"LOOKING BACK, LOOKING FORWARD": URBAN DEVELOPMENT AND TRANSPORT INFRASTRUCTURE IN GAUTENG PROVINCE

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ABSTRACT

Studies have shown that land-use and transportation systems have a two-way dependency. On one hand, the existing land-use structures influence trip distances and transport mode choice, while on the other hand transport infrastructure and systems have the potential to alter existing urban spatial structures. This paper qualitatively and quantitatively assesses one direction of this reciprocal relationship: the influences of transport infrastructure on urban development and mobility. It evaluates how past land-use (urban) development patterns in the Gauteng Province of South Africa may have been influenced by road and rail transport networks, including train stations. Following a time series analysis of Landsat satellite derived land-use change at three decadal intervals (1991, 2001 and 2009), spatial analysis of corridor (ribbon/linear) development was assessed using a series of urban growth maps in conjunction with transport infrastructure. Effects of transport infrastructure on land use development were assessed by analysing urban growth densities within buffer zones of major roads and railway stations, at 0.5 km intervals. Results show that despite suburban sprawl, transport infrastructure has enhanced corridor development in some areas of Gauteng Province over the last two decades, especially between 2001 and 2009.

1. INTRODUCTION

The research presented in this paper provides an in-depth analysis of the trends and dynamics in the evolution of spatial urban development in Gauteng Province over a period of two decades (1991 to 2009) based on satellite retrievals images (Landsat TM and ETM+). This is done in order to qualitatively and quantitatively evaluate how land-use (urban) development patterns in Gauteng Province have changed relative to the transport network (roads, railway lines and train stations) over in the assessment period based on sequential satellite-derived land cover maps as well as the corridor development theory of urban growth (a component of the New Urbanism / Smart Growth / Compact City approach) [Crane, 2008; Duany, 2008]. The research also explores the usefulness of remote sensing application in improved transport planning.

2. BACKGROUND

Over the last two decades, Gauteng has experienced significant economic and population growth, which has catalyzed land-use/cover changes. Suburban sprawl of various forms – low density housing, non-mixed-use-oriented shopping malls and single function office parks, industrial parks, housing subdivisions (gated communities) – has been taking place within the urban boundary established by the Gauteng Department of Economic Development in 2007. A number of spatial planning instruments have been developed to counter this type of development.

Various national and provincial planning frameworks have been formulated to guide spatial planning in the country and Gauteng Province. The National Spatial Development Perspective (NSDP) provides a framework for all national and sub-national spatial planning, inclusive of strategic plans, programmes and actions [PCAS, 2006]. The NSDP seeks to prioritise and target areas with high economic growth and/or potential for investment, especially around development nodes [Meiklejohn *et al.,* 2008]. New economic centres should be located in proximity to *labour pools* (particularly low income settlements). Moreover, future settlement and economic development opportunities should be channelled into activity corridors and nodes adjoining or linked to main growth centres. The Gauteng Growth and Development Strategy (GGDS) [GDED, 2005] promotes the identification of areas of good development potential for government investment. The Gauteng Spatial Development Perspective (GSDP) proposes and promotes an urban form that optimises land use, mobility and service provision efficiencies. A shared priority between the GGDS and GSDP is to provide an integrated, reliable, accessible and environmentally sustainable public transport system.

Research contained in this paper provides an alternative example of how the effectiveness of planning frameworks such as the NSDP and the GGDS could be assessed.

3. STUDY AREA

The study is confined to Gauteng Province, one of the nine provinces in South Africa. Gauteng Province is an integrated cluster of cities, towns and urban nodes that together make up the economic heartland of South Africa [Wray, 2010].

Despite the core comprising three cities, Johannesburg Ekurhuleni and Tshwane, the spatial configuration of Gauteng Province takes the form of a *poly-central region* (with multiple nodes), housing such rapidly-growing centres as Germiston, Springs, Alberton, Boksburg, Benoni, Krugersdorp, Randfontein, Westonaria, Vereeniging and Vanderbijlpark.

Gauteng Province contributes 33% and 10% to the national and African GDPs respectively. Being the economic hub of the country, Gauteng is strongly connected to other provinces by trunk transport routes, both rail and road. Figure 1 depicts how Gauteng Province is dissected by major (national roads) connecting to other provinces, as well as the locations of railway stations.

