CRIME MAPPING AND SPATIAL ANALYSIS IN GAUTENG

By

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DECLARATION

I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof. Further, I have acknowledged all sources used and have cited these in the reference section. It is submitted in partial fulfilment of the requirements of the degree of Master of Science in Geographical Information Systems (GIS) and Remote Sensing (in the field of Geography, Archaeology Environmental Studies) in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

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ABSTRACT

The study investigated the spatial distribution of five types of crimes (namely contact crimes, contact-related crimes, other serious crimes, property-related crimes and crime detected as a result of police action) in Gauteng using the traditional measure "crime count" and the five alternative measures of crimes namely: location quotient, Theil index, Herfindahl-Hirschman index, Specialisation index and Entropy index. The study found that the five types of crimes are differently distributed in the province. The five types of crimes tend to cluster in certain parts of the province. The contact crime cluster in the City of Johannesburg and the City of Tshwane municipality. The contact related crimes and property related crimes cluster in the City of Johannesburg and the West Rand District. The other serious crimes clustered in the City of Johannesburg and the City of Ekurhuleni municipality while the crimes detected as a result of police action specialisation clusters were found in West Rand District. The study found that police districts can be affected by two or more types of crimes e.g. The Johannesburg Central is affected by contact related crimes and other serious crimes. The investigation found that the five alternative measures of crime show similar spatial distribution of the five types of crimes in the Gauteng. The crime count shows a similar distribution with the Herfindahl-Hirschman index (HHI), while the location quotient (LQ), the Specialisation index (SI), the Theil index (TI), and the Entropy Index (EI) show a similar distribution of the five types of crimes. The LQ, TI, SI and EI are strongly related to each other while moderately related to the HHI. The study found that spatial autocorrelation was found present in all the five types of crimes, showing that the province has clusters of hot spots (high-high) and cold spots (low-low), and outlier hot spots and cold spots (high-low and low-high values) existing. The study also found that there are positive and negative changes in recorded crimes from the year 2014 to 2016. The contact crimes increased in recorded crimes, while the contact related crimes, property related crimes, other serious crimes and crimes detected as a result of police action decreased in recorded crimes. The five types of crimes decreased in the national effect. In contact crimes and property related crimes, decreased at the national level, and increased on the regional and industry mix. In contact related crimes, decreased at national level, increased on the industry mix and a decreased on the regional level. In other serious crimes and the crimes detected as a result of police action there is a decrease at the national level, industry mix and also on the regional shift.

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Contents

List of Tables

List of Figures

Abbreviations

EI	Entropy Index
GIS	Geographic Information System
HHI	Herfindahl-Hirschman Index
LQ	Location Quotients
SAPS	South African Police Service
SI	Specialisation Index
StatsSA	Statistics South Africa
TI	Theil Index

1 Introduction

Crime analysis involves a methodical study aimed at recognising patterns and trends in crime (Ratcliffe, 2007). Such a study is usually conducted to assist police departments or other organisations in setting up resources for combating and reducing crime. The measurement and mapping of crime patterns are two important activities in crime analysis and are particularly useful when comparing two or more spatial units to identify the geographical areas that need urgent attention or intervention (Rosser, Davies, Bowers, 2017).

The history of crime mapping dates to the 1800s and has developed considerably since then (Weisburd and McEwen, 1997). For many years, police departments relied on wall maps to study crime patterns. The wall maps had “push pins” which are drawing pins used to indicate the location and count of incidents of crime and to help the authorities navigate to the places where crime had occurred (Weisburd and McEwen, 1997). Advancement in computing has greatly increased the value of crime mapping and geographic information systems (GIS) now allow users to not only examine patterns of crime in space and time, but to include important attributes in the study of crime patterns.

There are three commonly used measures of crime, namely crime counts, crime rates and crime density (Andresen, 2005). These are referred to as “traditional measures” of crime in the rest of the research report. Crime counts represent the number of crime occurrences and are typically used to: assess the locations of hot spots (areas on a map that have high crime intensity), to assess police work loads and to estimate future resource needs (Brantingham and Brantingham, 1997). Crime rate measures the number of incidents recorded in an area divided by the population of the area at risk; and is often expressed per 1,000 population (Zhang and Peterson, 2007). Crime rates are used to assess the relative risk of crimes occurring to particular people in particular locations or at particular times (Brantingham and Brantingham, 1997). Crime rates are mostly useful in planning prevention campaigns and in assessing the impact of social conditions on the risk of crime (Zhang and Peterson 2007). Crime density is calculated by dividing the number of incidents of crime in an area usually by the size of the area, and it is expressed in km^2 (Zhang, Suresh and Qiu, 2012). Crime density focuses on the location where a criminal act occurs and can be used to explore the relationships between neighbourhood socio-economic characteristics and crime (Zhang and Peterson 2007).

A crime rate is calculated by dividing the number of reported crimes by the total population; the result is multiplied by 100,000. For example, in 2019 there were 58,100 robberies in South Arica and the population was 38,826,898. This equals a robbery crime rate of 149.6 per 100,000 general population.

$$\frac{58{,}100}{38{,}826{,}898}\ x\ 100{,}000 = 149.6$$

The denominator of the population is not always accurate because the population grows daily yet the population census is done every 10years.The crime counts are done yearly while the population count is done every 10 years. Therefore, the denominator or calculating this traditional measure is not always reliable.

