bank, 2002). Urban growth, the resulting urban morphology (urban land-use structures) and implications on transportation systems, mobility and energy have become concerns for most contemporary cities (Wegener & Fürst, 1999; Boarnet & Crane, 2001; Duany, 2008; Cao, Mokhtarian & Handy, 2009; Spiekermann & Wegener, 2006; Ewing & Cervero, 2010).

Urban land-use structures[2] (spatial configuration of the built environment) are complex phenomena reflecting physical manifestations of subtle interactions – over long periods – between various connected factors[3] (Bertaud, 2009). Moreover, these interactions change continuously as a result of dynamic socio-spatial processes (Pacione, 2005). Effective and systematic spatial development is a prime requisite for optimal economic and social development, and efficiency of city-regions (DRLA, 1993). However, the evolution of urban form is seldom monitored on a macro-scale. In the Gauteng City-Region, the land-use structure has evolved temporally and spatially, driven by a diversity of smaller scale decisions, with implications for overall transport and mobility related energy demands. Conversely, decisions on transport and mobility infrastructure have had major formative influences on the urban developments of Gauteng (Luoma et al., 2010; Mokonyama, 2009), for example the rapid development of the Midrand industrial and office parks associated with the construction and then widening of the N1 highway linking Johannesburg and Pretoria.

This study comprises two sub-sections. The first sub-section involves a review of historical planning documents to trace the evolution of urban spatial development between the 1890s and the late 1980s. Factors that influenced the spatial form of the *Southern Transvaal,* and PWV (short for *Pretoria-Witwatersrand-Vaal*) Complex – mining, topography, industry, commerce and apartheid spatial planning – are discussed. The second sub-section presents a detailed analysis of land-use/land cover changes (focusing on urban development) in the Gauteng City-Region over the last two decades (1991-2009), covering the transition and period of rapid change following the collapse of apartheid-dominated urban planning regime. This is based on interpretation of remote sensing images derived from the Landsat TM and ETM+ satellite-borne sensors. Land-use classes are mapped and quantified, describing the growth of the urban landscape (built-up areas) and corresponding reduction of other land-use/land-cover classes – indicating nodes of intensive growth, and areas of expansion and infill. The influences of various social, economic and political factors on the growth dynamic of the Gauteng City-Region are assessed. Although this study

[1] Currently, towns and cities are consuming roughly eighty per cent of global resources and generate the bulk of the world's carbon dioxide emissions (Cox, 2010).

[2] Defined by the average population density in the built-up area (number of inhabitants per km^2); the spatial distribution of densities and population; the pattern of daily trips (Bertaud, 2009).

[3] Land-use regulations, primary infrastructure investment and taxation (government action), market forces, topography etc.

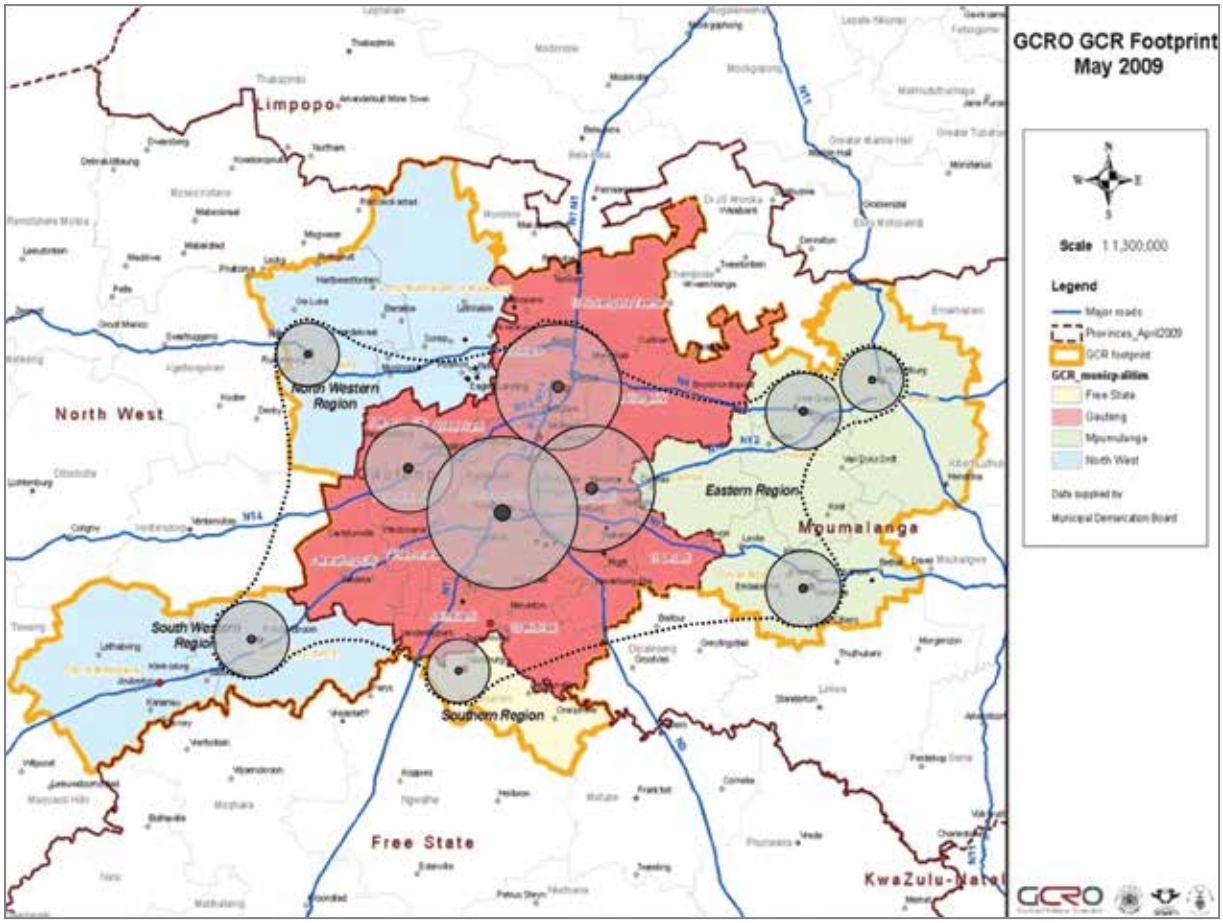
focuses primarily on the physical-spatial aspects of development, attention is also given to the interaction between physical, social and economic realities.

With the prediction of that Gauteng's population will double by the year 2055, there is an urgent need to understand the trends in urban form (land-use) change. An integrated regional approach is necessary to manage the urban growth within the constituent administrative blocks. Understanding such trends and current drivers of change is fundamental for formulating recommendations towards a desired outcome of a sustainable Gauteng City-Region, with improved living conditions, child-friendly environments, reduced traffic congestion and enhanced mobility, reduced loss of open or green spaces, improved air quality and lower total energy consumption, this study articulates and projects the century-long evolution of the Gauteng urban structure, informed by the three pillars of sustainability - social, environmental and economic. It is within this context that this study assesses the century-long evolution of urban spatial change within the Gauteng City-Region, so as to better predict likely growth trajectories from an informed position.

2. The Gauteng City-Region

This study focuses on the Gauteng City-Region - an integrated cluster of cities, towns and urban nodes (Wray & van Olst, 2010:3; Wray, 2010) - that together make up what is arguably Africa's leading city-region. Although the functional economic extent of the Gauteng City-Region, as opposed to the political boundary of the Gauteng province, still remains to be investigated and defined[4], studies have suggested that the city-region includes parts of at least three other provinces (Free State, Mpumalanga and North West) (Wray & van Olst, 2010). Based on functional considerations, the spatial configuration of the Gauteng City-Region may be considered as polycentric (Wray, 2010), as depicted in Figure 1.

Figure 1: Gauteng City-Region administrative boundaries (local and provincial) overlaid with conceptual view based on functionality



Source: Adapted from GCRO website, Accessed 4 July 2010.

[4] The initial GCR model proposed the main economic centres surrounding Gauteng (e.g. Rustenburg, Witbank) as the part of the GCR but ignored areas in the NE and NW that are very much functionally/economically connected with Gauteng as a result of a large proportion of the community commuting daily to Tshwane to work/look for work. The debate about the exact GCR boundaries is still on-going. This study, by virtue of extending across the broader GCR (also referred to as the local municipalities adjacent to Gauteng) gives a critical evaluation and enhances an understanding of land-use/land-cover change, which may help determine a more useful functional boundary for the GCR.

The core comprises the three metropolitan municipalities of Johannesburg, Ekurhuleni and Tshwane, together with a number of smaller urban centres such as Germiston, Boksburg, Benoni, Springs, Alberton, Vereeniging, Vanderbijlpark, Krugersdorp, Randfontein and Westonaria (Wray, 2010). Beyond the provincial boundary of Gauteng is a wider region characterized by several urban and industrial centres: Rustenburg in the north-west, a global centre of platinum mining; Sasolburg to the south, founded around the Sasol coal-to-liquid fuel plant, but now focused on the production of chemical feed stocks; to the south-west a patchwork of gold-mining towns (e.g. Potchefstroom and Klerksdorp). On the Mpumalanga Highveld to the east are medium size towns Witbank and Middleburg, centres of coal mining, power generation, and iron and steel production; and Secunda, location of the Sasol coal-to-liquid fuel operations (Wray & van Olst, 2010; Wray, 2010).

The area making up the Gauteng City-Region has experienced rapid population growth over the last century. Currently, Gauteng and the adjoining urban centres have an estimated population of 13.5 million people, a figure predicted to double by the year 2055. In order to plan for the concomitant urban and transportation developments, and to progress from the current status towards a low-carbon and less energy-intensive city-region, it is essential to understand the long-term spatial development trends and their *drivers*. Decisions made based on this knowledge could determine the structure of the city-region twenty or thirty years from now. Spatial planning is necessitated by the fact that spatial forms have decadal influences that once in place are more difficult to alter, and are resistant to changes in policies, priorities, governments, or even social and political revolutions.

3. Historical spatial change in the Southern Transvaal and Pretoria-Witwatersrand-Vereeniging (PWV) complex: 1890s - 1980s

3.1 1890s: Mining and urban growth in the Southern Transvaal

The *Southern Transvaal* was a group of towns and cities, connected by mining, industry and commerce, as well as the provision of power, water and transport. Initially, the *Southern Transvaal* comprised three metropolitan growth centres, namely; Pretoria, the Witwatersrand[5] and the Vaal Triangle (Vanderbijlpark, Vereeniging and Sasolburg). Over time, the *Southern Transvaal* evolved into what became known as the Pretoria-Witwatersrand-Vaal Triangle (PWV) complex. The PWV was an urban agglomeration, stretching east-west along the Witwatersrand from Heidelberg to Carletonville, and north-south from Pretoria to Vereeniging and Vanderbijlpark on the Vaal River to the south, including portions of the North-West Province (magisterial districts of Odi and Moretele), with an area of approximately 15 500 km^2. The PWV encompassed the magisterial districts of Pretoria, Randfontein, Roodepoort, Johannesburg, Germiston, Boksburg, Benoni, Brakpan, Nigel and Vereeniging (DPE, 1974; Roberts & Fair, 1973). It comprised of three separate but closely interwoven and functionally integrated urban systems centred on Pretoria, Johannesburg and Vereeniging (DRLA, 1993).

The evolution of the *Southern Transvaal*, its industrial development, rate of urban development and urban settlement pattern were greatly influenced by geology and mining, following the discovery of gold deposits in 1886 (DRLA, 1993). The influx of people to the nascent mining industry led to the establishment of a mining camp in 1886, which has evolved into a village, then town, city, metropolis of Johannesburg, and finally to become the Gauteng City-Region (an agglomeration of several metropolitan areas) that it is today (Beavon, 2001).

After the discovery of gold in 1886 in the territory of the *Zuid Afrikaanse Republiek* (ZAR), rapid development of the *Southern Transvaal* occurred. Many fortune seekers and prospective miners migrated from other parts of the country and abroad, leading to the development of an array of mining villages (Springs, Boksburg, Germiston and Krugersdorp) along the Witwatersrand, as depicted in Figure 2. This took place to the south of Pretoria[6], founded before Johannesburg in 1855. Rural indigenous Africans were coerced into providing labour to the new mining towns, through the imposition of government levied compulsory head taxes, payable in cash, on all adult males in the ZAR. This measure forced rural dwellers to seek paid employment in the burgeoning mines and support industries. This influx of labourers further boosted the population growth of the Witwatersrand. Pretoria, the administrative

[5] The Witwatersrand is the east-west stretch of land along the mining belt and across Johannesburg. It comprises of the East Rand – Boksburg, Benoni, Brakpan, Springs, Nigel; Central Witwatersrand – Johannesburg, Germiston, Alberton, Kempton Park and Edenvale; and West Rand – Roodepoort, Krugersdorp, Randfontein, and Westonaria.

[6] Pretoria (located in the northern part of the Gauteng City-Region, within the City of Tshwane Metropolitan Municipality) was founded in 1855 by Marthinus Pretorius, marking the end of the Boers' settlement movements of the Great Trek. It serves as the executive (administrative) capital of South Africa.

capital of the ZAR, was in an uneasy political and cultural relationship with the behaviour of the emerging mining camps on the Witwatersrand, and (rightly) saw these as a threat to their hard won independence from British influences.

Figure 2: Southern Transvaal settlement pattern 1896



Source: DPE, 1974:10

Transport infrastructure and land-use pattern (urban development) was influenced by mining. As far back as the 1880s, the west-east transport routes (predominantly railway) were established to link the Witwatersrand goldfields. As such, the emerging gold mining region was primarily linear, conforming to the primary outcropping of the gold bearing *reef* [7] along the east-west axis of the Witwatersrand[8] ridge. For example, one of the oldest arterial roads, Main Reef Road, with the Soweto highway and, more recently, the M2 highway, form a west-east axis that runs from Nigel in the east to Randfontein in

[7] Reef – colloquial word used to denote the conglomerate layers of quartzite rock containing the gold deposits.

[8] Witwatersrand, Wit… – literally white, referring to the extensive white quartzite rock forming part of the outcropping, …watersrand – archaic Dutch-German word for continental divide.

the west (i.e. to the West-Wits section) along the Witwatersrand gold mining corridor. It then extends south-westward from Carletonville to Welkom, connecting nodes such as Fochville, Potchefstroom and Klerksdorp that form what is known as the Vaal River mining section.

A series of towns of varying sizes developed along this axis, colloquially referred to as the *Rand* (literally ridge) (Figure 2). Later extensions of mining led this line of development to incline southwards at both extremities - the Far East Rand and the West Rand (Farquharson, 1963). Land-use was fragmented into agricultural land, mine workings, mine tailings facilities (sand dumps and slimes dams) and scattered urban developments. Consequently, the central zone was not a core but rather a sinuous curve stretching from Nigel in the east to Randfontein in the west (Fair et al., 1956). Subsequent discovery and exploitation of coal deposits resulted in the development of towns in the Witbank area to the west, and the northern Free State to the South (DPE, 1974), thereby enhancing the *poly-centric* structure of the region.