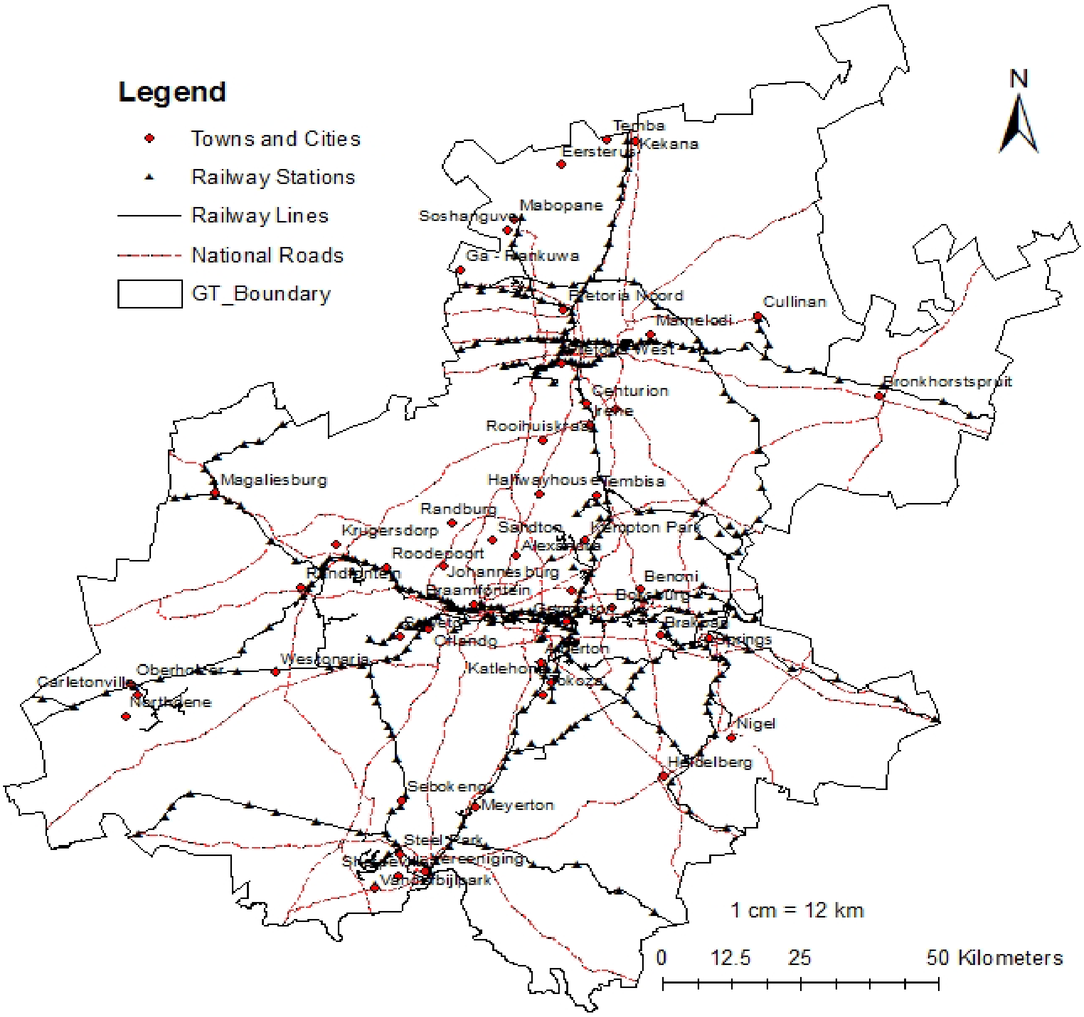

Figure 1: National roads, railways stations, towns and cities in Gauteng Province

4. RESEARCH QUESTIONS

Overall, the paper attempts to answer this research question: To what extent has transport network influenced spatial development patterns in Gauteng Province? The research question is necessary because much of the current planning postulates a strong association between transport infrastructure and development.

5. DATA PREPARATION

This section of the paper presents the approach adopted in this research, comprising data processing approach and evaluation methodology.

5.1 Data Processing

The land-use/cover maps for this study were derived from 1991 and 2009 Landsat5 TM (Thematic Mapper) and 2001 Landsat7 ETM+ (Enhanced Thematic Mapper Plus) satellite images. These were chosen because of their temporal acquisition continuity and multi-sensor comparability [Deng *et al*. 2009]. The

Landsat7 Enhanced Thematic Mapper Plus (ETM+) and Landsat5 Thematic Mapper (TM) were deemed the optimal sensors for this study, considering their temporal acquisition continuity and multi-sensor comparability[1] [Deng *et al*. 2009]. Depending on availability of cloud-free data, most of the scenes acquired are of the post-rainy season period (March – May), as an attempt to reduce the summer effect of water, cloud and vegetation.