The traditional measures of crime are simple to calculate and provide useful insights, but users often must contend with various challenges such as selecting an appropriate denominator for calculating rates and densities (Andresen, 2005). Moreover, measures such as crime rates are regarded as measures of crime concentration as they help reveal spatial areas with high degrees of crime and crime risks but do not inform users about the nature of specialisation of crime (Zhang and Peterson, 2007). Specialisation in crime measures the extent to which offenders tend to repeat the same specific offence or crime type in the same geographical area (Paternoster, 1998). Specialisation focuses on the classification of crime types; aims at providing insights into the different types of crime in an area (Andresen, 2014) and helps in informing the proper distribution of appropriate and often scarce resources for effectively tackling specific crimes.

A set of measures termed "alternative measures of crime" have been explored in the criminology literature as alternatives to the traditional measures of crime. These "alternative measures of crime" include, the location quotient (LQ), the Specialisation index (SI), the Theil index (TI), the Herfindahl-Hirschman index (HHI), and the Entropy Index (EI) (Andresen, 2014). Internationally, the alternative measures of crime have been used on their own or in conjunction with the traditional measures to help further the understanding of crime (Andresen, 2014; Brantingham and Brantingham, 1997). Andresen (2014) employed the LQ, SI, TI, HHI, EI to study crime specialisation and concentrations in Vancouver, Canada. In South Africa, there is limited research exploring the use of alternative measures of crime compared to the traditional measures. Researchers have typically employed the LQs in a very limited

geographical settings (examples are: Breetzke, Landman and Cohn, 2014; Mokhuwa, 2014) and have not done comparative analyses of the traditional and alternative measures of crime.

Crime patterns tend to change over time, either increasing or decreasing depending on the social, economic or other factors that affect it. Spatial-temporal studies of crime are needed to quantify structural changes in crime patterns over time. This is true for South Africa were little is known about regional structural changes of crime over time.

This research replicates the work of Andresen (2014) by analysing crime using alternative measures of crime in a developing country setting. It also explores the structural changes in crime over time in the Gauteng province, one of the nine provinces in South Africa. Gauteng's diversity in population and economic activities makes it an ideal candidate for the study. In addition, statistics from the South African Police Services (SAPS) revealed that Gauteng had the highest incidence of criminal activities in 2016; with 598 627 of 2 206 505 reported crimes in South Africa (SAPS, 2017).

1.1 Aim and objectives

The aim of this research is to analyse the spatial and temporal patterns of various crime types in the province of Gauteng.

To achieve this, the following objectives are addressed:

- To analyse the spatial distribution (hot spots and cold spots) of 5 types of crimes (contact crimes, contact related crimes, property related crimes, other serious crimes and crimes detected as a result of police action) using traditional and alternative measures of crime
- To identify temporal changes in the patterns of crime by analysing the changes in crime statistics using the shift-share analysis for the five types of crimes.

1.2 Research questions

This research will be guided by the following questions:

- How are the five types of crimes distributed over Gauteng?
- Do certain types of crime cluster together spatially in Gauteng?
- Are different police districts affected by particular and distinct crimes?

- Is there any correlation amongst the alternative measures of crime?
- Is there any correlation amongst the five types of crime?
- Has the spatial distribution of crime changed over time?

1.3 Structure of the research report

Following a brief introduction given in Chapter One, Chapter Two provides an overview of the literature related to the alternative measures of crime and the relevant theoretical framework. Chapter Three describes the study methodology with a specific focus on the five alternative measures of measures of crime's spatial distribution. Chapter Four presents the research results, followed by the summaries of major findings, conclusions, and discussions in Chapter Five.

2 Literature Review

In South Africa there is consensus among researchers and policy makers that crime is not only a security issue but has deep social and economic roots and consequences (Burger, 2013). In order to ensure proper planning for an effective response to crime, a holistic approach to community safety, which takes the study and understanding of crime locations, trends and patterns into account is required (Kruger, and Landman, 2008).

This Chapter provides a review of the main concepts used in the development of the research. Specifically, the literature on alternative measures of crime, the theories of spatial disorganisation and routine activity as well as those on spatial autocorrelation and role of GIS is crime analysis are reviewed.

2.1 Alternative measures of crime

Crime counts usually take the form of reported crimes incidents (Brantingham and Brantingham, 1997). Crime rates use crime incident as a numerator and some measures related to the units at risk as a denominator and such rates are used to assess the risk of crimes occurring to people in particular locations (Zhang and Peterson, 2007). Crime density is described as the sum of crime incidents within a certain area per unit of space (Zhang, Suresh and Qiu, 2012). Very limited information is found on crime density in the literature. Zang and Peterson (2007) used crime density as an alternative measure to crime rates and found that crime density is more appropriate as the indicator of crime concentration than the crime rates, as it focuses on spatial concentration of crime.

Despite the wide use of traditional crime measures such as crime count, crime rates and crime density, certain shortcomings are present when these measures are used. These include, the choice and reliability of denominators to construct the rates, as well as the difficulty in obtaining reasonable and recent estimates for denominators (Andresen, 2005). A problem encountered with crime rates is that it derived from the population size and it can mislead at lower geographical levels (Zhang and Peterson, 2010). The calculation of crime rates also places little emphasis on the socio-economic background of the affected individuals (Zhang and Peterson, 2007). A major challenge with the use of crime rates involves finding up-to-date

population numbers to use as a denominator. There is often a 10-year gap between population censuses and for this reason, the population counts used in the calculation of crime rates are not always reliable. Finally, the traditional measures of crime do not tell us the specialisation in the types of crime committed in an area (Zhang and Peterson, 2007).