3.2 1900s - 1930s: Colonial spatial planning and initial northward expansion

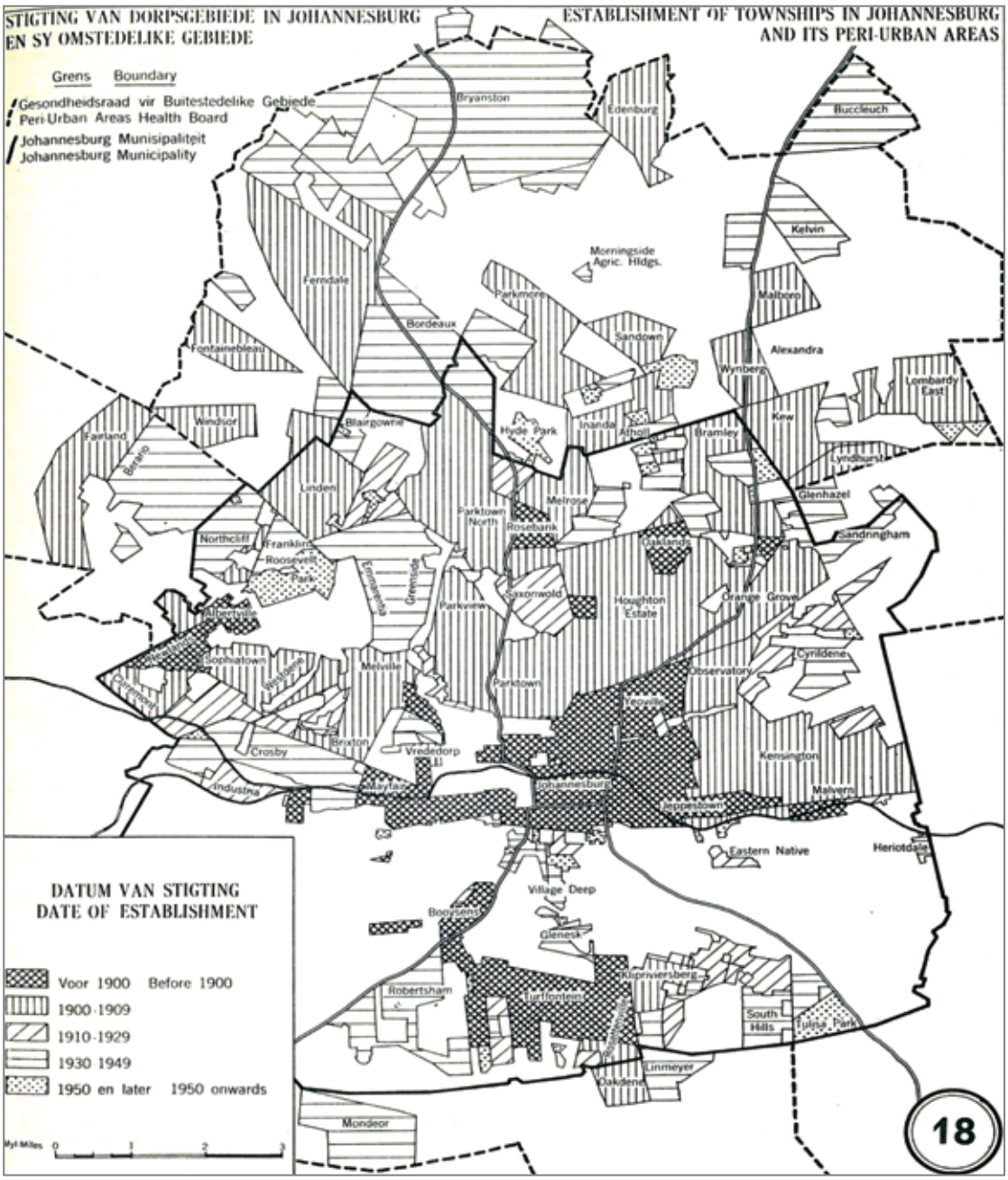
The design of South African cities is based more on the North American, Australian and British model of lateral expansion (suburban sprawl) than on the multi-level, multi-apartment buildings model characteristic of many other European countries (Cooper, 2007; Horn, 2009). However, the suburban sprawl of South African cities can also be ascribed to the intricate political history (Frescura, 1982; 1983; 1992; 1993; 2000; 2001; Frescura & Radford, 1982). In the period 1900 – 1910, there was an extensive growth of residential suburbs, in Johannesburg particularly to the north the Witwatersrand ridge (All mining activities were located on the south-facing slopes of the ridge). Colonial segregation planning (e.g. the Native Urban Areas Act of 1923 - before the apartheid regime) ushered in the first phase of racial segregation, separate development and fragmented growth (Fair et al., 1956; Roberts & Fair, 1973; Popovic, 1986; Frescura, 1993; 2000; 2001; Frescura & Radford, 1982). Municipalities were required to establish separate locations (townships for black residents), on the basis of race, and to preclude Blacks from purchasing land outside designated areas (Frescura, 1992; 2001). This period saw the establishment of such residential suburbs as Parktown, Melville, Linden, Ferndale, Windsor and Kensington (Figure 3). The spatial configuration of these new settlements was haphazard, resulting in the extensive subdivision of land (Fair et al., 1956). However, the rate of development decreased drastically in the late 1920s, with only a few new residential areas being established.

3.3 1930s - 1950s: Post-war industrialisation and post-colonial spatial planning

The late 1930s and again the post World War II period (1946 onwards) were characterised by further northward, mainly residential, expansion of Johannesburg. This second wave of northward expansion of Johannesburg coincided with the era of the motor vehicle, which increased the accessibility of many of these northern suburbs to the zones of work towards the south. The absence of a railway line to serve these northern suburbs fuelled the residents' dependence on private vehicles for transport to work. Consequently, an expansive road network had to be built to connect these suburbs to central Johannesburg. This road network promoted the establishment of further outlying affluent suburbs, such as Bryanston and Buccleuch (Figure 3).

This pattern of transport/land-use development has continued into the twenty-first century. The implications thereof include private car hegemony, and longer trip distances. The preference for private car usage and increase in ownership has resulted in the traffic congestion that characterise the GCR today.

Figure 3: Establishment of townships in Johannesburg and its peri-urban areas



Source: Fair et al., 1956:35

The post World War II (1946 to the late 1950s) years saw a pronounced growth in industrialisation and urbanisation in the PWV complex (Fair et al., 1956; Popovic, 1986). This brought about the further consolidation of the east-west development axis and the establishment of such industrial towns as Kempton Park and Alberton. The development of new steel (Iscor – Iron and Steel Corporation) and petrochemical industries (SASOL – *Suid Afrika Steenkool en OLie*, South African Coal and Oil), initiated as State interventions to transform South Africa into a modern industrial economy, led to the creation

or rapid further development of the three towns of the Vaal Triangle (Vanderbijlpark[9], Sasolburg and Vereeniging) (DPE, 1974). It was, however, the discriminatory racial segregation (*apartheid*) legislation (e.g. the Bantu Urban Areas Consolidation Act 25 of 1945 and the Group Areas Act 41 of 1950), enacted by the Nationalist Party after coming into power in 1948, that extensively transformed the land-use structure into the a*partheid city* (Frescura, 1993; 2000). Citizens were separated into so-called '*White*', '*Bantu*', '*Coloured*' and '*Asian*' precincts, separated by buffer strips of at least 100 m wide, or by distinct industrial or environmental buffer zones (Frescura, 1983; 1992; 2001).

In the 1950s, scattered residential settlements began to consolidate, either as a result of their expansion or the establishment of other settlements in between existing ones. Hyde Park (see Figure 3) exemplifies this form of growth. On the other hand, the development of new high density townships for designated '*Black*' citizens was prominent. Settlements were established on urban peripheries to relocate '*non-whites*' (predominantly black Africans, coloureds and working class Indians), who were forcibly moved from inner city suburbs. This period saw the establishment of Soweto (*SOuth WEstern TOwnships*) to house people forcible relocated from Sophiatown (the vacated suburb was re-developed to house low-income Afrikaans speaking citizens, and perversely named *Triomph* – triumph). On the East Rand, townships such as Katlehong and Tsakane[10] were established. Ultimately, the spatial configuration of the region widened and travel distances increased. To ensure that the relocated populations could still serve the industrial and commercial economy with their menial labour (again enforced by apartheid laws in the form of racially based job reservation Acts), the state constructed railway lines to the townships and heavily subsidised a commuter bus-service (PUTCO). In a security-related move, road access to the Black townships was restrained to relatively few entry and exit roads, so that the populations could be contained by roadblocks at a small number of points. All properties in the townships were state-owned and rented out at subsidised rates. Lack of ownership of homes and business premises, and insecurity of tenure, resulted in an almost total absence of normal home improvement and citizen-driven urban infrastructure improvement. Essentially, normal processes of urban development were deliberately stifled. As the government intended, these dormitory townships became temporary abodes to provide labour for the White-owned and controlled economy.

Transport and land-use interplay

In the 1950s, the land-use and transportation systems were closely interrelated in a two-way dependency. On the one hand, the pattern of settlement in the *Southern Transvaal* governed the road pattern, whilst on the other hand the increasing efficiency of road and rail transport not only speeded up the physical expansion of cities, but also, to a large extent, governed the direction of their growth. The motor car also extended the potential radius from the city centre (Fair et al., 1956). The tram system (suburban electric trains) was fairly limited in central Johannesburg and if it had not been eradicated in favour of buses, would have continued to focus and concentrate growth. Nonetheless, the major elements were the east-west mining belt, and the two metropolitan nuclei to the north and south, Pretoria (administrative) and Vereeniging (industrial) respectively (Fair et al., 1956). By 1960, railway routes for the whole *Southern Transvaal* region had converged at Germiston. The railway systems, though themselves determined by

[9] Named for Hendrik van der Bijl, the pioneering visionary and implementer of both the Electricity Supply Commission (Eskom) and Iscor, the state-owned primary steel producer that transformed the South African economy from a predominantly agrarian economy into a modern industrial state.

[10] Established in 1945, Katlehong township is located in the Ekurhuleni Metropolitan Municipality, about 3 km east of Johannesburg and south of Germiston, next to the N1 highway and between two other townships of Thokoza and Vosloorus. Together with Thokoza, it forms the second biggest black township in Gauteng after Soweto. Tsakane is on the East Rand, south of Springs close to the townships of Duduza and KwaThema.

location of the mining land, in their turn, exerted a strong influence on the direction and pattern of residential and industrial development of the PWV complex.

The spatial structure of Pretoria in the 1950s resembled that of a concentric-zone model, with a single nucleus (DPE, 1974). Beginning from a central core, the built-up area displayed a steady outward growth. However, the concentric form was partly broken by radial lines (roads and railways) extending outwards from the centre. This gave rise to ribbon development, depicted by the prolongation of residential and industrial areas east of Pretoria (DPE, 1974). Similarly, in Germiston, industry grew out to the north and to the south along the railway lines leading from the town. On the Witwatersrand, industries developed along the east-west railway line from Springs to Randfontein (DPE, 1974). Moreover, in Alberton, the initial direction of industrial development was southwards along the railway line from Germiston (which runs to the east of Alberton, past Lambton, Wadeville, Dinwiddie, Alrode) towards Vereeniging. Because of the convergence of railway lines at Germiston from Pretoria and Vereeniging, heavy industry in particular gravitated towards this area to the east of Johannesburg (Fair et al., 1956).

3.4 1960s - 1990s: Apartheid spatial planning and decline in gold mining

In the 1960s, spatial planning was vigorously designed to further separate Black residential communities from affluent Whites suburbs, in pursuit of social and economic race-based segregation. The apartheid government "…*force-removed Blacks from inner city areas*…" (GDED, 2010:37) and relocated them to either homelands or to segregated townships (also known as '*locations*') in peri-urban areas (Frescura, 1982; 1983; 1992; 1993; 2000; 2001; Frescura & Radford, 1982). In pursuit of this policy, areas such as Soweto were expanded; Lenasia, south of Soweto, was developed to house designated *Indians*, forcibly relocated from inner city suburbs such as Ferreirasdorp; and north of Pretoria the Bophuthatswana homelands were created. New suburbs were established, exclusively for Whites, to the north of Johannesburg (favourably far away from the dust blown off gold mine-tailing storage facilities). Black residents were legally restricted to dwell in government provided and owned housing in townships to the south of the Witwatersrand ridge. Inner city areas vacated through these policies were allocated to the rapidly urbanising 'poor White' Afrikaners (GDED, 2010).

It has been assumed cynically by some that the Black townships were deliberately placed adjacent to mine-tailing storage facilities. However, recent studies (Ojelede, 2011) show that when the townships were established in the 1950s, they were a considerable distance (2 to 3 km) away from mine-tailing storage facilities. Over time, the townships grew bigger; mine dumps spread wider and the two converged. For example, Reiger Park, Elsburg, Wadeville, Freeway Park Proper, Farrar Park Proper and Parkdene Proper grew around the East Rand Proprietary Mines (ERPM) tailings complex (i.e. 4/L/47, 4/L/48, 4/L/49, and 4/L/50). The expansion of Soweto also converged with that of the Crown Gold Recoveries (CGR) gold mine-tailings complex (also known as the 'big *three*', i.e. Homestead (3L5), Mooifontein (3L7) and GMTS (3L8)). Locations in Soweto include Orlando, Diepkloof and Riverlea (Ojelede, 2011). The apartheid policies had the underlying intention to keep rural Black inhabitants in rural areas and to allow only as many Black people into the cities as were required for mining and industrial labour needs (Frescura, 1992; 2001). There were deliberate industrial policies designed to establish industrial parks (growth points) in areas adjacent to designated 'Black homelands', promoting industrial growth using pools of cheap labour, without attracting Blacks into the White urban centres. In many cases, these industrial parks were isolated from the main infrastructure of the cities. When government subsidies were eventually withdrawn, many of these remote industrial hubs collapsed (e.g. near and beyond Rustenburg, as well as Babelegi to the north of Pretoria). This was a late apartheid development – part of a strategy of industrial deconcentration.

The apartheid ideology was based on the premise that Black citizens were not a permanent feature of urban life (Frescura, 1992). This assumption informed the decision to establish mass housing in *dormitory* suburbs (*townships/locations*) with few social amenities (other than traditional beer halls) and few internal economic opportunities. Residential areas and formal housing for Black urban populations were fully owned and tightly planned and controlled by the central government. Population surplus to the labour needs was repatriated to the rural areas and the repatriation was enforced by the state police system under apartheid laws. Up until the mid-eighties, the apartheid government built and owned all housing stock in the Black townships. Eventually the State was unable to keep up with the housing demand and attempted both to introduce limited tenure (in the form of 100-year leasehold) and to transfer the responsibility for developing lower socioeconomic housing to the (incapacitated) provincial and local government.