On acquisition, all the satellite imagery scenes were already ortho-rectified by the South African National Space Agency (SANSA) prior to publication, thus there was no need for geometric correction. Prior to any digital processing, geometric registration was done to transform all ortho-rectified images into a common geometric coordinate system [Hong, 2007]. All images were transformed into the Universal Transverse Mercator (UTM) geo-reference, the World Geodetic System 1984 (WGS84) coordinate system, zones 35 of the Southern Hemisphere (using the standard projections and transformations tool in ArcGIS™). Thereafter, the 1991 and 2009 Landsat5 images were resampled (image-to-image registration) to the ortho-rectified 2001 Landsat7 ETM+ images in order to synchronise the pixels of all the images[2] based on the standard Automatic Raster Resampling technique. The spatial resolution of 30 m was maintained for all images. The supervised classification approach [Jensen, 1996; Hardin *et al*. 2007; Dewan & Yamaguchi, 2009] and the post-classification change detection technique were adopted for this study, (rather than the pre-classification procedures[3]). This was because post-classification techniques allowed for the generating of the '*from'*—'*to'* maps [Rees, 2001; Jensen, 2005], thereby enabling the clarification of the location, magnitude and nature of the changes shown [Howarth & 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 (e.g. existing maps).

From the initial eight (8) broader land-use/cover categories: water, mines, urban (built-up), cultivated lands (crop and pasture), wetlands, woodlands, grasslands and bare, the images were aggregated (reclassified) into 4 classes: water, urban (built-up), mines and non-urban. The images were finally aggregated into 2 classes: urban (built-up) and non-urban, The binary class maps were used in analysing the effects of transport infrastructure on urban growth patterns.

5.2 Assessment Procedure

GIS layers such as road network, railway lines network and railway stations were acquired for Gauteng and set in the same coordinate systems as the satellite derived land-use/cover maps. In the Growth Management Strategy [City of Johannesburg, 2008], the areas within a kilometre of passenger rail stations, *Rea Vaya* BRT, Gautrain station precincts as well as CBDs, collectively referred to as

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

[2] To ensure that each point/pixel in an image corresponded to the same point in other images in the multi-temporal sequence. If not correctly correlated, the difference in the geometry and location of any feature in two images being compared might lead to a misinterpretation of offset errors as a land-use/cover change.

[3] 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 and Justice, 1995] and principle component analysis [Hartter et al., 2008].

Public Transport Management Areas, were earmarked for transport-land use integration. For the purposes of this study, a finer grained grid of eight buffer zones, at 0.5 km intervals were created around national roads and railway stations, outwards to a distance of 4 km (Figure 2).

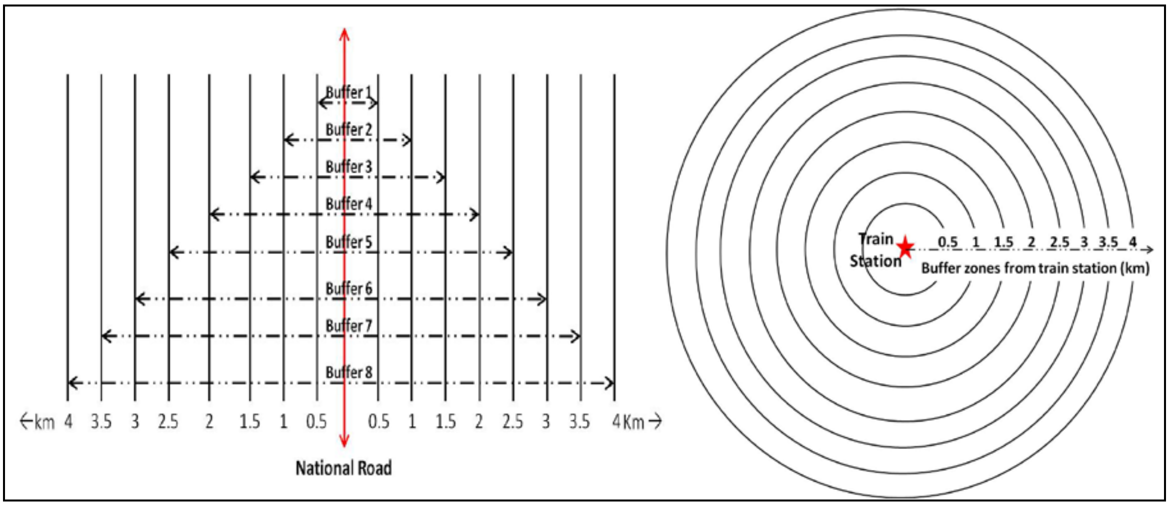

Figure 2: Buffer zones from (a) national roads and (b) train stations

Urban coverage densities corresponding to the buffer zones were deduced from the 1991, 2001 and 2009 land-use/cover maps as follows:

$$CovDENi = \frac{Ai}{Bi} \times 100$$

where CovDENi is the urban coverage density percentage; *Ai* is the built-up area; and *Bi* the total area of land in the *i*th zone.

The built-up coverage densities in the buffer zones (for the years 1991, 2001 and 2009) were compared to assess the rate, pattern and extent of linear development. While recognising the importance of mobility corridors (or 'function-based' corridors), this study focused on road and rail infrastructure.

