Geospatial Analysis of Informal Settlement Development in Cape Town

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Abstract

Informal settlements are a major influence in the urban growth of developing countries such as South Africa. There are also associated with negative socio-economic factors such as unemployment and are lacking in terms of secure land tenure arrangements. This research focuses on developing a geospatial understanding of the internal dynamics of informal settlement development within the City of Cape Town. To investigate how informal settlements are established and developed in a local context, the informal settlements of Imizamo Yethu, Langa, and Siqalo were monitored for the period 2011-2019 using image classification to determine the development, complexity, and compactness of the dwellings. The overall accuracy of the classified maps thus developed ranged between 88 and 96%. Change detection analysis was subsequently used to identify the geospatial trends for each informal settlement across all three. The combination of linear regression and ordinary least squares analysis determined that the major spatial trend driving growth was densification, which was correlated with the availability of open space, unemployment, poverty, and GDP. Furthermore, densification was identified along the major formal external transport routes and informal internal transport networks. It was found that individual settlements present unique internal geospatial development dynamics in the macroeconomic context of Cape Town, but that these tend to differ in the microeconomic context of the city. Among the explanatory variables for this situation were sloped lands, employment opportunities, and neighbouring areas where the incomes of the residents were higher. Across all the informal settlements, open space proved to be the most significant factor, while GDP played the most influential role in explaining shack compactness over time. This study could be used to contribute to policy and decision-making in the formalisation process in these informal settlements.

1. Introduction

In South Africa, socio-economic issues such as poverty and the lack of affordable housing present a host of challenges. One of these challenges is the proliferation of informal settlements (Wekesa et al, 2010). It has been well-documented that informal settlements are inadequate in

their capacity to provide basic services to the people residing in them (Onyekachi, 2014). In a local context, in the Western Cape one in every six people is living in an informal settlement (WCISSF, 2016). To minimize the negative effects of informal settlements, it is vital to understand how and why informal settlements are established and why and how they develop (Hofmann et al, 2017; Kohli et al, 2016). The unique contribution of this study is to identify the internal geospatial dynamics of informal settlements, given the same macro and micro socio-economic context, along with the respective neighbourhood variables that differ in terms of their attributes.

1.1. Informal Settlements

According to the United Nations (UN-Habitat, 2020), an informal settlement can be defined in terms of four parameters; (1) its inhabitants have no legal security in terms of the land or the dwellings they inhabit, (2) the respective neighbourhoods associated with these settlements lack access to basic infrastructure and services, (3) the housing within the settlements may not conform to the current planning and building regulations, and (4) the housing is situated in geographically and environmentally hazardous areas. The spatial patterns surrounding the establishment and development of informal settlements are according to a complex process that is influenced by physical, cultural, and economic factors. These geometric stages are divided into establishment, development, and formalisation (Augustijn-Beckers et al, 2011; Dovey, 2015; Sobreira et al, 2001).

1.1.1. Establishment

The establishment of informal settlements is accredited to the rapid rate of urban migration and the inability of the urban poor to afford the existing urban housing (Wekesa et al, 2010). To overcome the challenges faced socially, culturally, and economically, informal settlers look for any available land that may favour them in their search for employment opportunities. For this re) their formal settlements are established according to the following physical factors: (1) they are situated along major transport networks, such as highways, major roads, railways, rivers, and canals; (2) they are situated close to places offering employment, such as the city's CBD, industrial areas, or neighbourhoods of middle-to-high socio-economic status; and finally, (3) their proximity to transport networks and employment opportunities ─ which is viewed as the most important variable behind their establishment (Dovey, 2015; Dubovyk et al, 2010; Kohli et al, 2016; Kuffer et al, 2011; Naorem et al, 2016).

1.1.2. Development

The following factors are essential in understanding how shacks are built over time in informal settlements: There is a densification of shacks from the initially established shacks that takes place in the development stage. This process is described as infilling or the creation of new shacks in the immediate vicinity of the shacks already in existence (Augustijn-Beckers

et al, 2011). There is also a densification of shacks along informal transport networks – dirt roads and footpaths ─ (Augustijn-Beckers et al, 2011; Yonder, 2006) within the informal settlements, and along formal transport networks beyond the borders of the informal settlement (Kohli et al, 2016; Poelmans et al, 2009). Enlargement of shacks is also observed within informal settlements over time (Augustijn-Beckers et al, 2011). This serves as a contributing factor to explain how shacks take up space within informal settlements. Once all the suitable land within an informal settlement has been taken up and a population threshold has been reached, the built-up areas are extended to less favourable land in the immediate vicinity (Augustijn-Beckers et al, 2011; Shuvo et al, 2013).