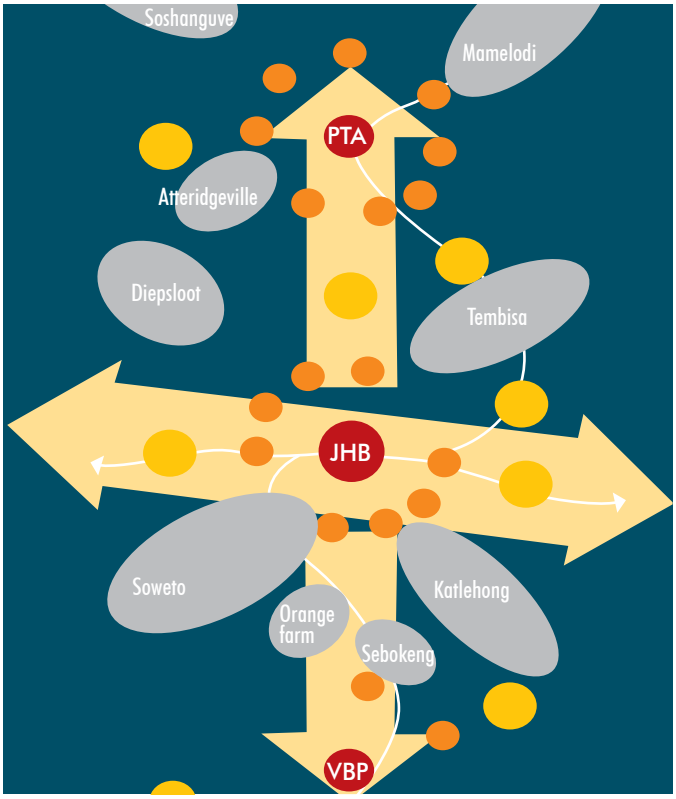
In a case of spatially dysfunctional planning, low-density suburbia, primarily for the '*White*' affluent, also gravitated towards the peripheral regions (GDED, 2010). These segregationist regulations and the continued establishment of townships left a strong spatial footprint and the legacy is still vivid in the configuration of the Gauteng City-Region. The unsustainable and inefficient cityscape urban planning persists well beyond the political transformation of 1994, and remains an issue in the planning of transforming South Africa cities into more egalitarian societies.

The repeal of the Group Areas Act in 1991 (and other discriminatory legislation at South Africa's political dispensation in 1994) triggered the start of a major rural-to-urban migration by segments of the Black population that had been forcibly kept out of towns and cities (Visagie, 2008; Horn, 2009). Government embarked on deliberate and significant programmes to upgrade existing townships and to integrate townships into the urban fabric (e.g. paving roads in Soweto, erecting normal street lighting in place of the high-rise security mast lighting, and permitting of suburban shopping facilities). New commercial areas within the townships were designated, often adjacent to the existing transportation hubs (e.g. Baragwanath bus/micro-bus taxi hub).

Despite the good intentions of the post-apartheid government to redress previous discriminatory housing policies (by building 2.4 million houses in the 15 years following the 1994 transformation, under the *Reconstruction and Development Programme* (RDP) economic and subsequent policies), the rate of construction has not matched the demand of the inward migration, natural population growth and the large influx of economic and political refugees from elsewhere in Africa (Sexwale, 2009). The shortfall in formal housing has resulted in the development of numerous informal settlements – occupation of land without formal planning permissions or without prior construction of essential infrastructure. At a recent count, some 187 informal settlements were recorded within the boundaries of metropolitan Johannesburg, and 625 within Gauteng Province (Eighty20, 2011).

The apartheid government had created Black residential areas well away from trunk transport infrastructure (outside transport corridors). According to the *New Urbanism/Smart Growth/Compact City* approach (Crane, 2008; Duany, 2008), residential areas at such distant locations are a disadvantage for residents, who cannot easily and affordably take part in economic activities because their mobility to commercial and industrial nodes is restricted. Post-apartheid, the Government has continued to establish 'locations' and informal settlements have developed on the outskirts, even more distant from city centres and still outside transport corridors (Figure 4). For example, Diepsloot is in a semi-rural area, about 17 km from the nearest urban centre (Sandton/Wynberg). Paradoxically, it is located near the intersection of two major trunk roads, the R51 and N14 highways, yet few of the informal dwellers can afford motor vehicles and there is no formal public transport infrastructure (bus or rail lines). There are few other complementary developments or amenities nearby.

Figure 4: Legacy of apartheid spatial planning: dysfunctional land-use/transport system



Source: GDED, 2010:37

This rapid growth in population and urban spatial extent has culminated in the emergence of what is now known as the Gauteng City-Region. The challenge for urban planning is that apartheid spatial planning has created a long lasting urban footprint and some elements are almost impossible to retrofit (Frescura, 1992; 2000; 2001).

Transport

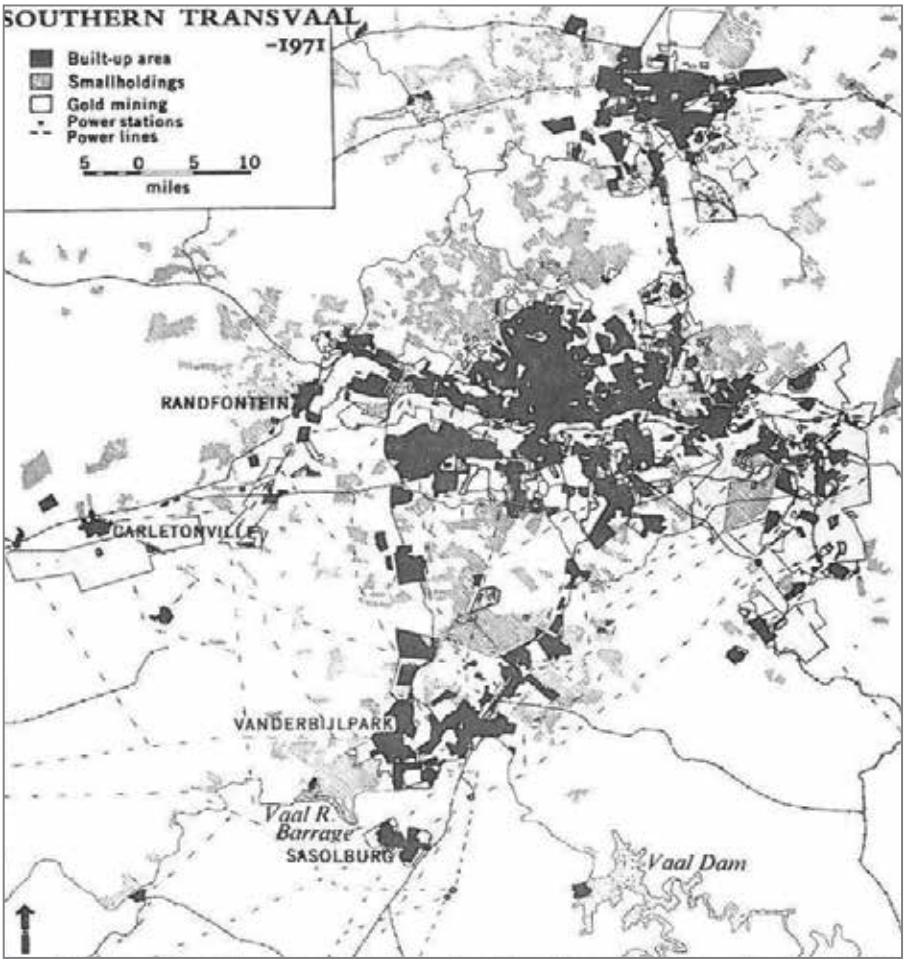
Public transport systems (bus and rail), heavily subsidised by the State, were established to transport workers from the dormitory townships to the (White-owned) industrial and commercial areas. Townships such as Soweto, Tokoza and Vosloorus were served by railway lines. The newly established Black settlements (e.g. Soweto, established in ~1949/50) necessitated the establishment of new roads or the relocation of existing main ones (for instance – the Old Potchefstroom Road which passed through Soweto). In many cases, although these were supposedly public roads, regular police road blocks discouraged Whites from travelling into the Black townships.

In the 1970s, investment in transport infrastructure shifted towards roads at the expense of rail transport (deemed too expensive at the time). This resulted in the dense network of roads that anchors the travel routes and the suburban sprawl which characterise contemporary Gauteng's current land-use/transport structure. Since the adoption of the White Paper on National Transport Policy (DOT, 1996), public transport has been regarded as a priority (Mokonyama & Schnackenberg, 2006). However, competing projects (e.g. poverty alleviation and basic service provision) have had the result that transport infrastructure investment became a secondary priority (Botha & Ittmann, 2008). No new urban rail infrastructure has been built in Gauteng for two decades, and rolling stock has not been renewed for a similar period. Several initiatives have been implemented, across the country, in an attempt to address private vehicle dependence. Preparations for the

2010 Soccer World Cup acted as a catalyst to expedite transport infrastructure development, in the form of rapid transit systems, following the Bagota model. However, after the World Cup in 2010, portions of the Johannesburg *Rea Vaya* bus rapid transport system that had not been completed in time have stalled, and two years later (July 2012) the original planned network is still incomplete.

Around 1976, gold output from the Witwatersrand (and South Africa) began to decline, due to depletion of shallow readily accessible reserves and increasing costs. The Witwatersrand economy had been in a state of transformation, with secondary and tertiary industries taking a leading role on the East Rand and West Rand, and Johannesburg and Sandton transforming into financial and service industry hubs. The spatial structure of the PWV complex was altered (DPE, 1974). Development began to extend more towards the northern suburbs of Johannesburg (Fair et al., 1956). Unlike the other phases of northward expansion discussed above, this particular strand of development was fuelled predominantly by decentralisation because of the industrial shift. Because the decline in mining was gradual, the change in the land-use pattern was also gradual. By contrast, the economy of the Vaal Triangle remained based in the mining and manufacturing industries, causing a relative stagnation in population growth and spatial expansion in that urban complex (DPE, 1974). Perversely, the perception and reality of poor air quality in the Vaal Triangle, from the metallurgical and petrochemical industries, were major factors inhibiting the economic transformation of the area, despite relatively cheap land, a skilled labour force, and access to water, power and transport infrastructure. The built-up area of the Witwatersrand and Pretoria became more consolidated and compact than that of the Vaal Triangle (Figure 5).

Figure 5: Southern Transvaal settlement pattern 1971



Source: DPE, 1974:10

Vegetation and reprocessing of mine dumps

Prior to 1970 the yellow-gold colour of the gold mine tailings storage facilities (colloquially known as *mine dumps*) were a signature feature, almost a tourist attraction, of the Witwatersrand. However, the convergence of urban expansion and increasing size of the mine dumps exacerbated living conditions for residents in the vicinity of the dumps due to wind-blown dust. Industry and commerce downwind of the dumps also suffered. Led by the Chamber of Mines, over the period 1965 to 1980, many of these dumps were successfully vegetated, substantially reducing wind and water erosion, and opening up land development, in some cases right up to the foot of the dumps (and in violation of regulations relating to physical safety buffer zones).

After this successful programme to vegetate the mine tailing storage facilities, the apartheid government allocated certain areas in proximity to the dumps for expansion of 'non-white' settlements. Suburbs designated for 'Coloured' occupation such as Fleurhof, tucked between two dumps just south of the Main Reef Road; Reiger Park, adjacent to the ERPM dump in Boksburg; and Davidsonville, adjacent to the Princess Dump in Roodepoort on the West Rand are a direct result of that process. With the formal or de facto closing of the mines on the Witwatersrand and in the absence of mine enforced security operations, informal settlement proliferation resulted in the rapid filling of gaps at the foot of many mine tailing storage dumps, for example at Angelo in Germiston and Erwat in Springs. Parts of Soweto (e.g. Dobsonville Section 6) are uncomfortably close to not fully rehabilitated mine dumps. These cases illustrate that urban development was greatly influenced by the changes in the mining dynamics, with both formal and informal residential developments filling in gaps close to mine tailings because such sites are close also to basic urban infrastructure such as roads, water, power and sewerage provisions, and importantly, to economic opportunities.

Despite the high demand for land in Gauteng, there is a shortage of proclaimed land for urban development. As such, the development of or reclamation of mine tailings has had a major influence on urban development in the Gauteng City-region, particularly in the southern part of Johannesburg. New technology was discovered in the late 1970s that allowed the profitable reworking of the mine tailing storage facilities to extract the residual gold at grades as low as 0.5 ppm. Thereafter, the land covered previously covered by the mine tailing storage facilities could be cleared and subsequently handed over for urban development. The late 1970s and early 1980s saw the commencement of major mine tailings reclamation operations initially on the East Rand, at Anglo Gold's ERGO reduction facility. Reprocessed waste was deposited on a new mega-dump, south of Springs. In 1981, Rand Mines Crown Gold operations commenced similar operations in the Central Witwatersrand area. The re-processed material was deposited on three large slimes dams near Nasrec and Diepkloof, Soweto. The cleared areas were then developed into industrial and commercial parks, close to the Johannesburg central business district. Despite rigorous inspection and enforcement by the National Nuclear Regulator, for removal of any residual radioactivity from the gold ore, anxiety on the part of provincial environmental officials has prevented any of this cleared land from being zoned for residential use. This precautionary official position is in stark contrast to the reality that several informal settlements on the West Rand are located on areas of elevated uranium content (e.g. Tudor Shaft informal settlement, Krugersdorp).

Growth of commercial centres

The ubiquitous growth of low-density residential concentrations was followed by the decentralisation of commerce (shopping centres and business areas, office parks, hotels, places of entertainment, markets, warehouses, storage places and services of all kinds) (DPE, 1974). Subsidiary shopping centres increased

(especially in the northern suburbs), often as isolated units in the peri-urban areas, long distances from the urban core. Commercial development also created ribbon-like lines following the major radiating roads e.g. along Barry Hertzog Avenue (now Beyers Naude Drive) radiating in a north-westerly direction from Johannesburg (DPE, 1974). This represented a combination of corridor development and urban sprawl. The centre of gravity shifted from the original Johannesburg CBD geographic centre towards the northern suburbs with the emergence of such economic hubs as Randburg, Sandton and Rosebank. Commercial centres paralleled the continuous mining and industrial spine, and were themselves, in turn, flanked by a discontinuously developed outer low-density residential band (DPE, 1974).