6. FINDINGS

Over the past two decades, different transport scenarios had varying effects on urban growth patterns, resulting in varying forms of the *corridor (ribbon) development*. Examples include: *corridor development* along national freeways; *corridor development* at the convergence of road and rail; *corridor development* between road and rail and the growth of informal settlements along (or at the convergence of) rail infrastructure. Figure 3 depicts a case of *corridor development* at the convergence of road and rail, in detail.

Orange Farm, Lenasia South and Oakmere Sweetwaters emerge 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 3a) and Lenasia South and Oakmere Sweetwaters (red in Box 3 of Figure 3a) could be attributed to this road-rail transport connectivity. The combined influence of rail and road transport appear to be an attracting factor well into the 2001–2009 decade, hence urban growth (red in Boxes 4 and 5 of Figure 3b) 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 3a and Figure 3b). Although the Winnie Camp (Box 2), Lawley (left of Box 3) and the area south of Stretford (Box 4) (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.

Urban growth at the convergence of road and rail is exemplified in Figure 4. 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 4a) and Lenasia South and Oakmere Sweetwaters (red in Box 3 of Figure 4a) 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 Boxes 4 and 5 of Figure 4b) 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 4a and Figure 4b). Although the Winnie Camp (Box 2), Lawley (left of Box 3) and the area south of Stretford (Box 4) (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.

Although each transport corridor has a unique set of qualities, evidence suggests that urban development has tended to gravitate towards the established transport infrastructure. The difference is mainly in the type of development. For instance, 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 confirmed through field checks. Irrespective of these differences, the study shows that major corridors act as a stimulus for business and residential development.