1.1.3. Formalisation

The investigations that have focused on the effects of formalisation have been stated from a socio-economic context (Dovey, 2011; Huchzermeyer, 2003; Massey, 2013) rather than from an analytical perspective. During the formalisation process, the building of formal housing requires the temporary relocation of the associated informal dwellers (Dovey, 2011; Huchzermeyer, 2003). Governmental projects would fund this relocation, and this would subsequently allow for the construction of formal houses (Huchzermeyer, 2003) in-situ.

1.2. Study Area

Imizamo Yethu (east) informal settlement is situated in Hout Bay, on the western side of Table Mountain in the City of Cape Town (Figure 1). It is approximately 22 km from the traditional Central Business District (CBD) in the City Bowl. This informal settlement was established in 1991. Langa informal settlement is the closest informal settlement to the CBD at approximately 12 km from it (Figure 1). The advantage in terms of its location is that it is close to potential job opportunities. Langa informal settlement was established in 1990. It is located parallel to a national road (N2) and near the Epping industrial area. According to the available aerial imagery, there is evidence of *in-situ* formalisation or upgrading that has taken place within portions of south-east Langa. Siqalo informal settlement is approximately 20 km from the CBD (Figure 1). However, the informal settlement has the added challenge of being located along routes that support heavy traffic volumes. The settlement is located along a major road, namely, Jakes Gerwal Drive, which is on its eastern side, and agricultural land on its other side.

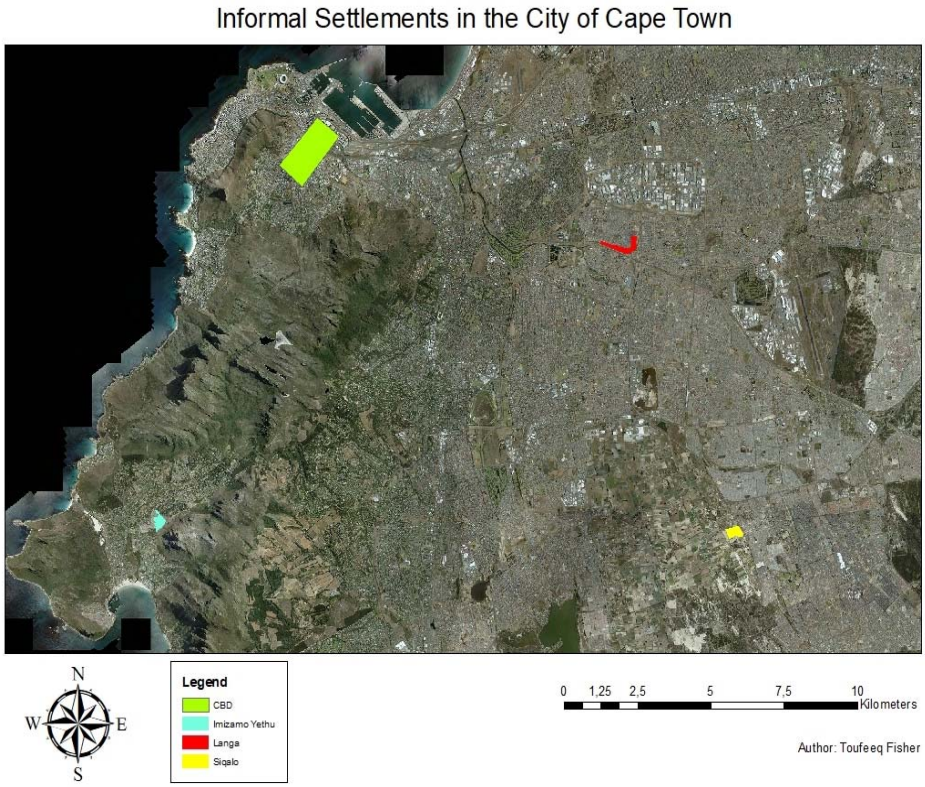

Figure 1. Locality of informal settlements in relation to Cape Town Central Business District

2. Materials and Method

This section covers the methodology flow (Figure 2) and the technique used to classify shacks in Imizamo Yethu, Langa, and Siqalo. It then goes on to assess the accuracy of the classifications, to detect change in the study area, to analyse the spatial statistics pertaining to the settlements, and to conduct an OLS analysis of the development of informal settlement growth.