Transport/land-use interplay

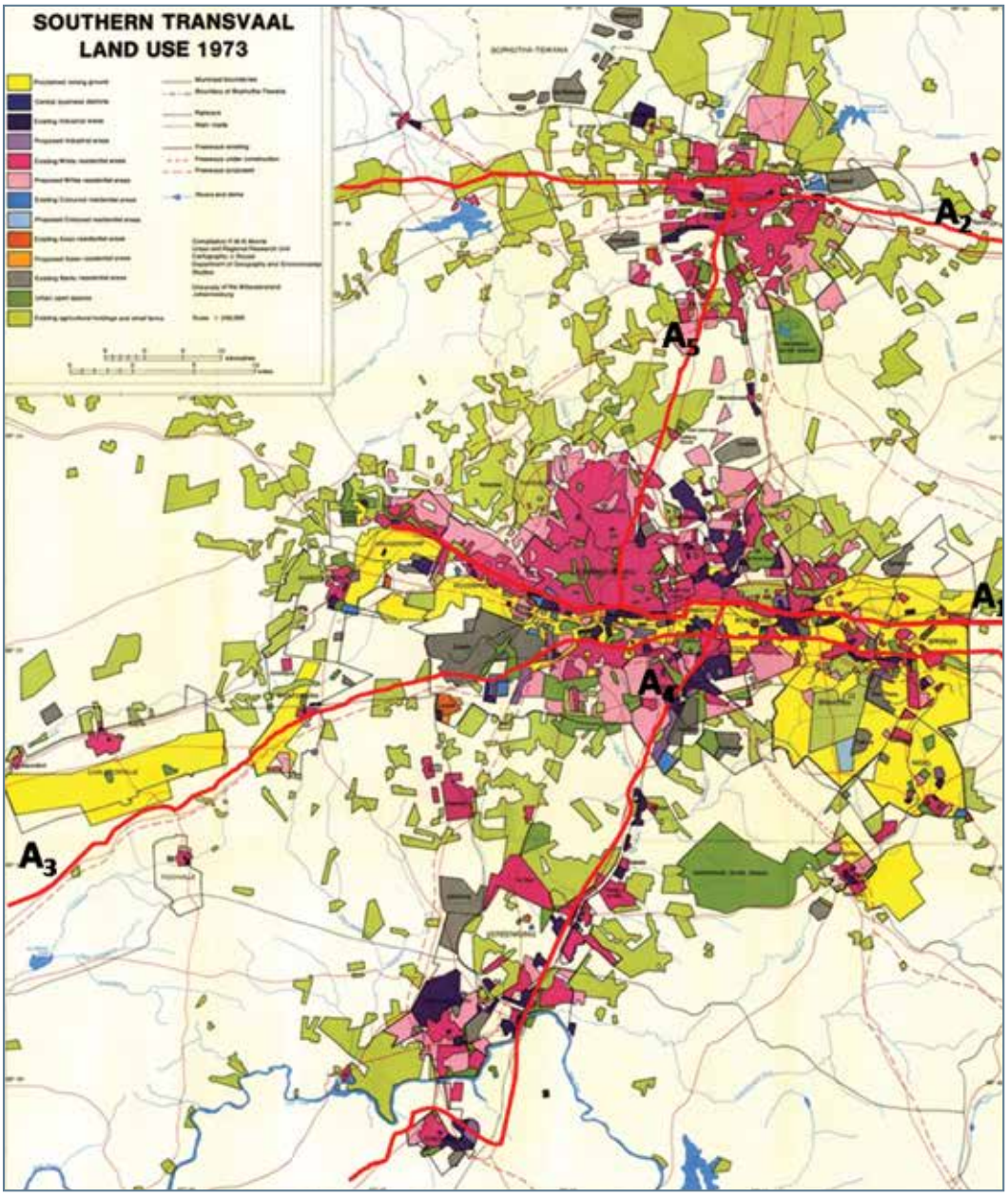
Land for further development in Pretoria has been constrained by its characteristic ridge and valley topography. Moreover, suitably spacious and flat land adjacent to rail lines (transport) could only be found towards the east and south-east (DPE, 1974). This explains the expansion of built-up area mainly towards the south-east, with a strong tendency to link up with the northern areas of the Johannesburg/ Witwatersrand central core. The establishment of the Council for Scientific and Industrial Research (CSIR) and various other government departments demanded large pieces of land. These developments in turn attracted others, leading to the further vigorous growth of Pretoria in an easterly direction.

In the central Witwatersrand area, the radial pattern of development was depicted by the string of residential suburbs and smallholdings along the roads leading northwards out of Johannesburg and by the growth of industry along the railway lines north and south of Germiston. Residential development took place, especially in a north-westerly direction (Krugersdorp), northwards (Randburg and Sandton), towards the north-east (in the direction of Kempton Park), and, once the mine tailings facilities had been grassed, also southwards from Johannesburg central (Figure 5).

The upgrading of station facilities and marshalling yards at Pretoria and Vereeniging, as well as the complete rebuilding of the Johannesburg station and the rail improvements (doubling of existing lines and electrification) of some lines[11] in the 1960s, affected the land-use planning of the region. Railway lines attracted other types of development, such as industry (DPE, 1974). Moreover, there was an increase in industry along the railway lines from Germiston towards Pretoria (e.g. at Olifantsfontein) and towards Vereeniging. There were also residential developments along and around the connection axes and between the northern, central (Witwatersrand) and the southern geographic components of the PWV complex (DPE, 1974). The built-up area of the PWV Complex showed one main development axis (corridor) – the east-west axis defined by the mining belt (A1 in Figure 6). However, as depicted by Figure 6, there were also two less well defined development axes: the northern development axis which extends from Middelburg in the east to Rustenburg in the west (A2); and the southern development axis which extends from Secunda in the east to Potchefstroom and Klerksdorp in the south-west (A3) (Du Plessis, 1981). The transport axis between the Vaal Triangle and Germiston was flanked by increased industrial development (A4). In addition, the dominant nuclei in the PWV complex, Pretoria and Johannesburg, formed nodal points on the extended north-south development axis (A5).

[11] A new line was built between Springs and Natalspruit and the ones southwards to Vereeniging were either doubled or electrified (Fair et al., 1956).

Figure 6: Pretoria-Witwatersrand-Vereeniging (PWV) Land-use 1973

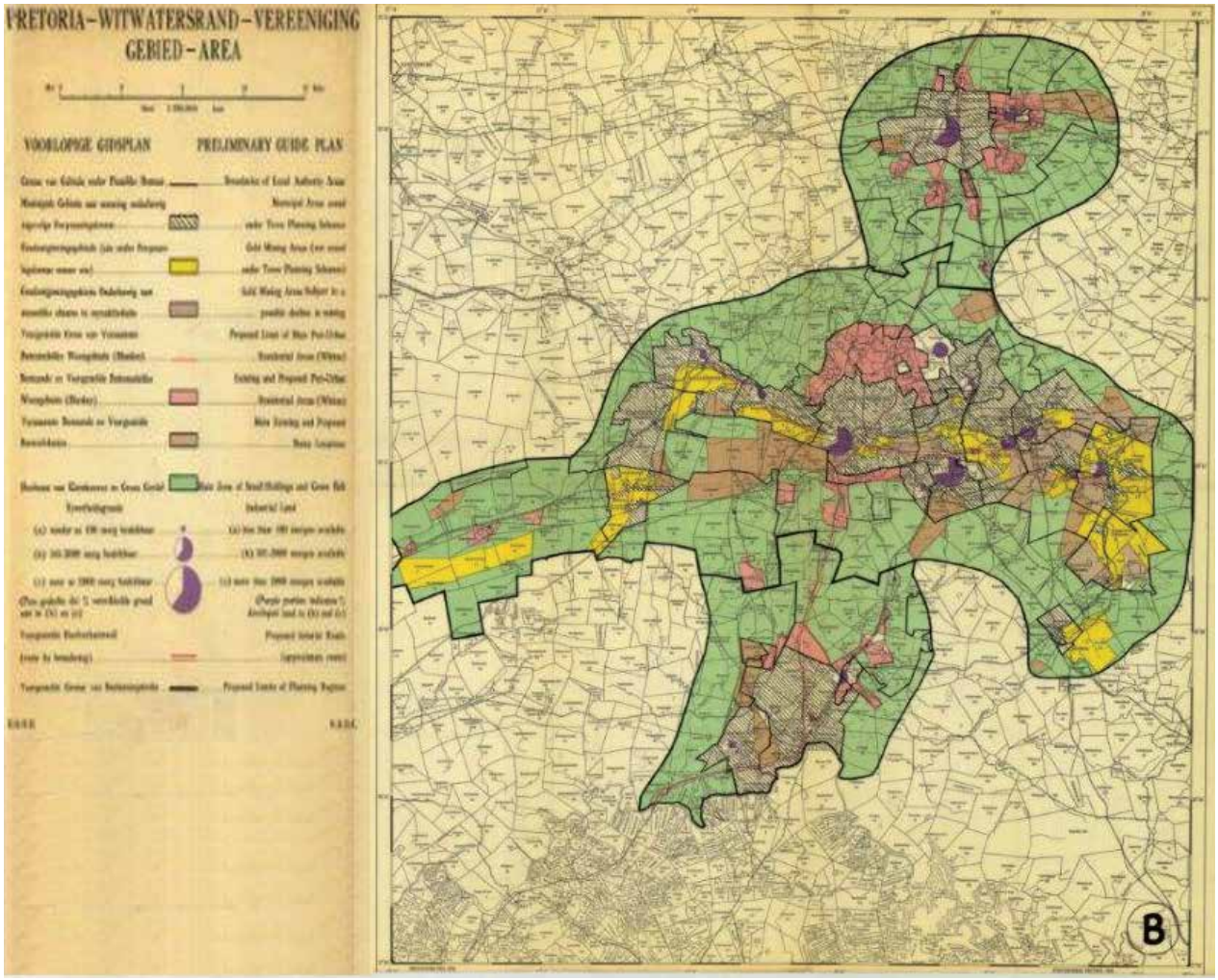


Source: DPE, 1974:29

Trends in land-use change and envisaged spatial patterns

In the 1950s, the government mandated the Natural Resources Development Council (NRDC) to formulate a Guide Plan (Figure 7) for the spatial development of the PWV Complex. This preliminary guide plan shows the city-region perspective held by the authorities at that time. The Guide Plan was prepared primarily to indicate, in general terms, the main land-use problems of the *Southern Transvaal* and some of the possible solutions, in a bid to address such issues as the effects of the eventual decline in gold mining on land-use, population distribution and the growth of towns; and the amount and location of future industrial land at a regional level (Fair et al., 1956).

Figure 7: Southern Transvaal, Preliminary Guide Plan (envisaged locations of various land-uses)



Source: Fair et al., 1956:36

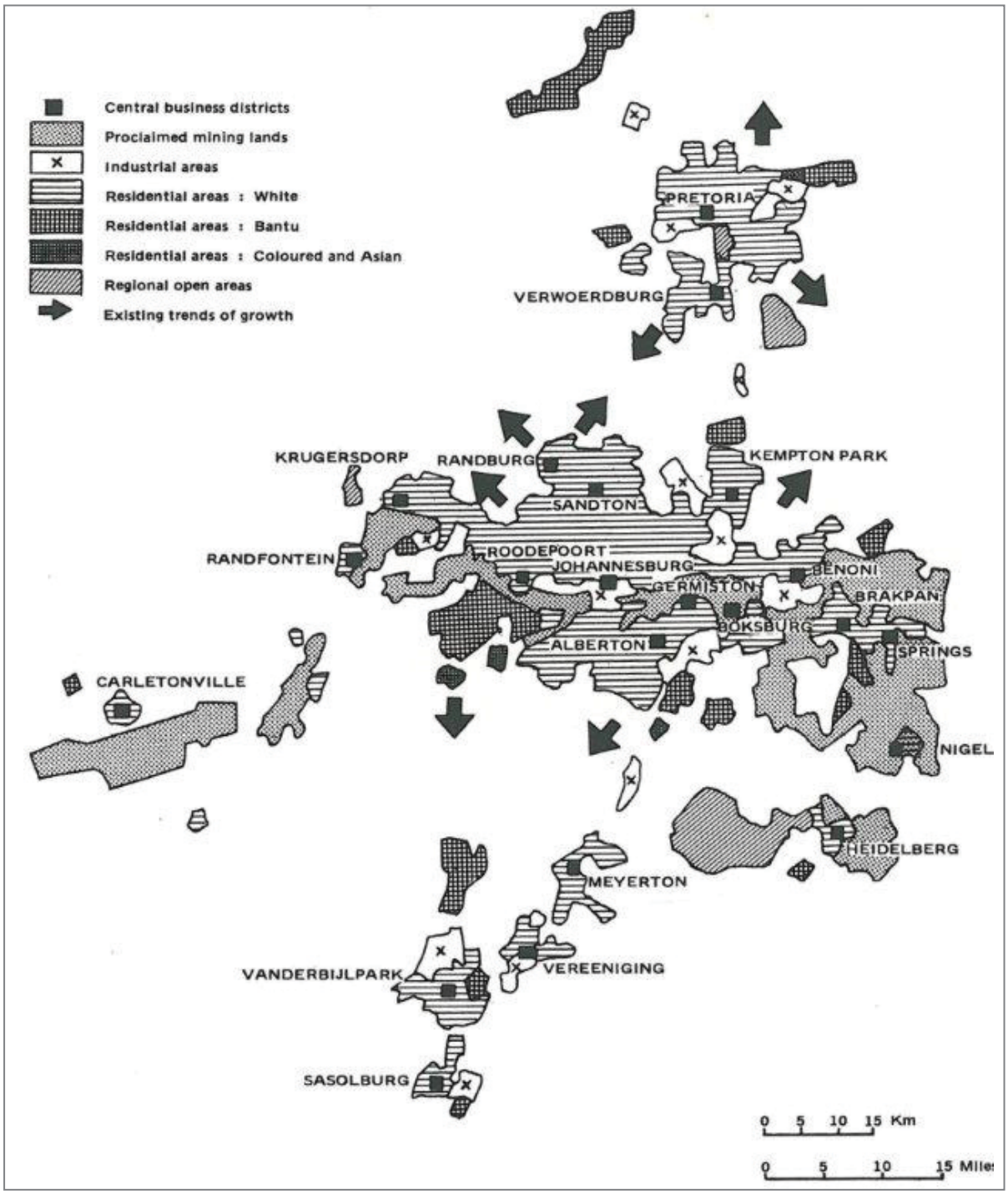
The Guide Plan (Figure 7) was an outline plan that gave a broad picture of the intentions and expectations of the regional planning body for the development of the *Southern Transvaal* (Fair et al., 1956). It was a statement of policy concerning the future development of the region within which the more detailed plans of local authorities (Integrated Development Plans) could be fitted, and to which government departments, developers and other users of the land could look for guidance on future trends of development and land-use (Fair et al., 1956).

The Guide Plan indicates that the areas where mining ground could be proclaimed and released for other purposes (depicted by yellow and brown in Figure 7) lay predominantly on the East Rand. Despite being earmarked for development under the town planning schemes, these areas were often broken into disjointed elements by large areas of proclaimed mining ground (Fair et al., 1956). These same areas were the most vulnerable to the impact of the decline in mining.

In Pretoria, the outer limit of the residential boundary incorporated the existing residential townships to the east, south-east and south, each of which was being planned in groups as dormitory towns. The idea was to control the northward growth of Pretoria. In Johannesburg, the plan was to round-off development in the northern areas, as well as to group existing residential areas in the south into dormitory towns. Beyond these limits, further residential growth was to be disallowed. Moreover, the outer areas were to

be regarded as green belts, to be kept as free from building development as far as possible (Fair et al., 1956). It was envisaged that spatial growth within the PWV Complex could be controlled by curbing further outward expansion by creating a green zone around the urban areas, beyond which no further development would be allowed (the urban margin concept) (Figure 7). However; the perceivable tendencies of the existing land-use pattern (shown by arrows in Figure 8) strongly contributed in the shaping of the morphological structure of the PWV complex (i.e. the existing - 1973 - and envisaged future land-use pattern).