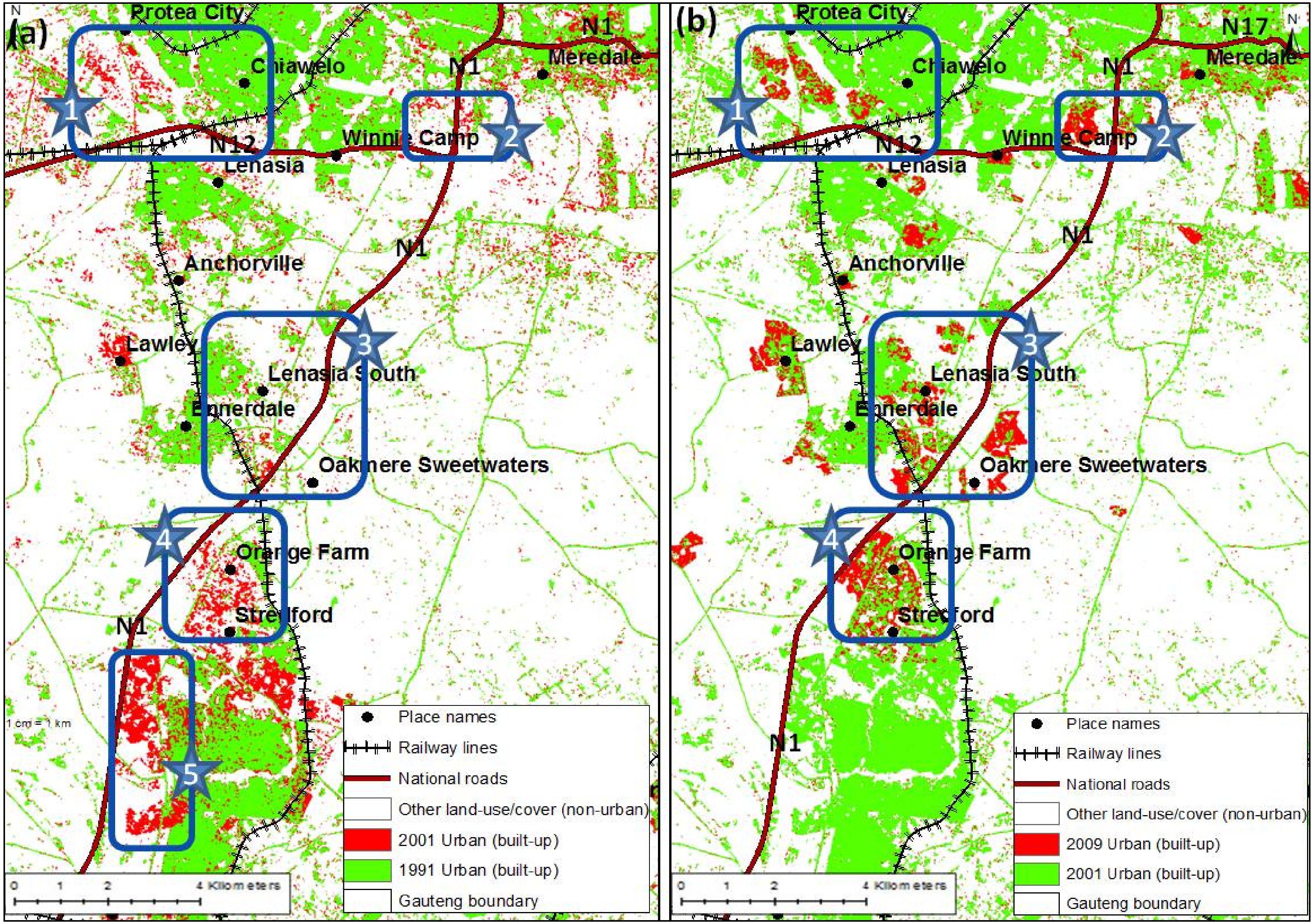

Figure 3: **Corridor development at convergence of road and rail in (a) 1991-2001and (b) 2001-2009.**

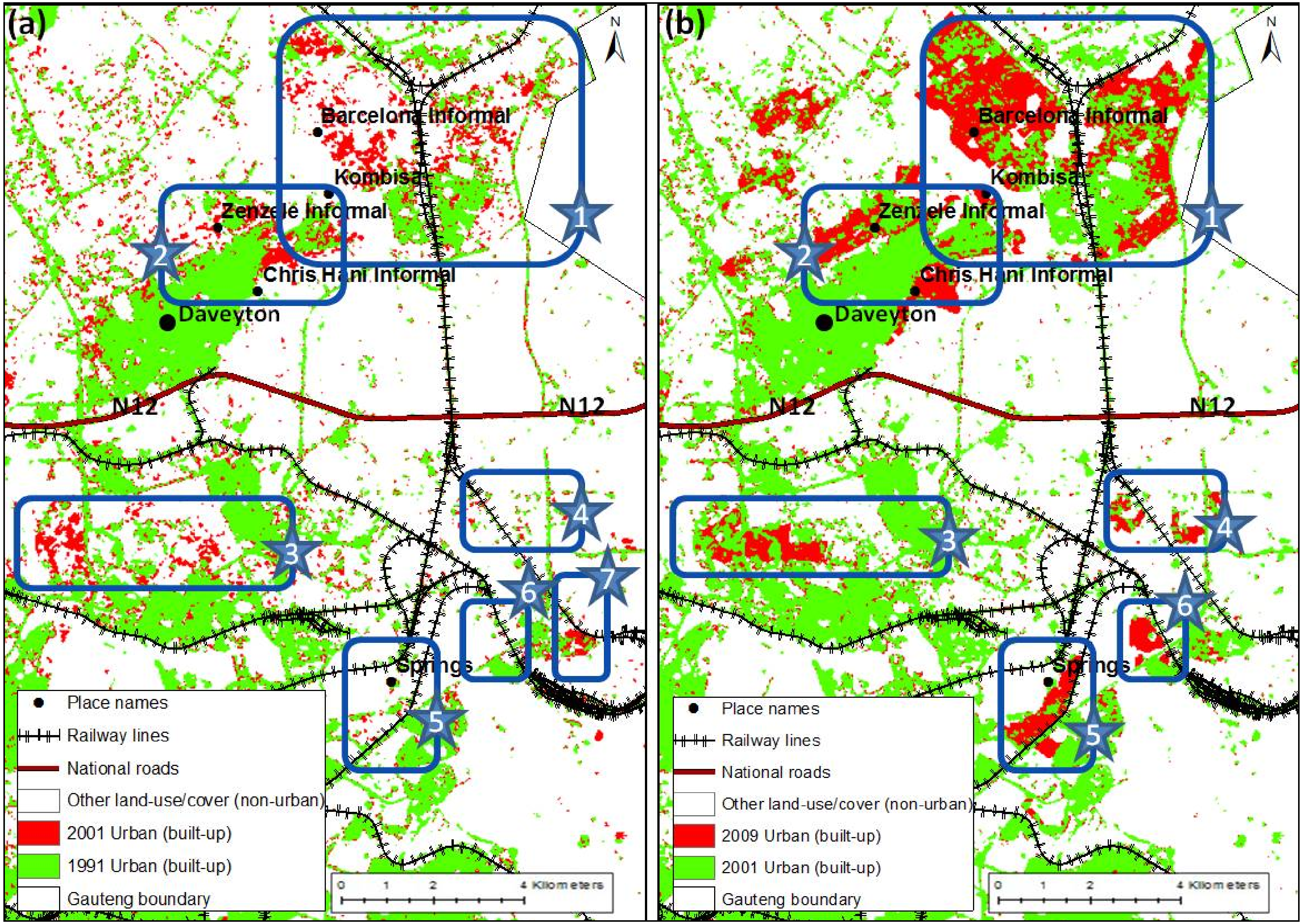

Figure 4: **Informal growth on fringes of Daveyton, along / at convergence of rail in (a) 1991-2001 and (b) 2001-2009.**