Brantingham and Brantingham (1997) demonstrated the utility of alternative measures of crime by analysing violent crimes across the cities of British Columbia in Canada using crime local quotients (LQs). The LQ, originated from in regional planning and economics to address the local economies structures and has been used in a number of studies investigating industry specialisation and clustering (Brantingham and Brantingham, 1993). The LQ measures how concentrated an activity in an area is compared to its surrounds. The advantage of the LQ as an alternative measure in crime analysis is that it does not require the number of victims at risk as required for the traditional crime measures. Brantingham and Brantingham (1995) recommended that LQs are useful in revealing the spatial differences of different types of crime across communities. Brantingham and Brantingham (1997) analysed violent crimes in the British Columbia city utilising three crime measures: counts, rates and crime LQs. There has since been a widespread adoption of the LQ in crime analysis (Cahill, 2005; Carcach and Muscat, 2002; Breetzke, Landman and Cohn, 2014; Mokhuwa, 2014; and Andresen, 2014). Carcach and Muscat (2002) for example, examined crime profiles in Australia using LQs and socio-economic characteristics to compare crime structures across geographical locations and found that crime specialisation varies due to factors such as socio-economic status and social stability. Cahill (2005) analysed the crime patterns using the LQs and land use measures and found that LQs can be used to determine what areas have disproportionate levels of crimes.

In South African context, Breetzke, Landman and Cohn (2014) used LQ to relate the extent of burglary crimes in gated communities in the City of Tshwane and concluded that gated communities are related to high levels of burglary. Mokhuwa (2014) used the LQ of crime and crime density to analyse the spatial patterns of six types of crime also in City of Tshwane in South Africa and found that although crime densities differ across police areas within Tshwane municipalities, contact crimes are more dominant in areas with poor socio-economic conditions.

Andresen (2014) explored the use of several alternative measures of crime, including the Theil index (TI), Herfindahl-Hirschman index (HHI), Specialisation index (SI), and the Entropy

index (EI) in understanding crime's relative and general specialisation and concentrations in Vancouver, Canada. While the alternative measures of crime produced different results, they proved to be suitable in outlining various aspects of specialisation of crime in revealing interesting spatial patterns associated with Burglary in Vancouver (Andresen, 2014). The alternative measures of crime are popular and convenient because they require few data for their computation (Crawley, Beynon, and Max 2012). The EI, HHI, TI and SI are considered in measuring crime because of their property of decomposability and that they can be expressed as the inequality measure (Kang, 2014).

The TI has been used in measuring economic inequality and economic segregation (Kang, 2014). This index uses a decomposition technique that enables researchers to examine the extent to which changes in an area level inequality is driven by local inequality within each neighbourhood and economic segregation across neighbourhoods. The TI is a powerful instrument to produce data, analyse patterns and dynamics of inequality (Nidhi, 2011). The HHI was formulated by Hirschman (1964) and Herfindahl (1950) to measure trade and industry inequality, and to understand the level of competition that exists within a market or industry. The HHI has been used to measure concentration in household income and revenue (Nidhi, 2011). Amber, Boydstun, Bevan, and Herschel (2014) found that the HHI was the best in identifying high and low levels of variation, leading to smoother measures of crime specialisations.

The SI is a general measure of specialisation (it does not provide information regarding which type of specialisation occurs in an area). The SI measure has mostly been used in technological and economic industries for understanding the position of regional activities in global value chains (Palan, 2010). Piquero et al, (1999) found the SI as a great measure of crime as it measures the degree of versatility in the crime. Finally, the EI is an inequality measure of factors such as income and crime (Maio, 2007). It is derived from information theory and has the advantage that it can be broken down to component parts such as population subgroups (Maio, 2007). This enables the analysis of between- and within-area effects (Hou and Myles, 2005). Eitle and McNulty (2010) analysed whether school-based crimes of juveniles for violent crimes were concentrated in United States metropolitan areas. Using the EI, they found that crimes were localised in within districts of the metropolitans and in metropolitan areas with higher than average levels of districts (Eitle and McNulty, 2010).

2.2 The social disorganisation and routine activity

The social disorganisation theory and the routine activity theory both help analyse the structure of a neighbourhood in association to criminal activities. According to Sampson and Groves (1989), the theory of social disorganization deals with the failure of a community to recognise the shared value of its people resulting in non-effective social controls. The social disorganisation theory suggests that socio-economic distresses such as unemployment and poverty contribute resulting in high crime levels (Zhang and Peterson, 2007). Sampson and Groves (1989) analysed their data using the social disorganisation theory and concluded that factors such as poor economic status, racial differences, family disruption and residential mobility increase crime. Kruger and Landman (2008) also found that socio-economic issues such as urbanisation and poverty are significant measures of social disorganisation as they limit access to education, training and employment which contribute to community growth. According to Kruger and Landman (2008), residents from areas with fewer developmental activities tend to engage in inappropriate activities such as crime.

The routine activity theory describes criminal activities through routines engaged by the victims, perpetrators, and the law enforcers. According to Cohen and Felson (1979), the theory of routine activity is based on convergence of activities related to the criminal, a victim, and the absence of security. The study assumes that crime occurs if the criminal sees a victim who does not have a capable guardian as protector. According to this theory, lower levels of crime can be linked to low population density communities that have monitored environments and restricted access for strangers (Hillier and Sahbaz, 2008).