Figure 8: PWV Complex – urban land-use 1973 (Simplified)



Source: DPE, 1974:39

4. Detailed analysis of land-use/ cover change in the Gauteng City-Region (1991 - 2009)

4.1 Research design

The second component of this study entailed the analysis of land-use/land-cover change in Gauteng, for the period from 1991 to 2009, in order to track urban development trends. The study used computer-assisted classification of digital multispectral satellite remote-sensing images. This was judged to be the most cost-effective methodology, given the spatial and temporal scale of the study. Several procedural steps in data preparation, classification and evaluation were undertaken. These are briefly described in the following sections (4.1.2 to 4.1.4). The classified-map comparison approach[12] (Wilson et al., 2003; Ololade et al., 2008) was adopted. Various facets of change – geographic extent, pattern and context[13] – were then quantitatively analysed, with focus on urban growth. The imagery used and all GIS layers generated are in a geo-referenced format (WGS84). Image pre-processing was carried out using ILWIS (Integrated Land and Water Information System) V3.7 open source GIS and remote sensing software, as well as other open source software, such as OpenEV and MultiSpec. Thereafter, image processing was carried out using ENVI (the Environment for Visualizing Images). Verification was done by field-checks and comparison with other land-use/land-cover maps, particularly the 2009 Gauteng land-cover dataset produced by GeoTerraImage- (GeoTerraImage, 2009).

4.2 Selection of satellite imagery

The Landsat7 ETM+ (Enhanced Thematic Mapper Plus) and Landsat5 TM (Thematic Mapper) were deemed to be the optimal sensors for this study, considering their temporal acquisition continuity and multi-spectral comparability[14] (Chander et al., 2009). Images were acquired for the periods 1991, 2001 and 2009 respectively (Table 1). Landsat5 TM and Landsat7 ETM+ were chosen, based on availability, for 1991 and 2001 respectively. For 2009, Landsat5 was chosen over Landsat7 ETM+ because of the failure of the scan line corrector on Landsat7 in 2003, which led to gaps within the imagery. Depending on availability of cloud-free data, most of the scenes acquired for the three time intervals are from the period April–May, in an attempt to reduce the summer effect of moisture, cloud and vegetation. The next section describes the procedure employed to obtain the land-use/land-cover maps.

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[12] This involves classifying images of different time intervals and then comparing the classification results to observe any changes. In this method, the 'from and to' classes are quantified for each changed pixel.

[13] This considers the location of the change (i.e. urban growth) in relation to other existing land-use/land-cover types (Wilson et al., 2003). It is important to assess, over and above identifying the level and form of change.

[14] Although the data was acquired from different sensors, it can be combined because the sensors have similar spatial, temporal and spectral resolutions.

Table 1: Satellite data and scenes used in this study

Assumed Year	Sensor	Path/Row	Acquisition date	Resolution
1991	Landsat5 TM	p170r077	1991/04/07	30m
		p170r078	1991/04/07	
		p170r079	1991/04/07	
		p171r078	1991/04/30	
2001	Landsat7 ETM+	p170r077	2002/01/07	30m
		p170r078	2002/01/07	
		p170r079	2001/02/05	
		p171r078	2001/01/11	
2009	Landsat5 TM	p170r077	2009/04/24	30m
		p170r078	2009/04/24	
		p170r079	2009/04/24	
		p171r078	2009/05/17	

Credit: B. Mubiwa, 2011

4.3 Image pre-processing

Prior to any digital processing, geometric registration was done to transform all orthorectified[15] images into a common geometric coordinate system – the Universal Transverse Mercator (UTM) geo-reference (the World Geodetic System 1984 (WGS84) coordinate system) covering zones 35 and 36 for the Southern Hemisphere (Hong, 2007). The 1991 and 2009 Landsat5 images were resampled (image-to-image registration) to the orthorectified 2001 Landsat7 ETM+ images in order to synchronise the pixels of all the images[16], based on the Automatic Raster Resampling technique. The spatial resolution of 30 m was maintained for all images.

The images used for this study were multisource and multi-temporal; all such images were atmospherically and radiometrically normalised (calibrated). The LHAZE formula and the dark-object subtraction (Moran et al., 1992; Chavez, 1996) were used to remove haze and thin clouds. Thereafter, the images were converted from digital numbers[17] (DN) to absolute units of at-sensor spectral reflectance[18] (Skirvin, 2000a; 2000b). The 1991 and 2009 images were normalised to the 2001 dataset because of its clear view and the better technology used in the sensor (Landsat7 ETM+).

[15] Therefore there was no need for geometric correction.

[16] To ensure that each point/pixel in an image correspond to the same point in other images in the multi-temporal sequence. If not, the difference in the geometry and location of any feature in two images being compared might lead to an incorrect reading of the error as actual for land use or land cover change.

[17] The digital numbers (DNs) 0-255 are a measure of at-satellite radiance, specific to each original image but not calibrated to allow for proper comparisons between images from different satellite sensors or dates. Therefore, to standardise the impact of illumination, DN images are converted first to at-satellite radiance and then to at-satellite reflectance (USGS, 2006).

[18] This conversion corrects for differences in the sun angle (time of day) and the intensity of the sun (which varies during the year due to the earth's elliptical orbit).

4.4 Training data creation and processing (classification and post-classification processing)

Multispectral Classification[19] can be categorised into two general approaches: *supervised* and *unsupervised*. The supervised classification approach (Jensen, 1996; Lu et al., 2004; Hardin et al., 2007; Dewan and Yamaguchi, 2009) and the post-classification change detection technique were adopted for this study (in preference to the pre-classification procedures[20]). This is because post-classification techniques allow for the generation of the 'from-to' maps (Jensen, 1996), thereby enabling the clarification of the location, magnitude and nature of the changes shown (Howarth and Wickware, 1981). *Training areas*, spectrally representative of the land cover classes of interest, were selected based on *a priori* knowledge of the study area and ancillary data (such as existing maps). These training areas were then used to classify the images based on the Gaussian Maximum Likelihood Classifier. After the multispectral classification on a pixel-by-pixel basis had been performed, a *majority filter*[21] was applied to incorporate the spatial context of the pixels. Post-classification processing techniques – clumping and sieving, combining classes and class colour - coding were then done. Land-use/land-cover classes were defined in line with National Land Use Classification and Methodology[22]. The classified land-use/land-cover maps were verified through existing land-use/land-cover maps (e.g. GeoTerraImage, 2009) and field checks. This gave simple but visually useful depictions of decadal development patterns.

From the initial thirteen land-use/land-cover categories[23] (defined as: water; urban (built-up); mines; cultivated lands (crop and pasture); wetlands; woodlands; plantations/woodlots; dense trees/bush; grasslands; wooded grasslands; rocky-grass matrix; natural bare rock and bare) the images were aggregated (reclassified) into eight broader classes: water; urban (built-up); mines; cultivated lands (crop and pasture); wetlands; woodlands; grasslands and bare. The image was further aggregated into four classes: water; urban (built-up); mines and non-urban and finally into just two classes: urban (built-up) and non-urban.

4.5 Results and discussion: Key land-use/land-cover changes and reasons

Land-use/land-cover classes (quantified per pixel counts, areas then percentages) were observed to have changed between 1991 and 2009, albeit more significantly between 1991 and 2001. Qualitative observations showed a highly dynamic interchange of land-use/land-cover, indicating competition for land between urbanisation, cultivation, grasslands and woodlands. This study has revealed that, at regional scale, urban development was prominent within and in areas adjacent to the main urban blocks of Pretoria and Johannesburg. Overall, grasslands have increased at the expense of woodlands during these two decades. Although there were strong conversions of pixels from wetlands and grasslands and woodlands, overall, the fluctuations in water and wetlands were minor.

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[19] The process of grouping pixels or regions of the image into classes intended to represent different features on the ground (Rees, 2001).

[20] Such as image differencing (Toll et al., 1980), band ratioing (Nelson, 1983), change vector analysis (Johnson & Kasischke, 1998), direct multi-date classification (Li & Yeh, 1998), vegetation index differencing (Townshend & Justice, 1995) and principle component analysis (Hartter et al., 2008).

[21] A 3 x 3 kernel (pixel neighbourhood) is investigated and the spurious pixels within this neighbourhood are reassigned to whichever class

[22] This also derives from the Land Cover Classification System (LCCS) (Di Gregorio, 2005).

[23] These land use/cover classes were defined in line with the Land Cover Classification System (LCCS) (Di Gregorio, 2005) and the National Land Use Classification and Methodology (DRDLR, 2009).

The inter-class land-use/cover conversions (at pixel level) are presented in Table 2 and Table 3. Some of the land-use/cover change percentages may appear to be large – however, the overall hectares for the total area of each class may not have changed much. Table 2 shows that, between 1991 and 2001, urban area increased significantly, including taking up 25% of the 1991 bare area, 5% of woodlands and 5% of grasslands. This can be seen in Figure 9, where the red (urban) patches increased in 2001. There was also significant conversion of land from grasslands to woodlands (5%), indicating increased forestation in some areas. However, a 4% conversion from grasslands to bare indicates simultaneous land degradation. Significant portions of bare area were converted to urban (24%) or naturally vegetated into grasslands (46%). Grasslands took up 70%, 57% and 46% of 1991 woodlands, wetlands and bare pixels respectively.

Table 2: Land-use/cover conversion (%), 1991-2001[24]

Changed to 2001 / Changed from		Water	Urban	Mines	Cultivated	Grasslands	Woodlands	Wetlands	Bare
1991	Water	88.78	1.40	0.06	0.12	6.77	1.48	0.44	0.41
	Urban	0	99.99	0	0	0.01	0	0	0
	Mines	0	0.02	99.97	0	0	0	0	0
	Cultivated	0.01	0.11	0	99.13	0.66	0.05	0.02	0.01
	Grasslands	0.21	4.79	0	0.3	84.90	4.65	0.78	4.35
	Woodlands	0.32	5.15	0	0.16	69.65	17.02	4.87	2.81
	Wetlands	0.23	2.98	0	0.06	56.57	5.61	32.80	1.72
	Bare	0.33	24.62	0	0.22	46.03	3.28	0.41	25.06

Credit: B. Mubiwa, 2013

The statistics in Table 3 depict the continued urban development between 2001 and 2009. Built-up area took up 4%, 4% and 5% of 2001 mines, grasslands and woodlands area respectively. This can be attributed to the stronger economic growth and population increase during this period. The level of urban development may be understated here because of the established urban forest. This ambiguity could be resolved by using object-based (as opposed to pixel-based) analysis. Grasslands took up 23%, 70% and 43% of 2001 mines, woodlands and wetlands area respectively. Woodlands continued to decrease – albeit at a slower rate than in the previous decade – to become gains for urban, grasslands and wetlands. Water decreased slightly from 2001 – 2009 (Table 4), possibly because the 2001 images were taken in January/February (normally wet summer rain season), whereas the 2009 images were taken in April/May (relatively drier autumn season).

[24] Diagonal represents unchanged fraction of each class.

Table 3: Land-use/cover conversion (%), 2001-2009[25]

Changed to		2009							
Changed from		Water	Urban	Mines	Cultivated	Grasslands	Woodlands	Wetlands	Bare
2001	Water	88.65	1.20	0.35	0.15	10.63	1.25	0.69	0.07
	Urban	0	100	0	0	0	0	0	0
	Mines	0.68	3.68	70.37	0.02	22.88	0.26	0.26	1.85
	Cultivated	0.01	0.72	0	98.42	0.80	0.03	0.01	0.01
	Grasslands	0.21	3.60	0.05	0.15	88.71	4.44	1.77	1.01
	Woodlands	0.38	4.91	0.03	0.15	70.07	19.12	4.28	1.01
	Wetlands	0.46	0.82	0	0.17	42.75	13.77	40.66	1.33
	Bare	0.10	4.68	0.02	0.10	79.05	5.54	1.66	9.34

Credit: B. Mubiwa, 2013

The programme of vegetation of the mine-tailings facilities during the 1960s and 1970s made it difficult to pick out these features on satellite images. Shape files for the boundaries of the mine-tailings storage facilities were obtained from independent sources and these areas were excluded from the change analysis in terms of vegetation and bare areas. In terms of land-use/cover proportions, Table 4 presents the land-use/cover hectares and percentage of total Gauteng land area at three time intervals.

Table 4: Land-use/land-cover hectares and percentage of total Gauteng land area

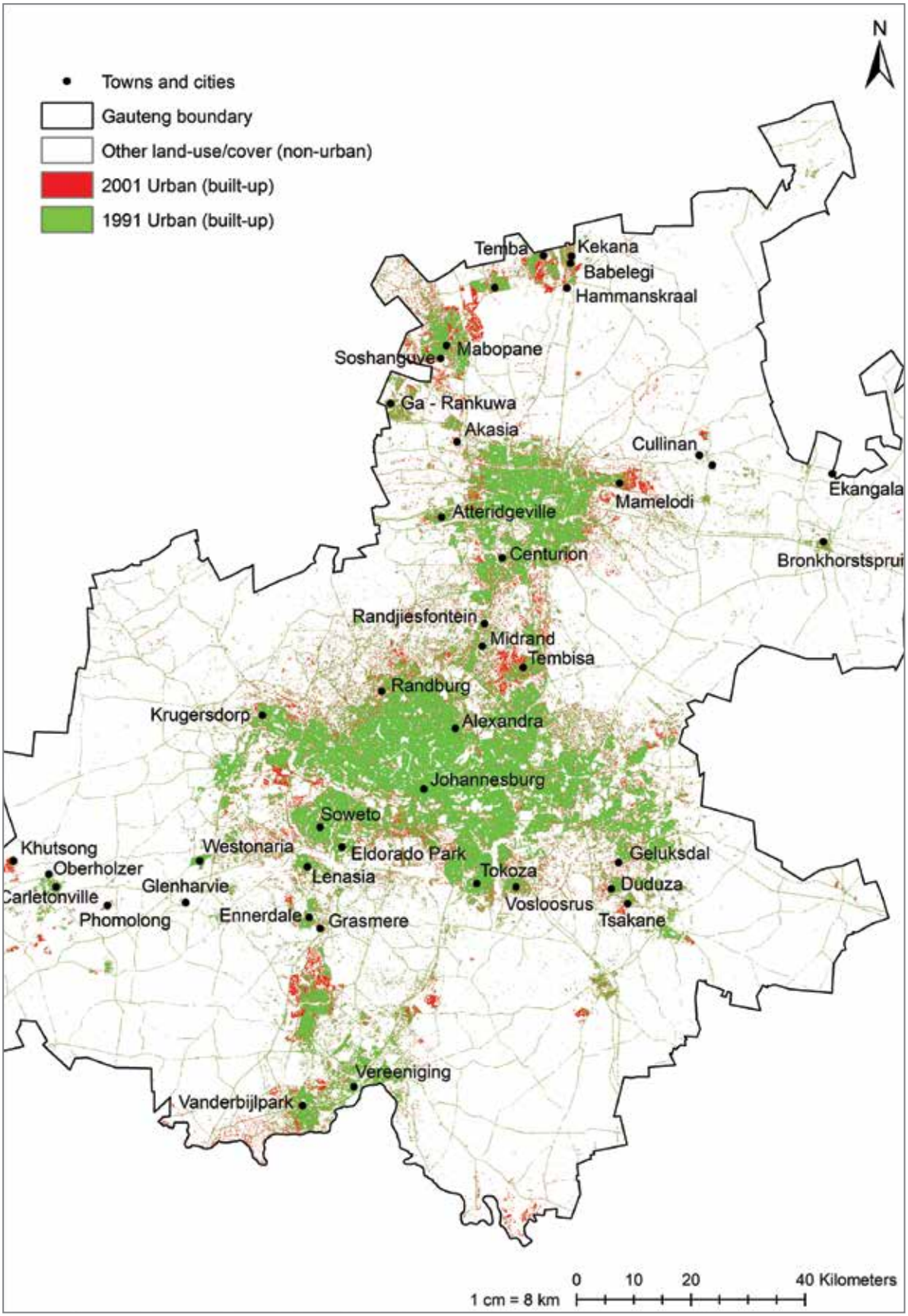
Landcover class	1991		2001		2009	
	Ha	%	Ha	%	Ha	%
Water	35 707.71	1.97	34 350.43	1.89	32 002.60	1.76
Urban (Built-up)	228 791.82	12.60	289 781.31	15.95	333 457.56	18.36
Mines	26 362.64	1.45	26 584.67	1.46	19 320.06	1.06
Cultivated	391 787.26	21.57	391 460.73	21.55	386 942.72	21.30
Grasslands	890 463.40	49.03	918 737.59	50.57	934 043.39	51.42
Woodlands	174 602.38	9.61	75 111.73	4.13	62 620.52	3.45
Wetlands	39 788.39	2.19	28 849.97	1.59	32 150.38	1.77
Bare	28 564.33	1.57	51 723.21	2.85	15 841.93	0.87

Credit: B. Mubiwa, 2013

The Gauteng urban development maps (Figure 9 and Figure 10) depict Gauteng as polycentric, with two large solid areas (Johannesburg and Tshwane) and several other distinct development nodes around them.