The densities of built-up areas within buffer zones (as a function of distance from Class 1 roads (i.e. national freeways and municipal routes) or from train stations) are presented in Figure 5. For both road-based and rail-based corridors (shown by triangular and diamond markers respectively), coverage density tends to decrease with the distance from the corridors in 1991, 2001 and 2009. Built-up coverage density increased sharply between 1991 and 2001; the change between 2001 and 2009 was smaller across all the buffer zones. A closer look shows that the density increase around railway stations between 2001 and 2009 was smaller than along roads during the same period.

The rail curves (curves annotated by diamond markers in Figure 5) depict an increased density across all distances up to 2 km. This shows that areas within the 2 km radius of rail transport infrastructure have been filling up. For rail, the gradient away from the train stations is much steeper than it is for road. The growth close to rail infrastructure in the second decade was much smaller than in the first decade, possibly indicating that the areas closer to rail transport were reaching saturation. From 2.5 km outwards, the influence of rail faded as densities were approximately the same as those for major highways at that distance. This indicates that the zone of influence of rail extends to ~2 km. For road transport infrastructure (curves annotated by triangular markers in Figure 5), the decrease in density beyond 1.5 km was very minor. This contrast between the rail and road density indicates that rail has a much stronger influence in naturally attracting densification than the freeways/highways. The decrease in built-up density outwards from railway stations is steep; the decrease with distance away from roads is more gradual. This indicates that the road-based corridors are much wider, with little variance in built-up coverage density going outwards, whereas the rail-based corridors were characterised by strong concentrations around railway stations.

The urban growth rates (as a percentage) within the Class 1 road buffers are presented in Figure 6a and rail buffers in Figure 6b for the two time intervals (1991-2001 and 2001-2009). The 1991–2001 curve (green in Figure 6a) is decreasing, indicating a decrease in urban growth intensity linked to the increasing distance from the road-based corridors. However, the 2001–2009 curve (green in Figure 6b) increased up to the 2 km buffer point. Although this indicates an increase in urban growth intensity further from the roads, it also indicates the outward expansion of the corridor to 2 km. The relative flatness of the graph could be an indication of urban sprawl — with rate of urban growth being constantly high (even far away from the roads). One can assume, therefore, that the road-based corridors are wider than the rail-based corridors. The divergence of the graphs at the beginning and convergence towards the end in Figure 6b indicates the decreasing intensity of development away from railway stations (between 1991 and 2001) and increasing intensity of development away from railway stations between 2001 and 2009. In the 1991–2001 decade, the percentage change (rate of urban growth) was higher closer to the train stations and decreased with distance from the train stations. Between 2001 and 2009, the percentage change was actually higher further away from the train stations.