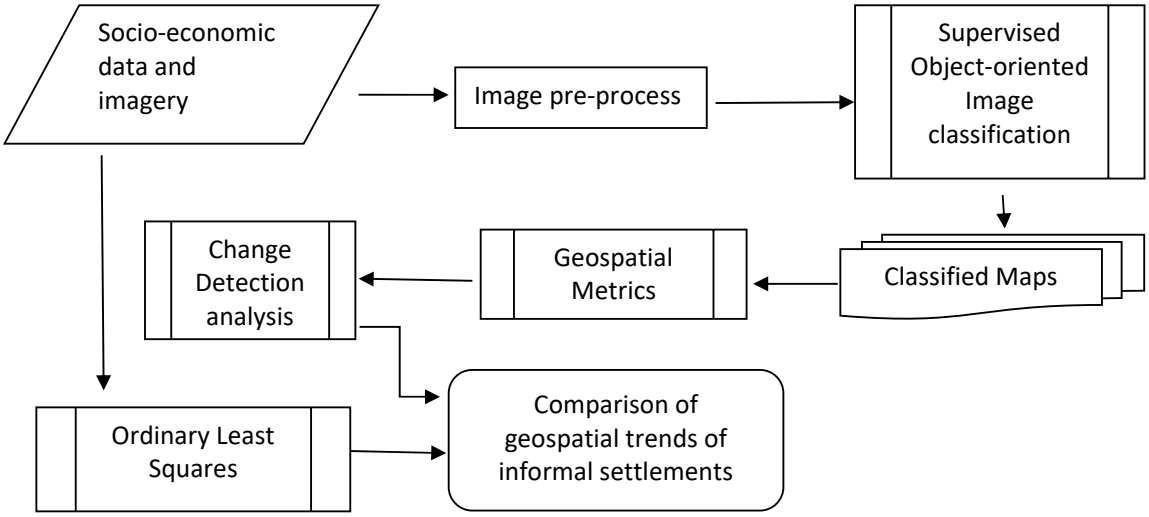

Figure 2. The methodology flow

2.1. Aerial Imagery Study Area

Aerial imagery was available for the years 2011, 2014, 2017, and 2019. The spatial resolution was 0.08m and the imagery was geo-referenced. The spectral resolution selected for the study covered the Red, Green, and Blue (RGB) spectrum and was deemed suitable for the study.

2.2. Classification Process

2.2.1. Supervised Object-based Classification

The classification was conducted using eCognition 9.0 software. The steps in conducting an object-oriented image classification (OOIC) in eCognition involved the processing of a multi-resolution (MR) segmentation, feature detection for the class to be classified, as well as classification processing to determine the details around the shacks in the scene.

2.2.2. Accuracy Assessment

To express the quality and validity of the classified images, an accuracy assessment was completed using a confusion matrix or a contingency table. Then, a kappa coefficient, representing the overall reliability of each classified image, was determined.

2.3. Spatial Metrics and Linear Regression

The spatial metrics contextualised the spatial context of shacks in each informal settlement for the years 2011, 2014, 2017, and 2019. This process was conducted in Fragstats 4.2, which permitted an assessment of the classified imagery. Linear regression analysis investigated the respective correlations of the metrics and the development, complexity, and compactness of the shacks over time. Metrics were used to explain the spatial developments for each informal settlement.