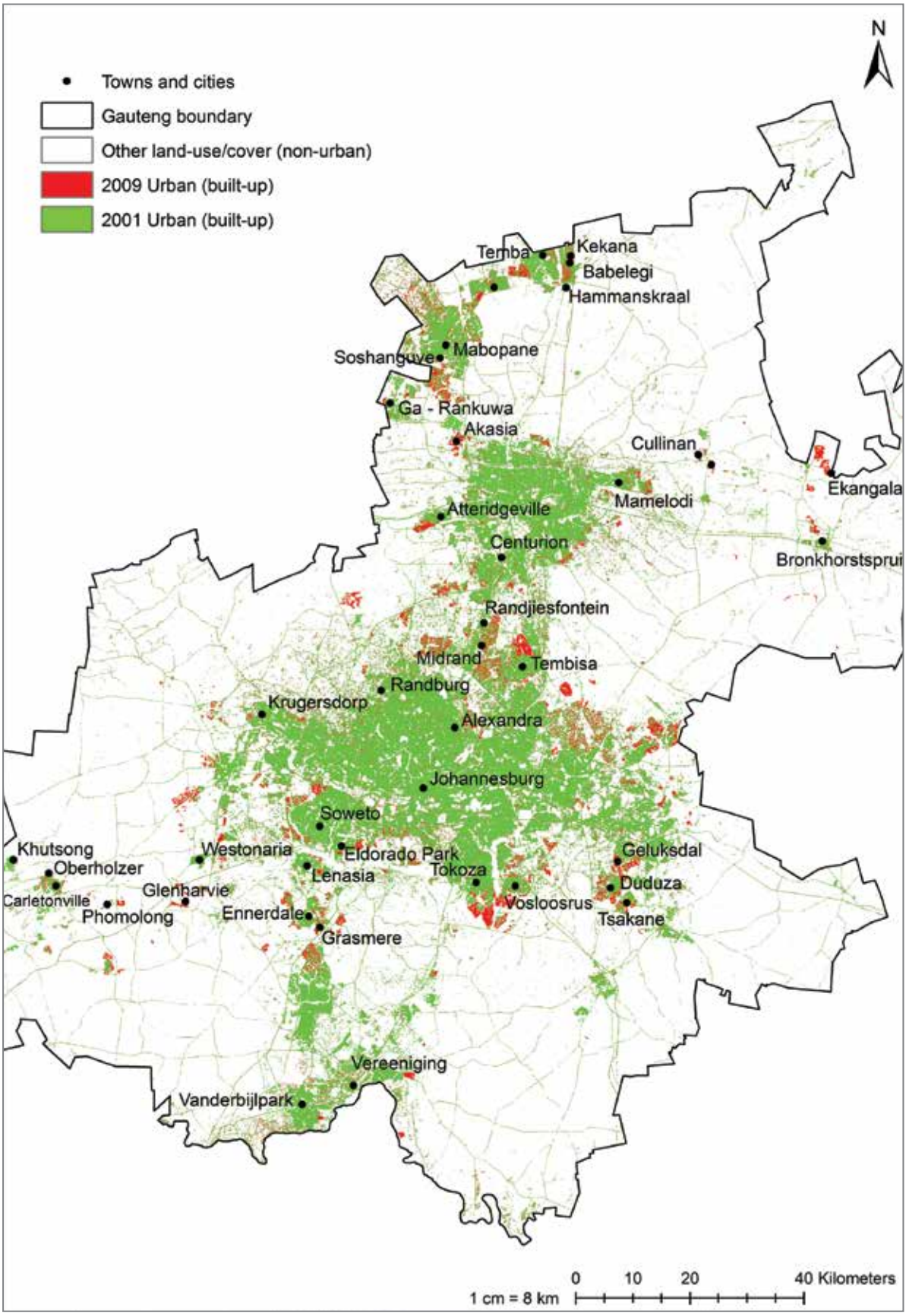
[25] Diagonal represents unchanged fraction of each class.

Figure 9: Gauteng urban development (1991-2001), derived from land cover/land use analysis of satellite images



Credit: B. Mubiwa, 2013

Figure 10: Gauteng urban development (2001-2009), derived from land cover/land use analysis of satellite images



Credit: B. Mubiwa, 2013

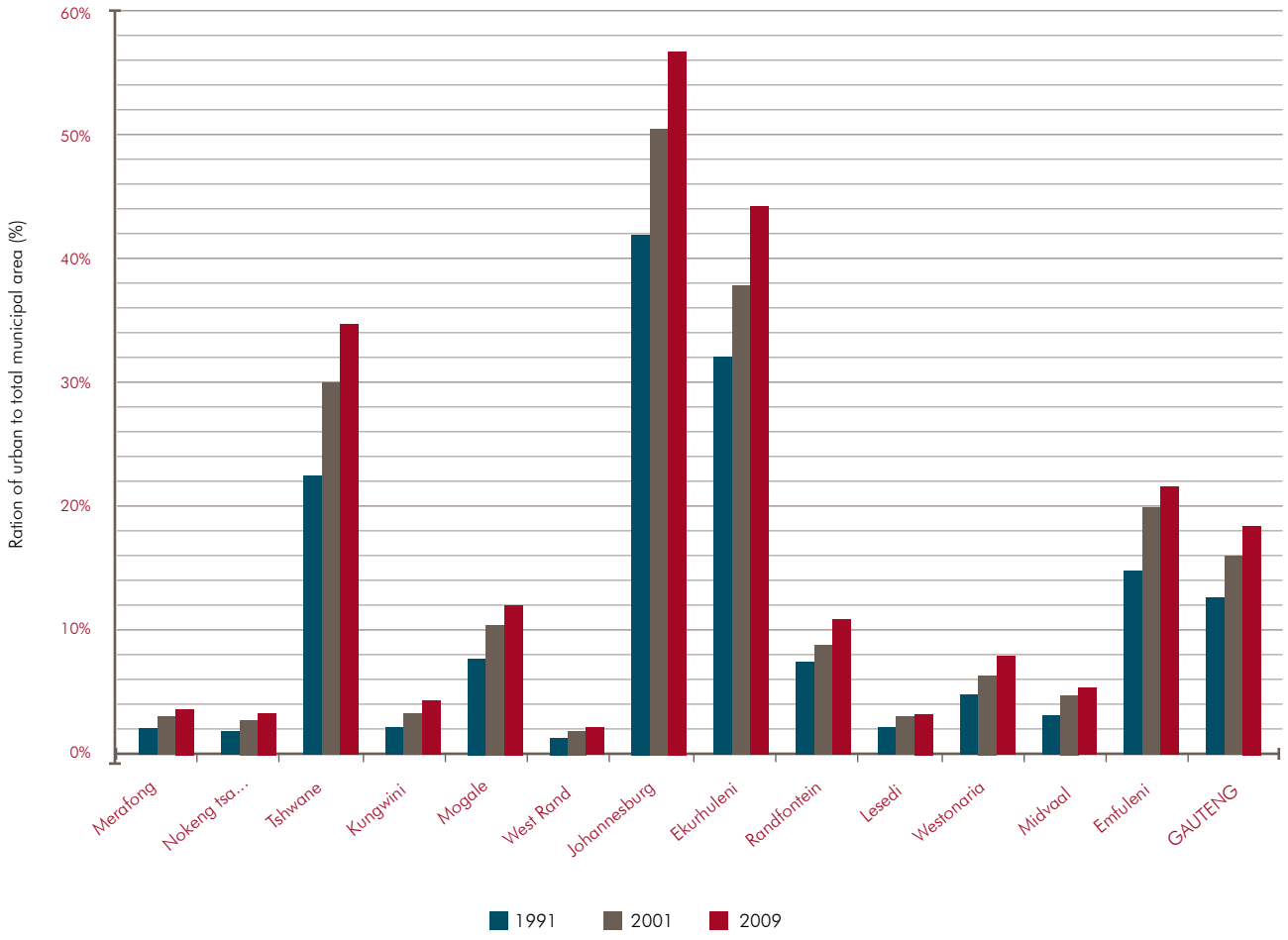
During the 1991-2001 decade (Figure 9), there were small portions of mining to urban conversion within proximity of the Johannesburg CBD. This form of infill development can be attributed to the reclamation of mine tailing storage facilities for industrial development. Areas of infill were identified along the M70 (also known as the Soweto Highway) and the M2 routes. Development was also contiguous with existing built-up areas (e.g. the southwards expansion of Soweto; north-eastward expansion of Mabopane, south-ward expansion of Eersterus and south-ward expansion of Temba and Kekana). Nodes such as Tembisa (in Johannesburg) and Mamelodi (in Tshwane) experienced similar patterns of urban growth. This greenfield urban expansion encroached upon grasslands, woodlands and bare areas. Infill development continued into the 2001-2009 decade, with land-use/land-cover change characterised by the urbanisation of open spaces in Johannesburg, Tshwane and Ekurhuleni. Haphazard expansion (sprawl) into rural areas was also registered in the same period. There was also strong infill and lateral expansion at the nodes in the hinterlands of the province: the Vaal Triangle area (particularly in Vanderbijlpark and Bophelong); around Bronkhorstspruit (and areas to the north) and around Heidelberg. Nonetheless, urbanisation around the south-western mining towns (Oberholzer, Carletonville, Northdene and Phomolong) was relatively low.

Qualitative analysis of the urban development map (Figure 10) indicates strong *ribbon development* along transport corridors, mainly along the M1/N1 freeways between Johannesburg and Pretoria. The rapid expansion encompasses the nodes of Midrand, Rooihuiskraal, Irene, Centurion (and other smaller nodes) along the same route. This explains the need to expand the existing on/off-ramps (e.g. at Edenvale, Olifantsfontein and New Road) as part of the Gauteng Freeway improvement project. '*Red-spots*' in this area correspond to residential areas such as the Kyalami Estates, the Birchacres Extension and Vorna Valley.

The most pronounced development, however, was in the Brits-Garankuwa-Soshanguve-Mabopane area to the north-west of Pretoria. Strong infill and lateral expansion also characterised development in the nodes of Eersterus, Temba and Kekana during the 2001-2009 decade. On the outskirts of Johannesburg, there was further westerly expansion of the Diepsloot area. There was both infill and lateral expansion in Tembisa; north-westward expansion of Randburg (into the area now known as Fourways) and south-ward expansion of Thokoza/Katlehong.

The changes in the urban footprint of the different municipalities of Gauteng varied between the different municipalities[26] and the three periods (Figure 11). In 1991, Johannesburg was the most urbanised municipality (with over 42% of total municipal area built-up), followed by Ekurhuleni and Tshwane (32% and 22% respectively). Between 1991 and 2001, the greatest urban development occurred in Johannesburg, where the proportion of urban land cover/use to total municipal area increased by 8,5%. During the same period, urban land cover/use in Tshwane increased by 7,5%, followed by Ekurhuleni with a 5,7% increase. Emfuleni also experienced significant growth with a 5% increase. In the remaining municipalities of Gauteng, urban development was less than 3%.

Figure 11: 1991, 2001 and 2009 percentage of urban (built-up) area to total municipal area



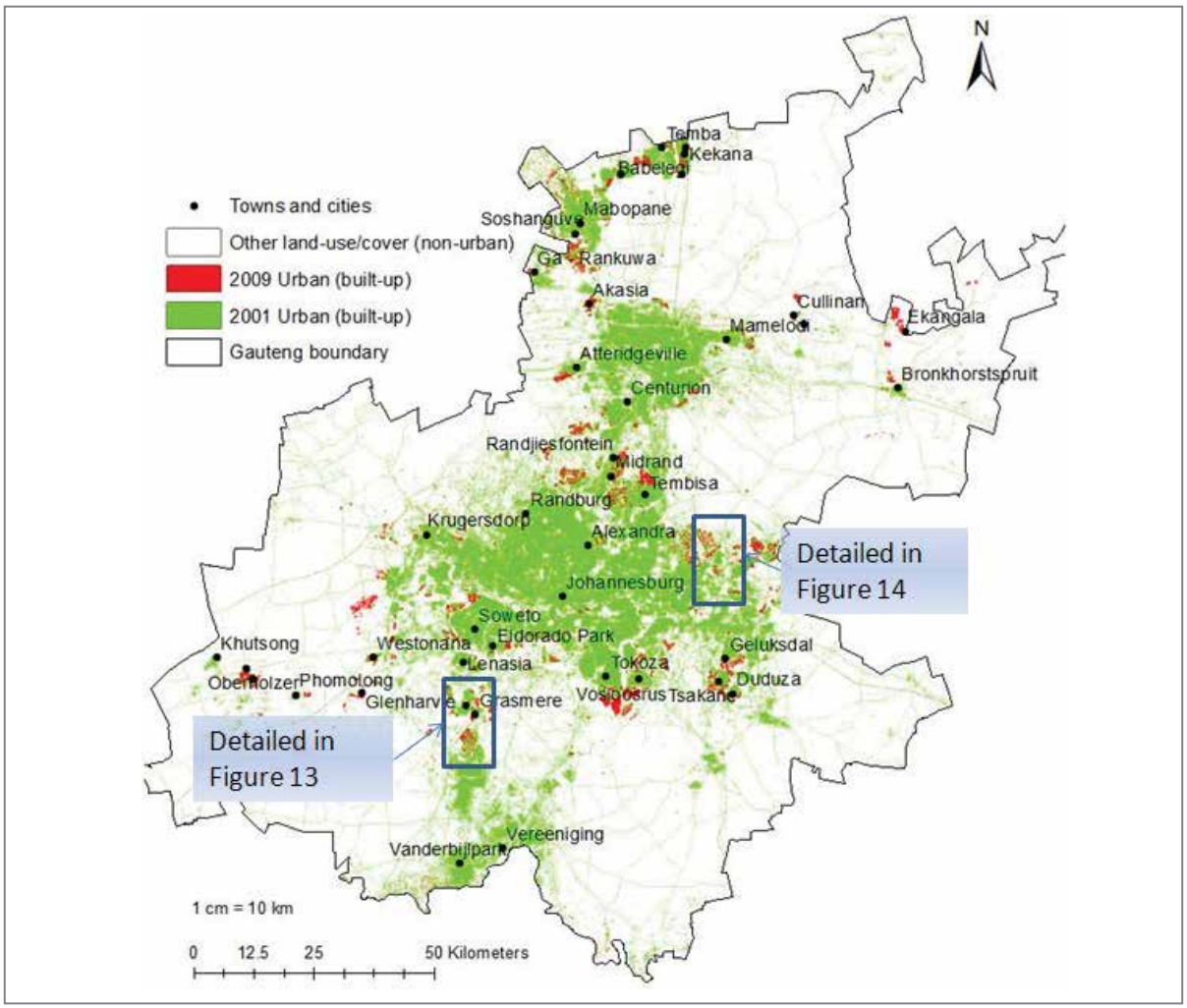
Credit: B. Mubiwa, 2013

[26] The analysis uses the 2006 municipal boundaries and not the latest (2011) boundaries which include Nokeng and Kungwini (Metsweding District Council) as part of Tshwane.