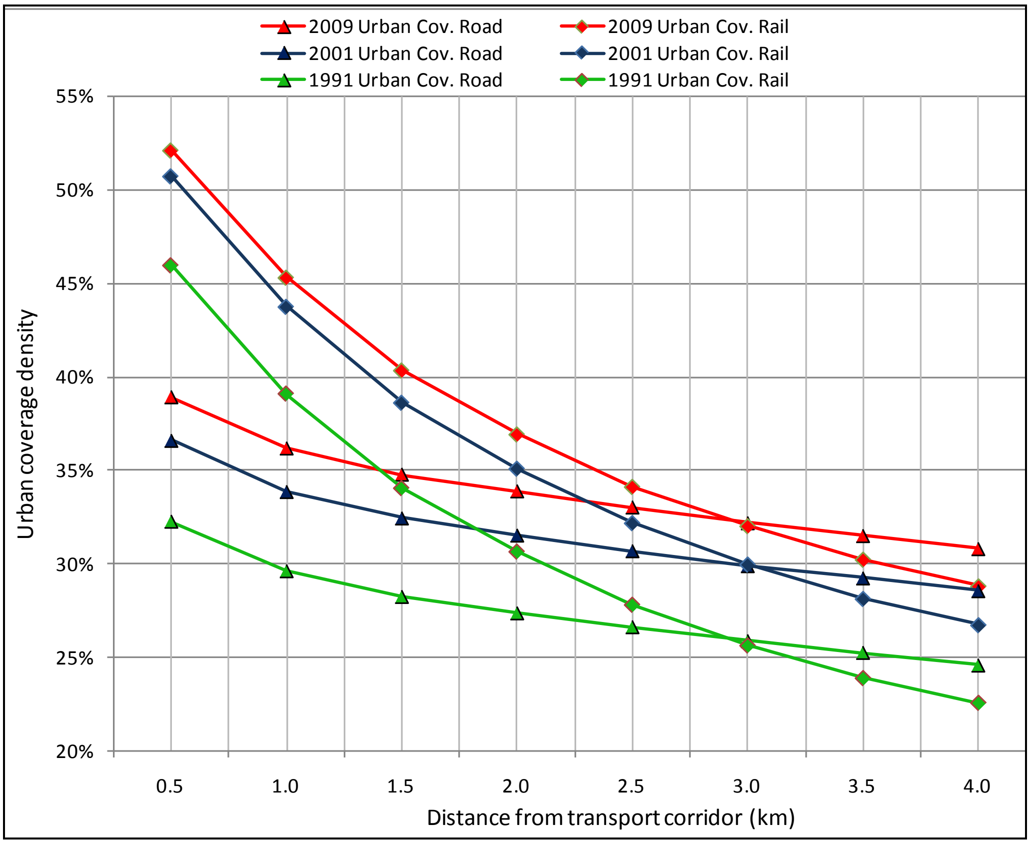

Figure 5: **Urban cover density within road and rail buffers, 1991, 2001, 2009**

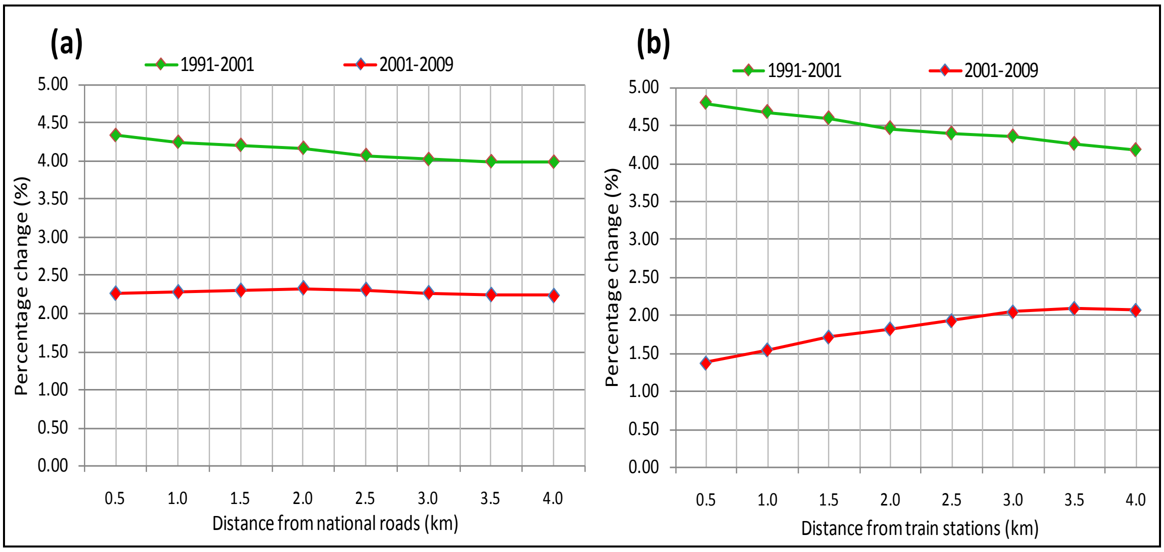

Figure 6: **Urban percentage change within (a) road and (b) rail buffers.**

7. CONCLUSIONS

The spatial analysis of urban growth in conjunction with transport infrastructure demonstrated that transport infrastructure has a strong influence on urban growth and enhances linear development (Table 1). It also showed the differential influences of the different infrastructures on urban growth patterns at particular time periods. Rail transport corridors had more influence in the first decade (1991–2001) than in the subsequent decade. From the historical spatial analysis, one can argue that rail is a stronger natural development attraction than road-infrastructure. If railway infrastructure is established, it is possible to 'densify' without forcing people to relocate, as exemplified by the natural gravitation of informal settlements towards rail transport infrastructure and expansion at rail intersections. Given the natural forces of transport attraction and gravitation, rail has had a much stronger influence on urban growth, particularly within a close radius of rail infrastructure.

Table 1: Ordinal results: Increase of urban area by spatial category and location, 1991-2009

Spatial category		**Location with regard to corridors**	
		major roads	**railway stations**
within corridors	0.5 – 2.0 km corridor	very high	high
	2.5 – 4.0 km corridor	high	high
outside 4 km corridor		very low	
total Gauteng		Medium	

< 5 % = very low increase; > 5.0 % < 5.5 % = low increase;
> 5.5 % < 6.0 % = medium increase;
> 6 % < 6.5 % = high increase; > 6.5 % = very high increase

Results indicate that the zone of influence of trains extends to 2 km, instead of the 1 km argued by the Growth Management Strategy [City of Johannesburg, 2008]. Beyond a 2 km radius, the urban density and influence of rail is difficult to distinguish from that along major highways. However, Gauteng's development pattern was influenced more by road than by rail corridors in the period 2001–2009. During this time, densification was higher along major roads than it was around train stations (at equal distances from the roads or stations respectively). It can be argued that such road-based corridor development resulted from deliberate direction through development planning and stands allocation, rather than natural gravitation.