2.3.1. Development

To assess informal settlement development, the following metrics were compared: Number of patches (NP) for shacks *vs* class area (CA) of shacks – the number of shacks classified in each epoch as opposed to the total area covered by shacks in each epoch. Mean Patch Area (MN AREA) of shacks *vs* CA – the mean area of shacks in each epoch as opposed to the total area covered by shacks in each epoch. Mean Euclidean nearest-neighbour distance (MN ENN vs CA – is the average distance between shacks in each epoch as opposed to the total area covered by shacks in each epoch. Mean Shape Index (MN SHAPE) of shacks vs CA – the average shape complexity of shacks in each epoch as opposed to the total area covered by shacks in each epoch.

2.3.2. Complexity of shacks

To assess the characteristics of the shacks, the following metrics were described. MN ENNs MN SHAPE – the average distance between shacks in each epoch as opposed to the mean shape of the shacks in each epoch. NP vs MN SHAPE – the number of shacks classified in each epoch as opposed to the mean shape of the shacks in each epoch. MN AREA vs MN SHAPE – the mean area of shacks in each epoch as opposed to the mean shape of the shacks in each epoch.

2.3.3. Compactness of shacks

To assess informal settlement clustering, the following metrics were compared. MN AREA vs MN ENN – the mean area of shacks in each epoch as opposed to the average distance between the shacks in each epoch. NPs MN ENN – the number of shacks classified in each epoch as opposed to the average distance between the shacks in each epoch.

2.4. Change Detection

Since spatial metrics describe the statistical context of shacks in each epoch, the change in these metrics was measured across consecutive epochs. While change detection would visually illustrate the development of shacks in each settlement, an analysis of the geospatial trends distinctive of the informal settlement, as well as those pertaining to the neighbourhood variables, would provide for a better representation of an informal settlement.

2.5. Ordinary Least Squares (OLS) Analysis

The available data representing the socio-economic factors include (1) the extent of open space available (that is, the percentage of open space, or the area within each informal settlement that does not accommodate shacks); (2) the rate of unemployment in the City of Cape Town for each classified year (percentage unemployment); and (3) the poverty coefficient and gross domestic product (GDP) respectively for the City of Cape Town. The p-values determined through the OLS analysis revealed the level of significance of the respective relationships with each of the selected socio-economic variables used to explain the

development of the respective informal settlements. The lower the p-values determined through the OLS analysis, the more statistically significant a socio-economic statistic will be in explaining the established development statistic in each informal settlement.

2.6. Comparison of Spatial Trends between each investigated Informal Settlement

The geospatial development of each informal settlement was determined through change detection analysis. The statistical significance of the relationships between the spatial development of each informal settlement and the respective socio-economic variables/factors as also determined using the OLS analysis. Comparisons were then made between the respective informal settlements. This provided an overview of the significant factors related to development across all informal settlements.

3. Results

The results of this research include accurate classifications for each informal settlement that were quantified by a kappa co-efficient, the spatial metrics determined to describe shacks in each informal settlement at the given epochs, and the socio-economic data used in the OLS analysis relative to the developmental statistics.

3.1. Accuracy Assessment Results for Image Classifications

The overall accuracies and kappa coefficients for all the classified images are presented in Table 1. All the kappa coefficients were found to fall within the 0.81 – 1.00 range. Further analysis issuing from these results was based on the classified images.

Table 1. Overall accuracy and kappa co-efficient determined for the classified imagery

Classified Informal Settlement (Year)	Overall Accuracy	Kappa value
Imizamo Yethu (2011), (2014), (2017), (2019)	87%, 96%, 87%, 92%	0,88, 0,96, 0,88, 0,92
Langa (2011), (2014), (2017), (2019)	96%, 91%, 89%, 90%	0,91, 0,89, 0,95, 0,90
Siqalo (2014), (2017), (2019)	96%, 91%, 94%	0,94, 0,91, 0,96

3.2. Change Detection Results

Maps were created to illustrate the change in location in the shacks in each informal settlement and used for the purpose of making comparisons to determine change. Comparisons were made between the consecutive epochs, displaying the locations of shacks in the first year of the research as opposed to the locations of the same shacks in the subsequent year, thus showing the change between the two years. The comparative analyses over time for each informal settlement can be viewed in Table 2 and Figures 3, 4, and 5.