Both the social disorganisation theory and the routine activity theory assume that the causes of crime are related to the conditions in which people live as well as their social interaction (Hillier and Sahbaz, 2008). With respect to the alternative measures of crime, the social disorganisation and routine theory can help identify the causes of crimes by analysing the economic state of the communities affected. Zhang (2002) analysed spatial patterns of four types of crimes (assault, robbery, auto-theft, and burglary) for the City of Omaha, Nebraska and found that crime patterns were related to the socio-economic characteristics. The social disorganisation theory and the routine activity theories assisted the researchers in their exploratory analysis of

how the crime patterns come about. Through the analysis of hot spots, Zhang (2002) found that property related crime (burglary) was happening mostly in residential areas, while robbery and violent crime in downtown, highly populated areas. This study is an exploratory study and does not explore the determinants of crime patterns.

The social disorganization theory's greatest challenge is the comparative absence of attention paid to the processes that facilitate the effect of the community characteristics (Kubrin and Weitzer, 2003). Sampson & Groves (1989) constructed community-level measures of neighbourhoods using social disorganization theory. They found out the structural conditions of the neighbourhoods do not influence crime. The social disorganization theory and the routine theory do not address why crime happens in areas that are not socially disadvantaged.

2.3 Spatial autocorrelation analysis and an understanding of hot spots, cold spots and spatial outliers

Lattice data has been the common way of presenting and analysing crime data in the literature. Lattice data are observations from processes than analyse spatial regions (Kaluzny, Vega, Cardoso and Shelly, 1998). A typical interest in the analysis of lattice data is the study of spatial autocorrelation which looks at how well objects correlate with other nearby objects across a spatial area. The commonly used statistical methods of analysing lattice data are the Moran's I statistic, Moran Scatterplot and Local Indicators of Spatial Association (LISA) (Anselin, 1995).

The Moran's I is a global measure of spatial autocorrelation, in the sense that the overall pattern in the data is summarized in a single statistic which indicates the presence of clustering (Anselin, Cohen, David Cook, Gorr, and Tita, 2000). The Moran's I is a cross-product coefficient similar to a Pearson correlation coefficient and scaled to be less than one in absolute value. When values closer to the mean are positive, the cross-product will be positive. When one value close to the mean is small and the other is larger, the cross-product will be negative. The larger the deviation from the mean, the larger the cross-product result. If the values in the dataset tend to cluster spatially (high values cluster near other high values; or low values cluster near other low values), the Moran's I will be positive. When high values are inversely related to low values the index will be negative. (Anselin, 1995).

The LISA provides a measure of the extent to which the arrangement of values around a specific area deviates from spatial randomness. LISA is designed to portray local forms that are derived from global statistics such as Moran's I and is best portrayed using maps, where locations with significant local statistics are outlined (Anselin, 1995). The cluster and outlier distinguishes between a statistically significant cluster of high values (HH), cluster of low values (LL), outlier in which a high value is surrounded primarily by low values (HL), and outlier in which a low value is surrounded primarily by high values (LH). In other words, LISA and the Moran's I scatterplot are useful in identifying clusters of high or low values (spatial outlier), high-high (hot spots) and low-low spatial clusters (cold spots), and high-low (spatial outlier). An understanding of hot spots, cold spots and spatial outliers in police districts could contribute to crime fighting strategies and effective policing (Ratcliffe, 2007).

Researchers often look for concentrations of individual events that might indicate a series of related crimes. In this regard, a range of concepts such as are crime hot spots, hot products, hot dots, hot places, hot targets, super-targets, risky facilities, risky routes, and crime sprees/spates have evolved (Tilley and Laycock, 2002). Hot spots are areas of concentrated crime. These concentrations can be plotted across time, space, and other dimensions along which they occur. Cold spots in crime are defined as areas of low crime, or spatial clusters of lower than expected crime incidents (Pieracci, 2010). Further, a spatial outlier is an extreme observation which deviates significantly in its spatial neighbourhood (Singh, 2016). Researchers also observe neighbourhoods and neighbourhood clusters with high crime and disorder levels and try to link these to underlying social conditions such as poverty (Eck, Chainey, Cameron, Leitner, and Wilson; 2005).

2.4 Spatial patterns and GIS

Spatial-analytical tools have gradually assessed crime data to analyse the complex spatial nature of crime specialisation (Bui and Pham 2016). Data management is mostly achieved using Geographic Information Systems (GIS) and database management systems are important throughout in spatial data analysis (Bui and Pham 2016). GIS is a platform used to validate the application of spatial analysis and introduce systematic approaches which integrate it with statistical software tools to enhance assessments (Bui and Pham 2016). The GIS platforms

provide tools for visualization, exploration and modelling (Gao, 2009). GIS and statistical software tools help in finding spatial clustering of crime, the spatial distribution of crime.

Spatial patterns have also been widely used in crime analysis using GIS and spatial statistics in the United States and Canada. Crime trends and patterns can be used analysed to determine that crime is distributed differently in the community and can help with mitigation strategies of reducing crimes (Pieracci, 2010). Hot spot analysis can in crime intelligence in order to identify locations of future crimes based on past trends (Eck, Chainey, Cameron, Leitner and Wilson, 2005). Spatial outlier analysis is useful in GIS applications including public safety (Shekhar et al. 2003).