Between 2001 and 2009, urban development was strongest in Ekurhuleni and Johannesburg with a 6,4% and 6,2% proportional (as a percentage of the total) increase respectively. Urban development was also significant in Tshwane and Randfontein (which registered 4,7% and 2% proportional growth respectively). In 2009, Johannesburg remained the most urbanised municipality, with 56% built-up area, followed by Ekurhuleni and Tshwane with a built-up area of 44% and 35% respectively. A fifth of the land in Emfuleni was urbanised in 2009; while approximately 12% of land cover/use in Mogale was urban. While Johannesburg, Tshwane (Pretoria) and Ekurhuleni remain the most urbanised municipalities, municipalities such as Emfuleni, Mogale and Randfontein have also been strongly urbanised. The rate of urbanisation of Johannesburg, Tshwane and Ekurhuleni in the 2001-2009 period has been higher than the provincial average. By and large, all municipalities experienced rapid urban development over the two decades, with the most pronounced urbanisation occurring in the first decade.

Results indicate a strong trend of dispersed patterns of urban growth. However; a closer look (zoomed-in) at some locations depicts more detail with regards to the transport/land-use correlation over the past two decades, resulting in varying forms of urban growth (e.g. *corridor/ribbon/linear development*). Figure 12 shows the location of two (although there are several examples) instances of the *corridor development* in Gauteng, indicating *corridor development* at the convergence of road and rail and the growth of informal settlements along (or at the convergence of) rail infrastructure.

Figure 12: Location map for expanded (zoomed in) detail



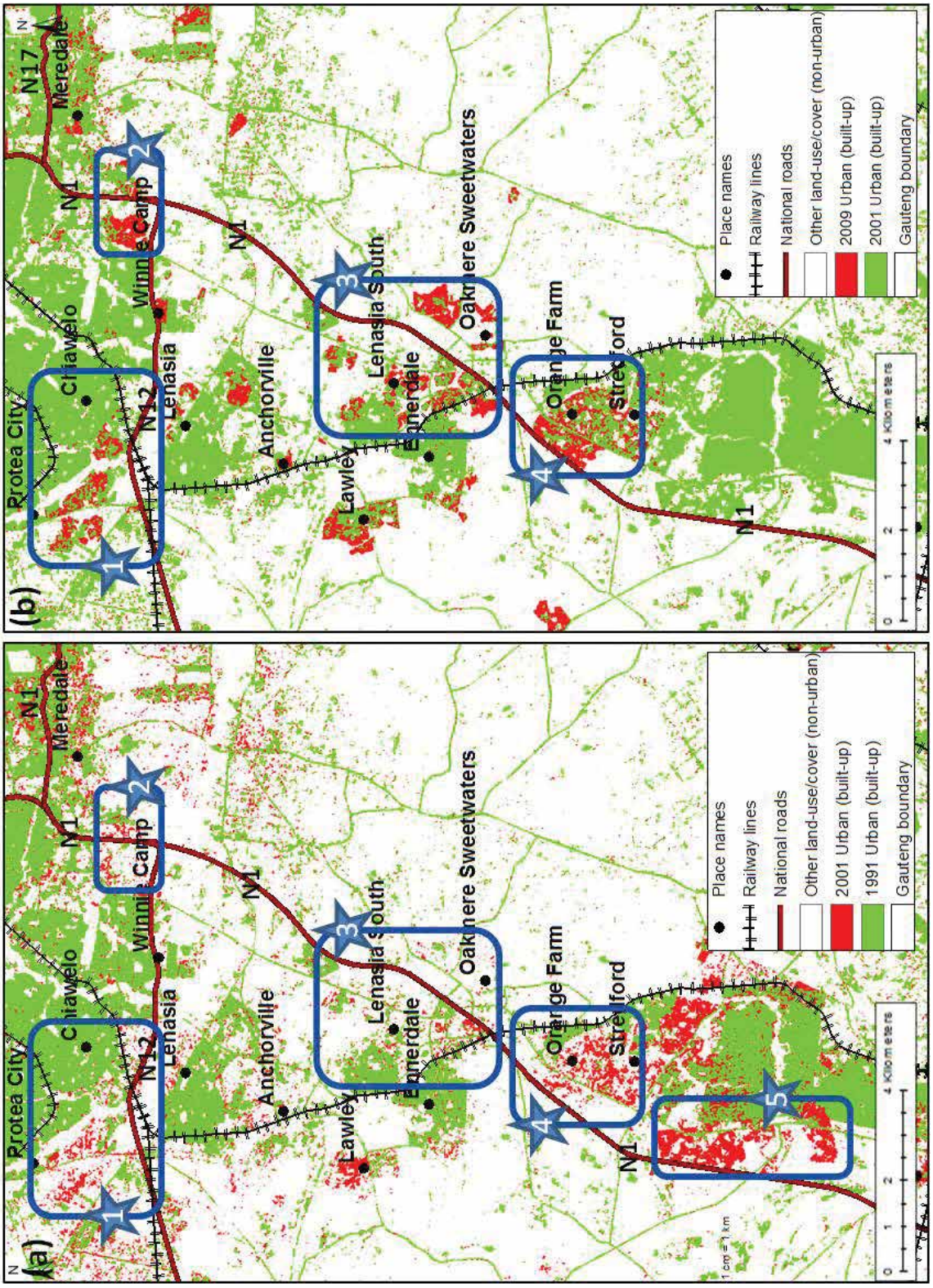
Credit: B. Mubiwa, 2013

Urban growth at the convergence of road and rail is exemplified in Figure 12. Orange Farm, Lenasia South and Oakmere Sweetwaters are among the fastest growing areas in Gauteng. They are situated south of Johannesburg, at the convergence of the N1 route and a railway line. The strong urban growth, between 1991 and 2001, at Orange Farm (red in Box 4 of Figure 13a) and Lenasia South and Oakmere Sweetwaters (red in Box 3 of Figure 13a) can be attributed to this road-rail transport connectivity. The combined influence of rail and road transport continued to be an attracting factor well into the 2001–2009 decade, hence urban growth (red in Box 4 of Figure 13b) continued to gravitate toward the intersection point. The area westward of Chiawelo also grew towards the road-rail intersection, over the two decades (red in Box 1 in both Figure 13a and Figure 13b). Although the area south of Stretford (south of Box 4) and the Winnie Camp area (Box 2) (which experienced intense urbanisation in the first and second decades respectively) are closer to a major road than railway line, they are both still within 4 km of the rail transport infrastructure. The growth of these areas can be attributed to the diversity of mode choice and high transport accessibility.

The growth of informal settlements at an intersection of railway lines is presented in Figure 14. Box 1 illustrates the growth of the Barcelona and Kombisa informal settlements on the fringes of a town called Daveyton. During the 1991-2000 period (Figure 14a), there were small spots of urban growth. However, between 2001 and 2009, the higher intensity and spread of red in Figure 14b indicates strong infill development and lateral expansion of the informal settlements at the intersection of these three railway lines. The growth of Zenzele and Chris Hani informal settlements (Box 2 of Figure 14), was in the direction of rail transport infrastructure. Boxes 3, 4, 5 (Springs) and Box 6 also represent the gravitation of urban growth towards or location of new developments in between the rail transport infrastructure. Urban growth of informal settlements (presented in Figure 14) was influenced, to a great extent, by the railway transport connectivity of the settlements. Railways provide an affordable transport mode for the residents of informal settlements, where most of the residents belong to the low income group. This explains the attractiveness of the area for informal settlers and its growth during the 2001-2009 period.

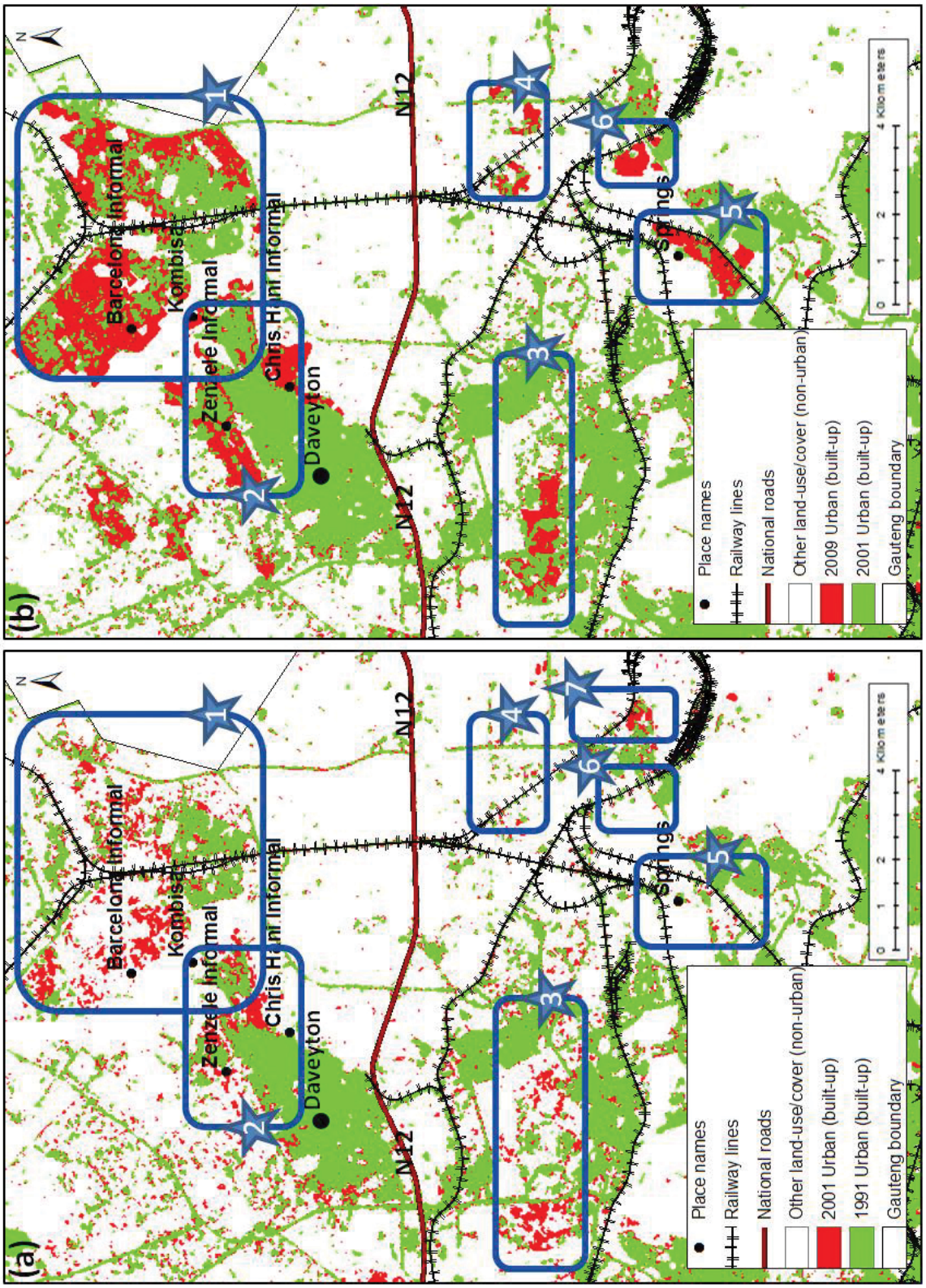
On the basis of the presented examples (Figure 13 and Figure 14) it is argued that, along the major transport corridors going out of Gauteng, there is strong *ribbon development*. Although each transport corridor has a unique set of qualities, evidence suggests that there are several cases where urban development has tended to gravitate towards the established transport infrastructure. Train stations have tended to attract and promote the expansion of informal settlements; development along the major road-based corridors has been predominantly retail, industrial and office parks. This was established through field checks. Irrespective of these differences, the study shows that major corridors have potential to guide urban growth patterns.

Figure 13: Corridor development at convergence of road and rail in (a) 1991-2001and (b) 2001-2009



Credit: B. Mubiwa, 2013. Source: Map created from Landsat5 TM satellite imagery.

Figure 14: Informal growth on fringes of Daveyton, along / at convergence of rail in (a) 1991-2001 and (b) 2001-2009



Credit: B. Mubiwa, 2013. Source: Map created from Landsat5 TM satellite imagery.

4.6 Accuracy assessment and limitations of the study

The classification procedure discussed above proved effectual in extracting land-use/land-cover information. Spectrally separable classes of urban (built-up) area, water and mining areas were relatively easily identified and classified. However, the classification of spectral-signature-based categories did not adequately discriminate between spectrally similar classes (e.g. grasslands and vegetated mine tailings storage facilities; barren, bare-cultivated lands; un-vegetated tailings storage facilities and some built-up areas), resulting in classification confusion/misclassifications. This confirms the misclassification challenges faced by Angel et al. (2005) as a result of spectral inseparability. Apparent errors were detected by comparing the classification results/maps with true and false colour composites of the source images and resolved by way of on-screen editing, a process known as "*heads-up digitizing*" (Hong, 2007).

Thematic and spatial accuracy verification and improvements were made by reference to other land-use/land-cover datasets with higher precision (because of their higher spatial resolution or possession of a known higher classification accuracy themselves), such as the GTI (2009), as well as Google Earth maps. The prior knowledge of the study area also proved useful. The drawback of the post-classification approach used in this study, however, was that the accuracy of the resultant land-use/land-cover change maps depended on the accuracy of the individual classification, thus such techniques are subject to error propagation (Yuan et al., 2005; Dewan and Yamaguchi, 2009), and some errors may remain. Using the confusion matrix tool in ENVI™, the overall accuracy of the land-use/cover change detection was calculated to be 90% and the Kappa Index[27] was 0.89.