Guided transit oriented corridor (ribbon) development is a key element in shaping the growth of the Gauteng City-Region towards a more compact megacity/urban form with better mobility.

8. RECOMMENDATIONS

By 2040, Gauteng is estimated to be home to over 19 million inhabitants [Wehnert *et al.,* 2010]. As such, it is imperative that all new development, preferably high density cluster developments (e.g. townhouses, office parks, industrial parks), ideally of mixed-use, be located within comfortable walking distance to train stations to make rail transit a viable transport option for commuters. This could be more effective than trying to preserve the urban boundary. A full range of amenities can then be provided within 1 km zones. Whilst the 1 km zone to transport corridors is ideal for TOD, the 2-4 km could be the region in which people could use bicycles or park and ride. Inversely, development should be constrained in areas that are outside the buffer regions, especially outside the 4 km buffer. Such an urban form would have potential for achieving lower social, economic and environmental costs relative to suburban sprawl. To realise this, a combination of policy instruments can be used: regulation instruments (e.g. land-use plans), fiscal instruments (e.g. taxes, incentives and/or disincentives) and communicative instruments (e.g. awareness campaigns). TOD, targeting nodes along trunk transport infrastructure (particularly rail transport) for redevelopment and infill, has the potential to increase high capacity public transport viability, optimise land-use and thereby increase the use of non-motorised transport.

Apart from transport corridors, other factors not assessed with this paper (e.g. population growth, economic dynamics, lifestyle and preferences) do have influence on urban growth patterns. Further studies could be done to systematically examine the magnitude of influence of such variables using “regression analysis”, in the context of Gauteng. Research could also be done to model and project Gauteng’s future urban growth based on the current trends.

9. REFERENCES

Crane, R. (2008) Counterpoint: Accessibility and sprawl, *Journal of Transport and Land Use 1(1)*, 13-19.

Dewan, A.M., Yamaguchi, Y. (2009) Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanisation, *Applied Geography 29(3)*, 390-401.

Duany, A. (2008) (Video recording) On the Edge: Latest views from Andrés Duany, Vancouver, BC [on-line] http://www.youtube.com/watch?v=jftwNC3k65o, accessed 10 October 2010.

GDED (2005) *A Growth and Development Strategy (GDS) for the Gauteng Province*. Johannesburg: Gauteng Department of Economic Development.

Hardin, P.J., Jackson, M.W., Otterstrom, S.M. (2007) Mapping, measuring and modeling urban growth, in R.R. Jensen, J.D. Gatrell, D. McLean (Eds), *Geo-spatial Technologies in the Urban Environments: Policy, Practice and Pixels (2nd edition)*. Heidelberg: Springer, pp. 141-176.

Hartter, J., Lucas, C., Gaughan, Andrea, E., Aranda, L.L. (2008) Detecting tropical dry forest succession in a shifting cultivation mosaic of the Yucatän Peninsula, Mexico, *Applied Geography 28(2)*, 134-149.

Hong, G., Zhang, Y. (2008) A comparative study on radiometric normalisation using high resolution satellite images, *International Journal of Remote Sensing 29(2)*, 425-438.

Howarth, P.J., Wickware, G.M. (1981) Procedures for change detection using Landsat digital data, *International Journal of Remote Sensing 2(3)*, 277-291.

Jensen, J.R. (2005), *Introductory Digital Image Processing: A Remote Sensing Perspective (3rd edition).* Upper Saddle River, NJ: Prentice Hall.

Johnson, R.D., Kasischke, E.S. (1998) Change vector analysis: a technique for the multi-temporal monitoring of land cover and condition, *International Journal of Remote Sensing 19(3)*, 411-426.

Meiklejohn, C., Goss, H., Whisken, J. (2008) Achieving focused infrastructure investment in South Africa: Technical advances in provincial spatial planning. [on-line] http://hdl.handle.net/10204/2534, accessed 12 April 2009.

PCAS (2006) *National Spatial Development Perspective (NSDP)*. Pretoria: Policy Coordination and Advisory Service, The Presidency, Republic of South Africa.

Rees, W. G. (2001), *Physical Principles of Remote Sensing (2nd edition).*Cambridge: Cambridge University Press.

Wray, C. (2010) Working towards a successful Gauteng City-Region, *PositionIT Jan/Feb 2010*, pp. 38-42.