Groff, Weisburd and Morris (2009) analysed how types of crimes were distributed in a state using spatial statistics and GIS. In their research they concluded that there is a tendency for one crime type to be clustered. However, they found that crime can vary block by block temporally.

Brantingham and Brantingham (1993) illustrated that crime occurs at any particular place and also showed how certain types of incidences relate to crime in general. In their study, they used the LQ to identify whether a specific crime pattern is disproportionately high or low in a particular place or location (Brantingham and Brantingham, 1997). Brantingham and Brantingham (1997) discovered that although LQs can be used along the traditional measures such as counts and rates to provide a relative view of crime specialisation. The LQ measure makes it possible to identify geographical spaces where different criminal activities happen (Brantingham and Brantingham, 1997). De Kock, Schwabe and Currin (2015) also used the LQs to analyse the concentration of crime at the police station level in South Africa and found that selected police precincts in South Africa bear the burden of the violent and property related crimes.

3 Methodology

3.1 Study area

The Gauteng province is the smallest province in South Africa with an area of 18 176 km² (StatsSA, 2015). According to the 2017 midyear population estimate, Gauteng has a population of approximately 14.7 million people and is highly urbanised with 97.2 % people residing in urban areas (StatsSA, 2017). Gauteng's 143 police districts (the division of a geographical area that a specific police station is responsible for) are shown in Figure 3.1. A list of the individual policing districts appears in Table 5.2 in Table A1 in Appendix A. Gauteng province, when compared to other provinces, had the highest recorded incidents activities with 626 749 reported crimes in 2017 (SAPS, 2017). Its diversity in population and economic activities makes it an ideal candidate for the study.

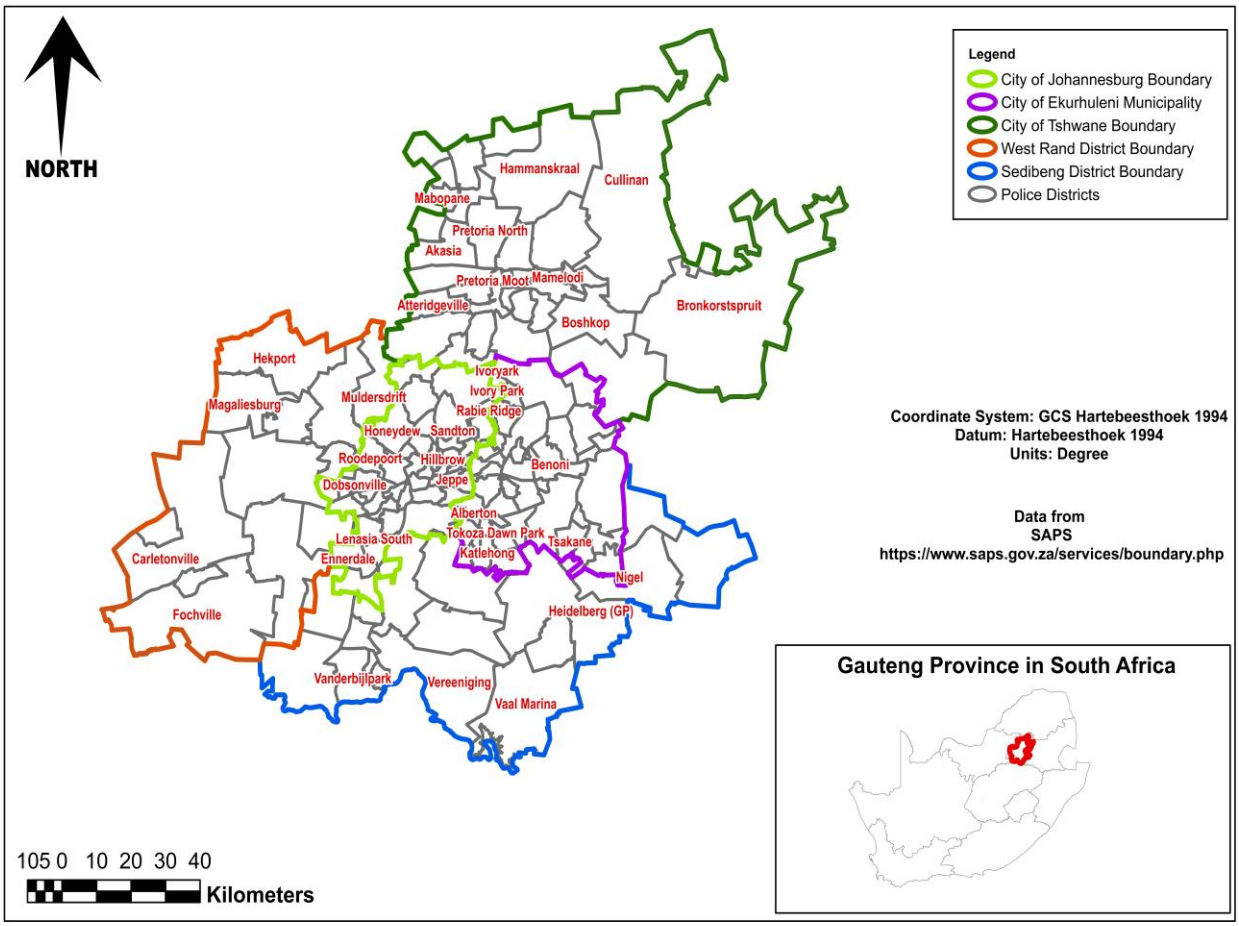


Figure 3.1 Map showing the Gauteng Province and its police districts

3.2 Data

The research report utilises secondary data obtained from the SAPS (SAPS, 2017). Victims typically report crime incidents at the police stations upon experiencing a crime. These incidents are captured in the Crime Administration System (CAS) of SAPS and aggregated into five broad crime categories (Table 3.1) before being made publicly available. The research focuses on the 2015/2016 crime statistics release which includes data from 2011 to 2016 (SAPS, 2017).