Atmospheric correction and image normalisation was implemented to correct for the differences in the conditions under which the images were recorded. However, physical conditions on the ground may still have been slightly different. For instance, an image recorded under relatively wetter conditions might have shown slightly more vegetation cover than one taken under drier conditions in a different year, despite both being images captured during same season or even the same month.

The urban (built-up) area increase could have been slightly underestimated for the three different time points because of the extent of urban forest prevalent in Gauteng – an ambiguity that could be resolved by the use of object-based, as opposed to pixel-based, analysis. For analysis at a zoomed-in level or local scale (e.g. at a township, CBD, suburb or farm level), small misclassifications of the urban land cover class may be evident. Further refinement, using data of a higher resolution, is required in order to improve the accuracy of the land-use/cover maps for use at a local zoomed-in scale.

[27] Kappa Index is a reliability coefficient representing the concordance between two datasets having identical number of categories (e.g. R, G, and B; or rows and columns); in this case a classified raster image and a ground truth image.

5. Discussion

Over the last century, Gauteng's urban form has been constantly transforming. The existence, evolution, rate and patterns of urban development have been influenced by various factors at different periods. In the 1890s, the discovery of gold acted as the catalyst for an influx of migrant workers, culminating in the establishment of the Johannesburg mining camp. With the establishment of further mines, the land-use pattern (both transportation and settlements) was essentially linear, conforming to the east-west mining belt of the Witwatersrand gold basin. The initial northward expansion between the 1900 and 1920 can be attributed to the continued influx of people and growth in affluence, and avoidance of growth to the south because of the presence of mines and mine tailings.

Post-war industrialisation (1930 to 1950) further fuelled this northward expansion trend. Consequently, a road network was built to connect the newer northern suburbs to central Johannesburg. In the 1950s, the scattered residential settlements began to consolidate as a result of suburban expansion, or the establishment of new settlements between the existing suburbs. Development of high density townships (primarily for *non-whites*[28]) on the periphery of towns commenced during this period, driven by apartheid-forced re-settlement policies. The apartheid policies required forced re-location of inner city non-whites to new black residential areas (so-called locations) on the perimeters of cities, or beyond, far from the zones of work and economic activity. Readily available, inexpensive land, a burgeoning motor vehicle industry, and the development of a suburban electric train infrastructure promoted suburban low-density urban development (especially for the legally-privileged '*white*' group), and resultant longer trip distances between home and workplace (Fair et al., 1956; Popovic, 1986; Roberts & Fair, 1973).

The 1960s were characterised by further aggressive enforcement of apartheid spatial planning. This necessitated the establishment of new road and rail infrastructure. These segregation-driven developments left a strong spatial footprint, a legacy that is still vivid in the Gauteng City-Region spatial configuration.

The onset of a decline of gold mining, after peak annual production was reached circa 1976, accelerated the shift from manufacturing towards tertiary service industry and service-based economy. This in turn stimulated the rapid growth of low-density residential suburbs and the decentralisation of commerce to the peri-urban areas, at comparatively long distances from the now decaying urban core of the Johannesburg central. It marked another expansion phase of the northern suburbs with the creation of new economic hubs in Randburg and Sandton (Frescura, 1982; 1983; 1992; 1993; 2000; 2001; Frescura & Radford, 1982; Visagie, 2008; Horn, 2009; Sexwale, 2009; GDED, 2010; Eighty20, 2011; Ojelede, 2011). In the southern suburbs of the Witwatersrand, the vegetation and reprocessing of mine dumps coincided with the proliferation of informal settlements along the former mining belt, as existing residents and economic migrants from rural areas opted to stay within proximity to employment.

Results presented show a highly dynamic transformation of land-use/land-cover from agricultural areas (cultivation), grassland or woodland to urbanisation. Overall, woodlands and bare areas have been reduced and the urban area has increased over the two decades. During the 1991-2001 decade, there were small portions of mining to urban conversion within proximity to Johannesburg CBD, which could attributed to the reclamation of mine tailing storage facilities for industrial development.

[28] The term "non-whites" applied under apartheid legislation to persons not of European decent, nor regarded as an unacceptable derogatory word.

The detailed study of land-use/cover change also shows varied rates and patterns of urban development per locality, across different municipalities and over time. This is in line with the fact that Gauteng is composed of various constituent municipalities, with separate (even different) socio-economic profiles, functions and spatial systems – diversities reflected in the different growth dynamics and urban structures of the municipalities. However; an integrated regional approach is integral to guiding the urban evolution of the constituent administrative blocks.

Urban development dynamics in the two decades since 1990 are shown to be different. The rate of growth between 1991 and 2001 is steeper than during the subsequent period (2001-2009), attributable to the differences in the driving factors. The earlier decade coincided with the repeal of the discriminatory legislation and South Africa's new political dispensation in 1994. This triggered a drastic increase of rural-to-urban migration by segments of the Black population that had been forcibly kept out of towns and cities.

The urban development experienced between 2001 and 2009 was as a result of the proliferation of informal settlements (promoted by multiple factors, such as the deepening of poverty and inequality, and indirectly fed by weakening control of cross-border illegal immigration), government RDP housing projects, office parks, industrial parks, residential estates (gated communities) and associated shopping complexes. This period was characterised by strong economic growth and population increase. Transport infrastructure (especially road) expansion in preparation for the 2010 World Cup also coincided with this decade. With regards to growth patterns, ribbon development along the M1/N1 freeways between Johannesburg and Pretoria was intense during the 2001-2009 period, as the residential areas of Midrand and Tembisa and the commercial/industrial development along the highway transformed from a predominantly peri-urban agricultural area to a major urban conglomerate.

6. Conclusions

Urban planning has played a significant part in designing the structure of Gauteng; however, several other factors have had an effect on urban growth patterns, such as mining, natural environment, demographics economics, the transport system, consumer preferences for proximity, and governance. In the specific context of Gauteng (and especially Johannesburg) factors such as the mining history, vegetation of mine dumps, apartheid spatial planning and, more recently, the reprocessing of tailing storage facilities (mine dumps) and the establishment of high density new townships, have all been strong spatial development trajectory determinant factors. Despite the influence of planners and authorities on spatial growth trajectories, both in the past and hopefully more so in the future, the above mentioned factors have also been significantly powerful in shaping the Gauteng urban structure.

The initial growth patterns of Gauteng's urban form were primarily linear, conforming to the east-west mining belt across the Witwatersrand. Global technological advancements (especially the private cars) altered the urban structure as development on the outskirts increased. This was exemplified by the development of the '*northern (urban) bulge*'. Social and economic race-based segregation – a feature of apartheid spatial planning – created a highly fragmented urban landscape. The establishment of large (low-cost mass housing) dormitory settlements (through the *Reconstruction and Development Programme* (RDP), despite good intentions) and growth of informal settlements long distances (where land is cheaper) from the economic centres perpetuated the apartheid urban form. The development of single-use office-parks separate from residential areas has propagated fragmentation. This suggests that the footprint of the apartheid spatial planning is proving difficult to retrofit. However; there is sufficient evidence to show that over the last two decades (despite widespread sprawl), there have been cases of *managed growth* (e.g. *corridor development, urban densification, decentralised concentration*).

In light of adverse social, economic and environmental costs of continued unrestrained lateral expansion, it is crucial to manage urban growth. One of the urban densification options could be to reclaim and redevelop *brown fields*[29] instead of converting new lands for urban growth. As land-use structures also have effects on transport-related energy consumption, mobility patterns, trip-distances and modes of transport, it is essential to pursue growth trajectories that promote spatial, mobility and energy efficiencies.

With regards to the methodology, this study demonstrates that remote sensing applications offer viable options in accurately monitoring the land-use (urban growth) changes underway, showing either continuities or discontinuities from the historical data. Further studies can be done to differentiate between urban cover types. If the current trends continue, negative implications of some land-use conversions are imminent. With land being a finite resource – with the region already at 18% of provincial land-use/land-cover – and the social, economic and environmental costs of suburban sprawl, it is crucial to inform decision makers to support smart planning for growth, new urbanism and compact development.

[29] Pre-existing (abandoned, idle or under-utilised) property or sites or urban spaces within the built-up urban area that can be re-claimed, restored and availed for industrial, business or residential development, through a process known as land recycling. Brownfield redevelopment is a form of infill (development within an already developed area) (GDED, 2010).

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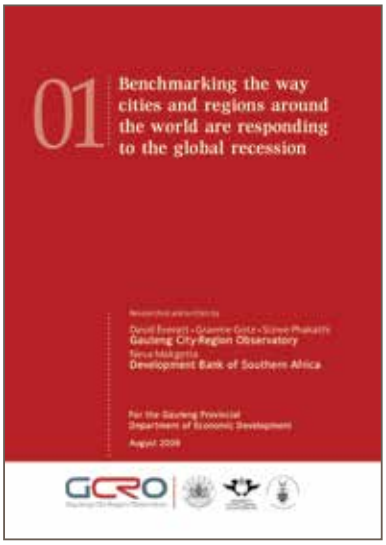
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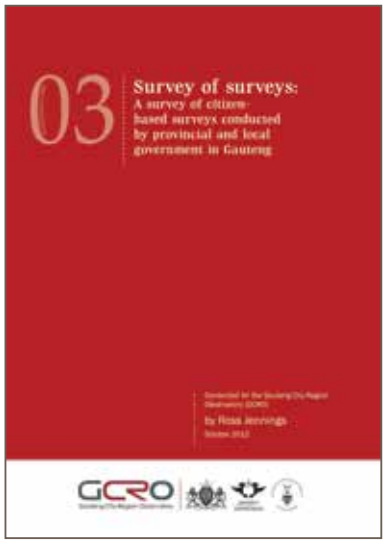




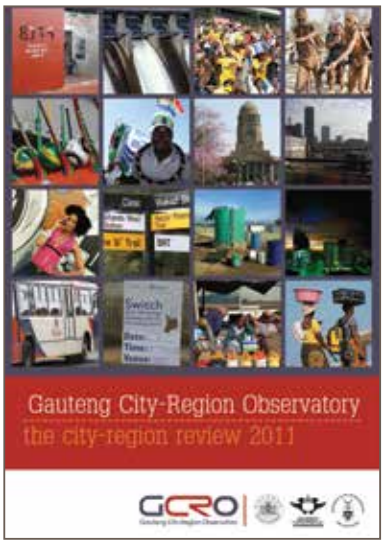
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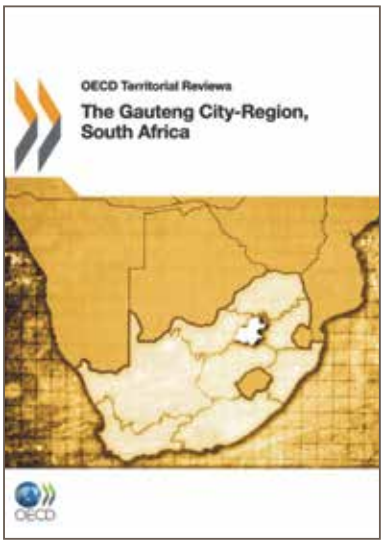




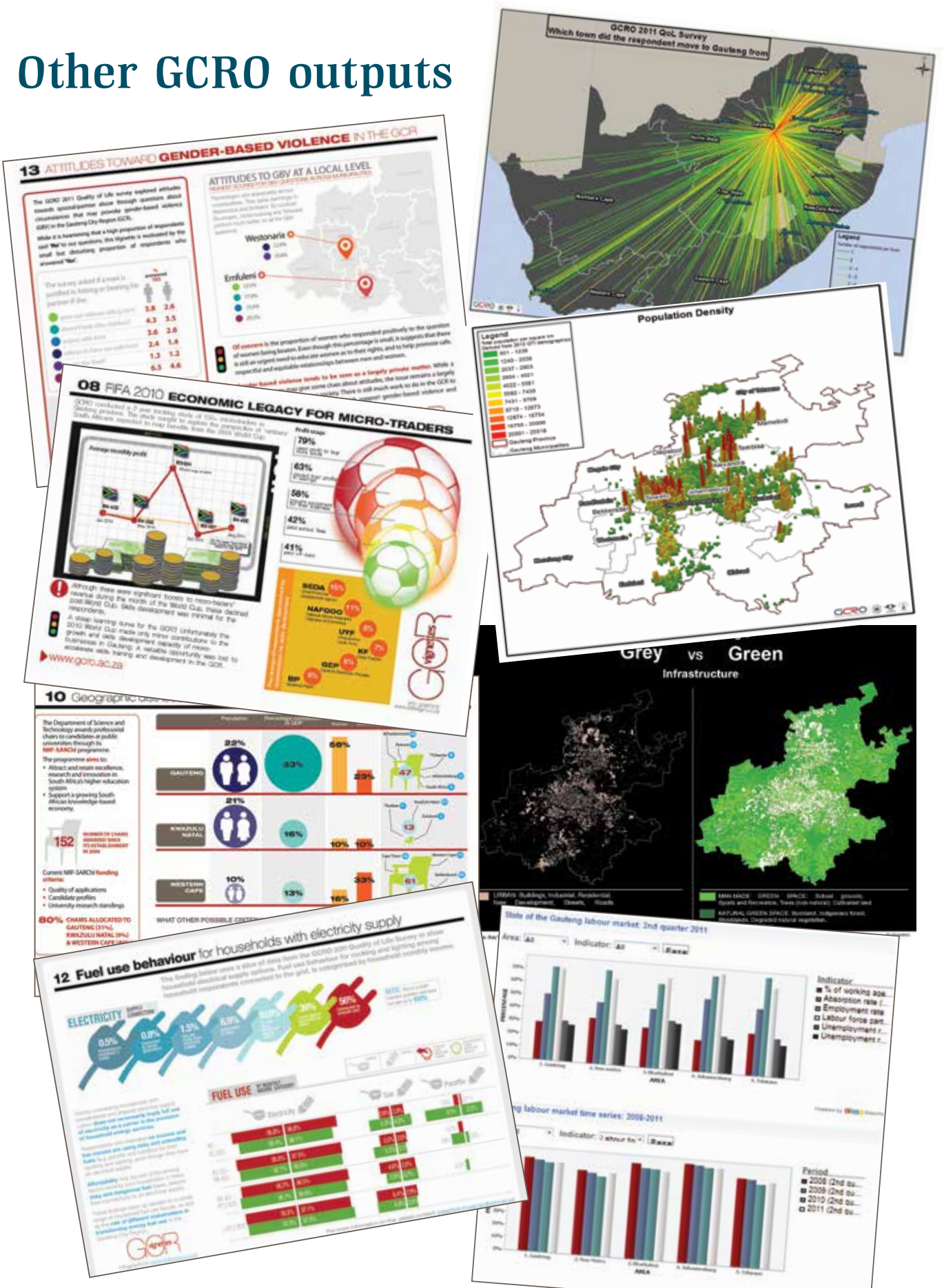


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