Table 2. Spatial metrics used to define the spatial trends in the informal settlements

	Informal Settlement												
	Imizamo Yethu					Langa					Siqalo		
	2011	2014	2017	2019		2011	2014	2017	2019		2014	2017	2019
CA (m^2)	54751	60967	66759	68288		67471	51239	51535	54311		44389	53972	56615
PLAND (%)	38,95	43,38	47,50	48,59		30,16	22,90	23,03	24,28		27,17	33,03	34,65
MN AREA (m^2)	36	40	55	48		31	28	35	36		22	27	28
MN PARA	11582,5	11913,9	10491,4	10904,5		11799,5	11878,8	11755,6	12053,7		12727,5	12434,8	13226,8
MN SHAPE	1,4649	1,511	1,6001	1,5354		1,3669	1,3615	1,4346	1,4568		1,3368	1,3674	1,3668
MN FRAC	1,222	1,2306	1,2379	1,2309		1,1907	1,1862	1,2011	1,2121		1,1964	1,2039	1,1995
MN ENN (m)	0,65	0,54	0,50	0,56		0,59	0,65	0,55	0,39		0,95	0,96	0,87
NP	1518	1513	1221	1432		2207	1799	1467	1526		1988	2035	2022
PD (NP/1km^2)	10800	10765	8687	10189		9864	8041	6557	6821		12167	12454	12375

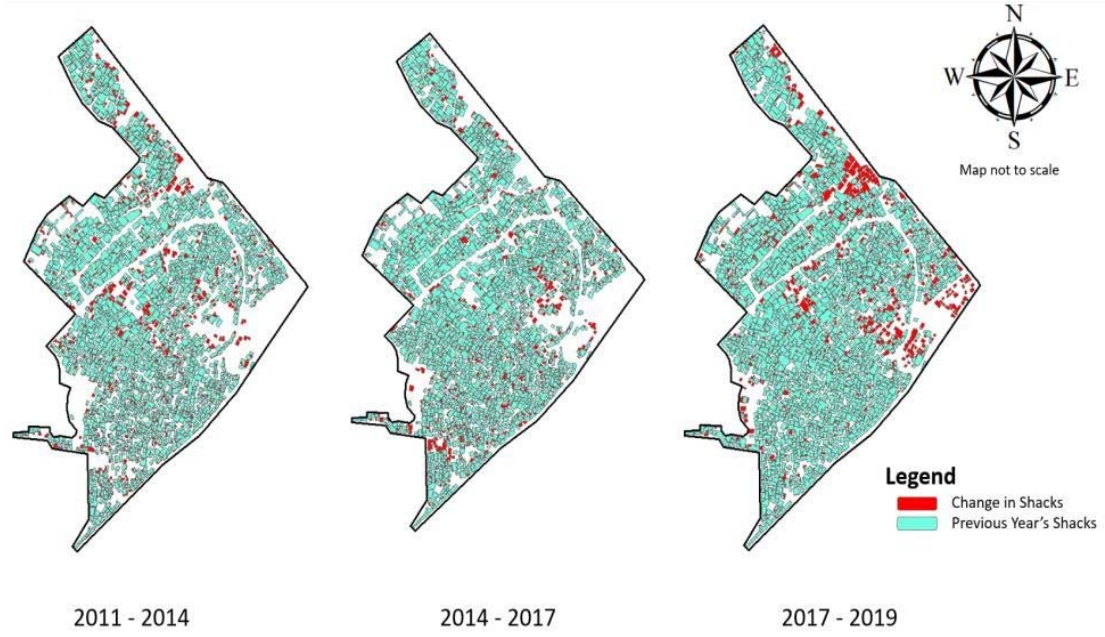

Figure 3. Change in location of shacks in Imizamo Yethu (2011-2019)