Table 3.1 Community crimes reported by SAPS (SAPS, 2017)

Contact Crimes	Contact Related Crimes	Property Related Crimes	Other Serious Crimes	Crimes detected as a result of police action

• Murder
• Sexual Offences:
  ○ *Rape*
  ○ *Contact Sexual Offences*
  ○ *Attempted Sexual Offence*
  ○ *Sexual Assault*
• Attempted Murder
• Assault GBH
• Common Assault
• Common Robbery
• Robbery Aggravated:
  ○ *Carjacking*
  ○ *Robbery: Residential*
  ○ *Robbery: Non-Residential*
  ○ *Robbery CIT*
  ○ *Bank Robbery*
  ○ *Truck Hijacking*
	• Arson
	• Malicious damage to property
		• Burglary at residential premises
		• Burglary at non-residential premises
		• Theft of motor vehicle and motorcycle
		• Theft out of or from motor vehicle
			• Other Theft
			• Commercial Crime
			• Shoplifting
				• Illegal Possession of firearm and ammunition
				• Drug-Related Crimes
				• Driving under the influence of alcohol and drugs
				• Sexual offences detected as a result of police action

3.3 Analysis

3.3.1 Software used

Three software applications were used for this research. R software (R Core Team, 2013) was used to conduct the correlation analysis, while ArcGIS 10.5 (ESRI, 2016) was mainly used for spatial analysis as well as map generation. Microsoft Excel (Microsoft, 2016) was used to calculate the various indices, to obtain the relevant summary statistics and to calculate changes in crime needed to measure the regional changes of crime.

3.3.2 Summary statistics

Summary statistics are composed of the sum, minimum, maximum, as well as mean and standard deviation. The minimum value represents the police district(s) with the lowest crime count(s) while the maximum value represents the police district(s) with the highest crime count(s). The mean is the average of crimes counts in all the police districts in the province. The standard deviation quantifies the amount of variation or dispersion in the data.

3.3.3 Correlation analysis

The correlation analysis is computed in R (R Core Team, 2013). The Pearson's correlation coefficient helps in identifying the relationships between any two variables. A correlation value of -1.0 shows a perfect negative correlation, while a correlation of 1.0 shows a perfect positive correlation. A correlation of 0.0 shows no linear relationship between two variables. The closer the correlation is to 1.0 (in absolute terms), the stronger the relationship between the two variables.

3.3.4 Global Autocorrelation

The Moran's I for measuring global spatial autocorrelation as described by Moran (1950), is as follows:

$$\mathrm{I} = \left(\frac{n}{\sum_i \sum_j w_{ij}}\right)\left(\frac{\sum_i \sum_j w_{ij}\,(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2}\right),$$

where, *n* is the number of areal units; x_i is the value of variable at location i, x_j is the value of a variable at location j; w_{ij} is the weight that determines the relationship between i and j; while $\bar{x}$ is the mean of the variable (Anselin, Cohen, Cook, Gorr and Tita, 2000). The Moran's Index takes on values between -1.0 and 1.0. Positive values of the Moran's I represent clustering of similar values, while negative values represent negative spatial autocorrelation showing clustering of dissimilar values (Anselin, Cohen, Cook, Gorr and Tita, 2000). Moran scatter plots and the non-parametric spatial correlogram are often used to visualise the magnitude and the range of the spatial autocorrelation (Anselin,2018).

The boundaries shared between spatial units play in important role in determining degree of the spatial influence. According to Anselin (1995), the neighbourhood or contiguity structure of a data set is formalized in a spatial weight matrix named w_{ij}. The spatial weights matrix has elements w_{ij} =1 when area *i* and area *j* are neighbours (Anselin, 1995). The spatial weight matrix imposes a structure in terms of what are the neighbours for each location and assigns weights that measure the intensity of the relationship among pairs of spatial units (Anselin, 1995). Neighbours in this case are defined under the "first-order queen" convention, meaning that the neighbours share a boundary with any immediate neighbours in any direction (Voss, Long, Hammer and Friedman, 2006). The advantage of the first-order queen representation is that distances are easily computed. The Moran's I for crime counts and the five types of crimes were calculated along with their variances and the *p*-values using the R software. The hypothesis tested was to analyse if spatial distribution was present in the province. Moran I will give result of a z-score and p-value indicating whether the hypothesis is statistically significant or not. When the p-value is statistically significant, you can reject the null hypothesis. P-values are numerical approximations of the area under the curve for a known distribution, limited by the test statistic (Getis and Ord,1992). The *p*-value indicates the significances of the Moran's I results. Statistical significance is set at the 0.05 and values smaller than 0.05 are considered statistically significant.

3.3.5 Moran's scatterplots

The Moran scatterplot (Anselin, 1995) provides a visual means of understanding the extent and nature of spatial clustering. The scatterplot expresses police districts crime counts in relation to the weighted counts in the neighbouring suburbs based on a weight matrix (Murray, Mcguffog, Western and Mullins 2001).

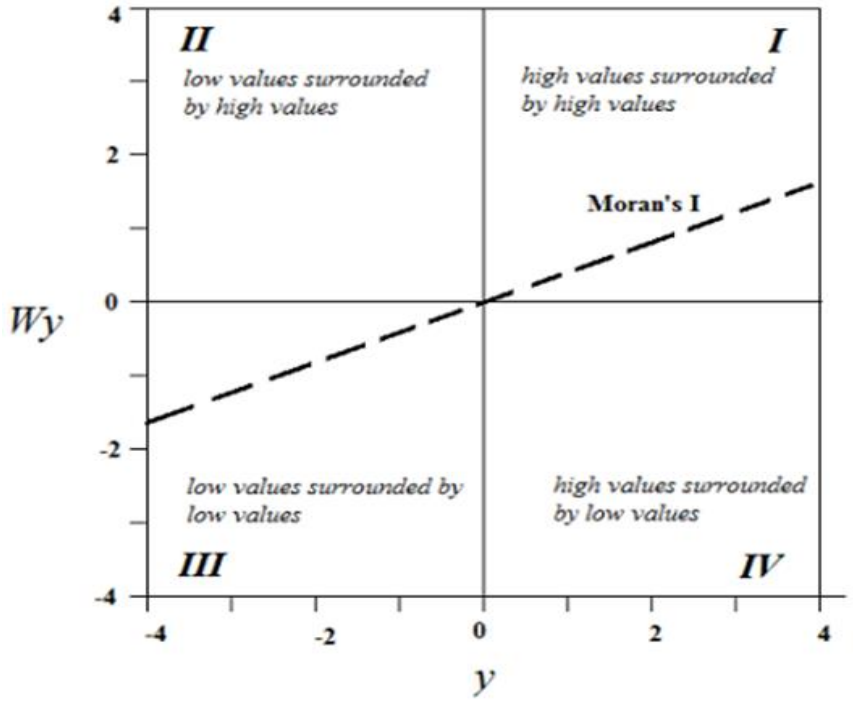


Figure 3.2 Moran scatter plot as detailed by Anselin (1995)

Data points found in quadrant I of the Moran scatterplot (Figure 3.2) refer to police districts with above average values that also share boundaries with neighbouring police districts that have above average values on the same variable (high-high). The quadrant III shows police districts with below average values surrounded by neighbouring districts that also have below average values (low-low). The quadrant IV displays police districts with above average values surrounded by police districts with below average values (high-low), and quadrant II contains the reverse (low-high) (Voss, Long, Hammer and Friedman, 2006). The slope of the regression line through points expresses the global Moran's I value (Anselin, 1995).

3.3.6 Local Autocorrelation

The LISA is helpful in identifying local clusters and expressed as detailed by (Anselin, 1995) as:

$$I_i = \frac{(x_i - \bar{x})}{S_I^2} \sum_{j=1}^{n} w_{ij} (x_j - \bar{x})$$

where $\bar{x}$ is the mean of values with sample size n; w_{ij} is a measure of contiguity between areas (as defined in 3.3.5); x_i is the value of the variable at location i; x_j is the value of the variable at location j.

The Local Moran's I statistic is a local form of the Global Moran's I in that each location, receive its own I value, as well as its own variance, z value, expected I, and variance of I.

3.3.7 Alternative measures of Crime

The spatial analyses in this report includes the calculation and mapping of crime specialisation using five alternative measures of crime, namely LQ, TI, HHI, SI and EI. Each alternative measure of crime is described in the following section. The intention is to replicate the analysis of Andresen (2014) and gain understanding of the results from these measures in a developing country setting. A few definitions relevant in understanding the areas of utilisation of these measures is given below.

Crime specialisation is often used in describing the distribution of events in a geographical extent. In crime analysis applications, it shows how a particular crime in one police district compares to other police districts in the same region (Eck, Clarke and Guerrete, 2007). There are two types of specialisation as per Andresen (2014), the general and the relative specialisation. Relative specialisation measures highlight the particular type of crime the perpetrators tend to specialise in, in a police district (Andresen, 2014; Carcach and Muscat, 2002).

3.3.7.1 Location quotient (LQ)

The LQ is a measure of crime specialisation. The LQ as detailed in Andresen (2014) are calculated as follows:

$$\mathrm{LQ} = \frac{\mathrm{C}_{ij} \,/ \sum_{j=1}^{N} \mathrm{C}_{ij}}{\mathrm{C}_{tj} / \sum_{j=1}^{N} \mathrm{C}_{tj}}$$

The LQ is calculated for crime *i* for police district j, where *i* is the type of crime, *j* is the individual police district, N is the total number of police districts in the province. C_i is the count of crime *i* in each police district and C_t is the total count of crime incidents in each police

district. LQ values closes to 0 indicate little or no specialisation of that specific crime type. If the LQ equals to 1 then it means that the crime share for that crime type is equal to the whole province. If the LQ is more than 1 it means that crime specialises in that particular districts (Andresen, 2014).