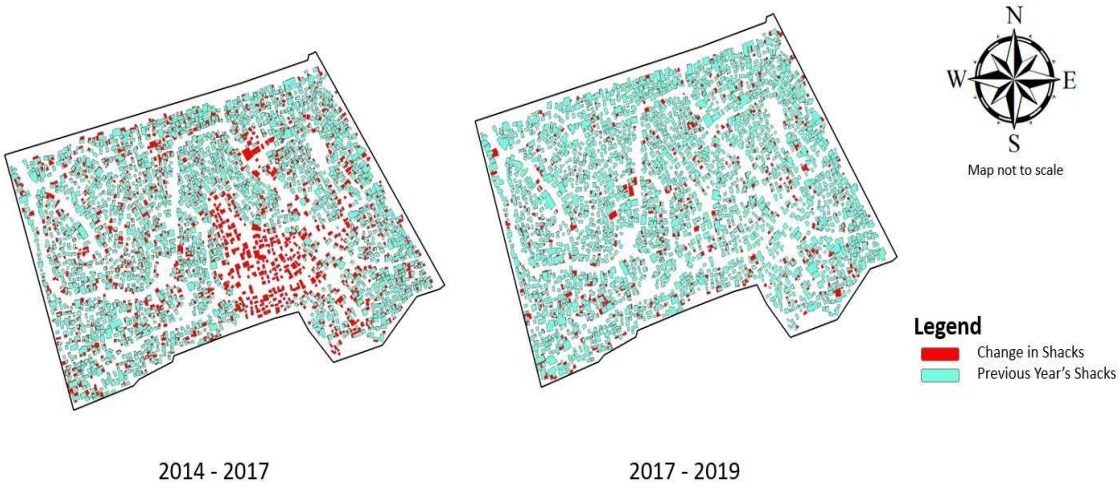

Figure 4. Change in location of shacks in Siqalo (2014-2019)

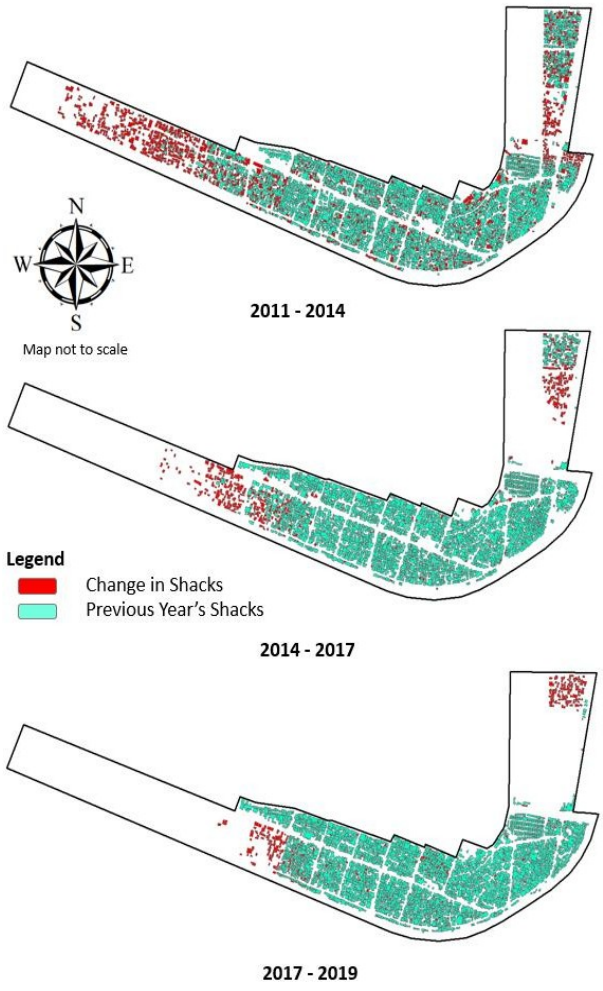

Figure 5. Change in location of shacks in Langa (2011-2019)

3.3. OLS Analysis

The following statistics were determined from the OLS analysis of each informal settlement with respect to its observed independent variable (CA, MN_SHAPE, and MN_ENN) and dependent variables (multi-variates of percentage open space, rate of unemployment, poverty coefficient and GDP).

3.3.1. Imizamo Yethu

Table 3. OLS comparison of Imizamo Yethu's development against socio-economic variables

CA	Standard error	t-stat	p-value
Open_Space	202,765	-6,508	0,003
Unemployment	167,476	0,165	0,877
Poverty	15406,457	0,475	0,660
GDP	2,010	-0,579	0,594

According to the OLS analysis of Imizamo Yethu's development against each of the socio-economic statistics, the most statistically significant variable was found to be that of open space.

Table 4. OLS comparison of Imizamo Yethu's shack complexity against socio-economic variables

MN_Shape	Standard error	t-stat	p-value
Open_Space	0,015	-1,631	0,178
Unemployment	0,013	0,125	0,906
Poverty	1,165	-0,896	0,421
GDP	0,000	0,776	0,481

According to the OLS analysis of Imizamo Yethu's shack complexity against each of the socio-economic variables, the most statistically significant variable was found to be that of open space.

Table 5. OLS comparison of Imizamo Yethu's shack compactness against socio-economic variables

MN_ENN	Standard error	t-stat	p-value
Open_Space	0,009	2,380	0,076
Unemployment	0,008	0,508	0,638
Poverty	0,704	1,093	0,336
GDP	0,000	-4,385	0,012

According to the OLS analysis of Imizamo Yethu's shack compactness against each of the socio-economic variables, the most statistically significant variable was found to be that of GDP.

3.3.2. Langa

Table 6. OLS comparison of Langa's development against socio-economic variables

CA	Standard error	t-stat	p-value
Open_Space	17,916	-123,863	0,000
Unemployment	16,579	3,171	0,034
Poverty	957,719	0,140	0,896
GDP	0,516	-1,309	0,261

According to the OLS analysis of Langa's development against each of the socio-economic variables, the most statistically significant variable was found to be that of open space.

Table 7.OLS comparison of Langa's shack complexity against socio-economic variables

MN_Shape	Standard error	t-stat	p-value
Open_Space	0,007	0,348	0,746
Unemployment	0,007	0,178	0,867
Poverty	0,384	1,350	0,248
GDP	0,000	-1,391	0,237

According to the OLS analysis of Langa's shack complexity against each of the socio-economic variables, the most statistically significant variable was found to be that of poverty.

Table 8. OLS comparison of Langa's shack compactness against socio-economic variables

MN_ENN	Standard error	t-stat	p-value
Open_Space	0,015	0,137	0,898
Unemployment	0,014	-0,581	0,593
Poverty	0,812	-1,452	0,220
GDP	0,000	1,851	0,138

According to the OLS analysis of Langa's shack compactness against each of the socio-economic variables, the most statistically significant variable was found to be that of GDP.

3.3.1 Siqalo

Table 9. OLS comparison of Siqalo's development against socio-economic variables

CA	Standard error	t-stat	p-value
Open_Space	1,564	-1048,986	0,001
Unemployment	2,063	0,241	0,850
Poverty	186,277	-3,764	0,165
GDP	0,048	0,032	0,980

According to the OLS analysis of Siqalo's development against each of the socio-economic variables, the most statistically significant variable was found to be that of open space.

Table 10. OLS comparison of Siqalo's shack complexity against socio-economic variables

MN_Shape	Standard error	t-stat	p-value
Open_Space	0,001	-10,874	0,058
Unemployment	0,001	1,014	0,496
Poverty	0,087	-2,860	0,214
GDP	0,000	2,134	0,279

According to the OLS of Siqalo's shack complexity against each of the socio-economic variables, the most statistically significant variable was found to be that of open space.

Table 11. OLS comparison of Langa's shack compactness against socio-economic variables

MN_ENN	Standard error	t-stat	p-value
Open_Space	0,010	-3,110	0,198
Unemployment	0,013	0,722	0,602
Poverty	1,140	-2,321	0,259
GDP	0,000	1,630	0,350

According to the OLS analysis of Siqlao's shack compactness against each of the socio-economic variables, the most statistically significant variable was found to be that of poverty.

3.4. Comparison of Spatial Trends

According to the OLS analysis of the statistical results, the most significant statistics (lowest p-value) relating to the outlined socio-economic and developmental data, respectively, are presented in Table 12.

Table 12. Most statistically significant socio-economic variables when related to the developmental statistics of each informal settlement

	Imizamo Yethu	Langa	Siqalo
lowest p value: CA	Open Space	Open Space	Open Space
lowest p value: MN_SHAPE	Open Space	GDP	Poverty
lowest p value: MN_ENN	GDP	GDP	Open Space

4. Discussion

The total area covered by shacks in Imizamo Yethu has increased, thus leading to the conclusion that densification is on the rise (Table 2 and Figure 3). Even though Imizamo Yethu was established 32 years ago, it has revealed a changing physical structure of densification following the establishment and development (in geometric stages) of informal settlements. The reasoning behind the densification of shacks lies in the availability of employment opportunities, proximity to formal and informal transport networks, and the need to extend shack development to less favourable locations within the settlement site once a threshold of settlers has been accommodated within the settlement. Imizamo Yethu is near places offering employment opportunities and formal transport networks. Because Imizamo Yethu enjoys such attributes/characteristics, it is a most suitable site for informal dwellers. Thus, open space in this informal settlement as found to be of high importance relative to the other OLS factors investigated (Tables 3 and 4).

Additionally, according to the change results (Table 2), the shape of the shacks in Imizamo Yethu became more complex over the investigative period. In its developmental stage, the more complex shack shapes led to an increase in the total shack area. At this stage, the shacks also became more elaborate in shape when compared to the square shack shapes observed in the initial stages of the investigative period. This development can be attributed to the fact that Imizamo Yethu is situated on the slopes of a very steep valley. Here, informal development, as opposed to formal development, has thrived as the latter generally elects to be situated on more favourable land. Initial development occurred on the gentler slopes, and densification on the steeper slopes. However, when evaluating the mean nearest neighbour distance of shacks in the settlement, the GDP was determined as the most influential factor (Table 5).

In Langa, GDP was the most influential factor in shack development over the investigative period (Tables 7 and 8). In a geospatial context, Langa is the closest to the CBD (Figure 1). Langa also has many other economic advantages, such as a central location and proximity to a national road and to Epping Industrial, a major industrial area, providing employment opportunities. These may be localised explanations as to why GDP may play as influential a role as it does in the context of shack development in Langa as opposed to its role in the other two informal settlements that were investigated and that exhibit different geospatial trends. According to the change detection findings, Langa underwent formalisation during the investigative period (Table 2). This resulted in an initial decline in the total area covered by shacks. However, when compared to Imizamo Yethu, the development of the settlement continued in similar fashion. Subsequent densification and an increase in the shack area occurred even though formalisation occurred throughout the investigative period. The amount of space in the settlement would then have decreased, giving it less of an influence when compared to the GDP pull factors in the local area (Table 2). This influence extended to the

shape of the shacks and the space between them. According to the OLS analysis, open space is the most statistically significant variable/factor related to the total area covered by shacks (Table 6). This means that every available space within the settlement would have been used in terms of its ability to accommodate shacks. This, in turn, provides an interesting context relative to the formalisation of the site. Even though the settlement site offered less space for the total area covered by shacks, the GDP pull factor may have made the open space more attractive for shacks to be built within the settlement (Tables 7 and 8).

In Siqalo, the availability of open space for shack development was the most influential driving force (Tables 9 and 10). This is the same result as that for Imizamo Yethu. However, the difference between Siqalo and Imizamo Yethu lies in the time of establishment. Siqalo was established within the investigative period, between the years 2011 and 2014. As a result, Siqalo exhibits more establishment factors in its geometric developmental stage. Siqalo was established and developed near a major transport network. Its physical location is also near to the middle-class socio-economically more advantaged neighbourhood suburb of Mitchell's Plain.

The similarities between Imizamo Yethu and Siqalo include the unattractiveness of the site. Whereas Imizamo Yethu was established on a sloped valley, Siqalo was established on marshy land. The developmental characteristics of Siqalo in a change detection context compare well with those of Imizamo Yethu's initial densification of shacks (Table 2). Thereafter, shacks were developed near the formal major road and the informal or internal informal roads of the settlement (Figures 3 and 4). On the other hand, shack shape was influenced by the poverty coefficient of Cape Town during the investigative period (Table 10). Shack shape in Siqalo became more complex as the rate of poverty in Cape Town increased (Table 9). The nearest neighbour distance between shacks was found to be largely influenced by open space (Table 11).

5. Conclusion

This study presents an analytical geospatial perspective of the development of informal settlements in Cape Town. Across all the informal settlements, open space proved to be the most significant factor, while GDP played the most influential role in explaining shack compactness over time. Future interdisciplinary research on this theme could be supplemented by qualitative-based research and could assist in policy and decision-making.

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