3.3.7.2 The Theil index (TI)

TI is a general measure of specialisation. The TI as detailed in Andresen (2014) is calculated as follows:

$$TI = \sum_{k=1}^{n} \frac{\mathrm{x}_{jk}}{\mathrm{x}_{j}} \ \ln\left(LQ_{jk}\right)$$

where x_{jk} is the count of crime of category k in police district j, x_j is the count of all crime in police district j, LQ_{jk} is the LQ for crime k in the police district j, and j is the number of individual police districts. The TI varies from 0 to above ln(z). If T_j is equal to zero and below 0, shows there is little specialization. If the share of crime in a police district is zero, the TI will remain undefined as its' LQ will also be equal to zero (Andresen, 2014).

3.3.7.3 The Herfindahl-Hirschman Index (HHI)

The HHI is a general measure of specialisation. The normalised HHI as detailed in Andresen (2014) is calculated as follows:

$$H^{*} = \frac{\mathrm{H} - \frac{1}{n}}{1 - \frac{1}{n}}$$

where, H^{*} represents the normalised HHI, H is defined as $(S_1^2 + S_2^2 + S_3^2 + .. S_n^2)$, n is the number of police districts in and S_i denotes the relative share of the i^{th} district. Higher values of the index indicate higher crime specialisation (Hayes, 2020).

3.3.7.4 The Specialisation Index (SI)

The SI is a general measure of specialisation meaning it measures how crime is spatially specialised in an area. The SI as detailed in Andresen (2014) is calculated as follows,

$$SI = \frac{\sum_{i=1}^{n} |h_{ij} - h_j}{2}$$

where h_{ij} is the share crime j at police district *i* and h_j is the share crime *j* in the province. SI ranges from 0 to 1. If SI is equal to zero, there is no specialisation. The SI varies from 0 to 1. If SI is equal to zero, there is no specialisation and when it is below 0, it shows there no or is little specialisation in the police district. If the share of crime in a police district is zero, the SI will remain undefined (Andresen, 2014). The share crime is the number of crimes in a police district compared to either the total number of crimes in a province or country.

3.3.7.5 The Entropy Index (EI)

The EI is a general measure of specialisation. The EI as detailed in Andresen (2014) is calculated as follows,

$$EI = 1 - \left(\frac{-\sum_{i=1}^{n} p_i \mathrm{l}mp_i}{\mathrm{m}}\right)$$

where m is the total number of crime categories and p_i is the share of crime category *i*. E_j ranges from 0 to 1, where values closer to 0 show little specialization, while values closer to one show the presence of specialisation.

3.3.8 Shift-share analysis

The main objective of the shift-share technique is the quantification of geographical changes Dunn (1960). Thus, the shift-share examines the growth or change in crime between two periods by identifying the relative contribution of national, sectoral and competitive effects. This type of analysis helps the researcher to explain the effect of factors such as political and economic constraints and how they contribute to the increase or decrease in crime.

National growth effect represents the share of crime in a police district attributed to growth of crime in the national level. Industrial mix effect represents the effects that a specific crime trends at the national level have on the crime in the local level (Michael and Don, 1992). This component captures the fact that, at the national level, some crimes grow faster or slower than others. This component highlights the crimes in the locality that are increasing on a national

level (Michael and Don, 1992). Regional effect shows how types of crimes in the locality performed relative to those groups at national level (Michael and Don, 1992). It assumes that for the same types of crimes, sometimes the locality may not follow the national trends with the same magnitude. The sectoral effect can be referred as the industry mix while the regional effect can be referred at as the local effect.

The regional change in the variable X within district *i* between the two years X_{ij2} and X_{ij} is defined as the sum of the three shift-share components: national growth effect NE_{ij}, industry mix effect SE_{ij}, and local share effect CE_{ij}.

$$X_{ij2} - X_{ij} = Neij + SE_{ij} + CE_{ij}$$

The components of the shift-share as detailed by Mayor and Lopez (2008) are,

The national effect $NE_{ij} = X_{ij}r$

The sectoral effect $SE_{ij} = X_{ij}(r_i - r)$

The regional effect $CE_{ij} = X_{ij}(r_{ij} - r)$

X_{ij} is the initial value of crime and X_{ij2} is the last value of crime in a police district. The total percent change in the crime in the whole province combined is *r*, while the sectoral and regional percent changes are r_i and r_{ij}, respectively.

The national growth considers the positive or negative contributions derived from each spatial environment, known as the net effect. The sectoral effect collects the positive and negative influences on the growth of the specialisation of the worst crime in police districts with growth rates over or under the average, respectively (Mayor and Lopez, 2008). The competitive effect then collects the special dynamism of types of crime in a police district or region in comparison to the dynamism of the same types of crime at national level.

4 Results

As an initial investigation, summary statistics were used to describe the data and bivariate correlation coefficient to describe the relationship between variables. The study investigated the spatial distribution, concentration, specialisation of five types of crimes using crime counts and the five alternative measures namely LQ, TI, HHI, SI and EI. The study also analysed how the five types of crimes; contact crimes (CC), contact related crimes (CRC), other serious crimes (OSC), property related crimes (PRC) and crime detected as a result of police action (CPDA) changed between 2014 to year 2016.

4.1 Crime Counts

4.1.1 Summary Statistics for Crime Counts

Table 4.1 displays the summary statistics for all the five types of crimes using the crime counts. There was a total of 598 627 recorded crimes in the province of Gauteng in 2016. The contact crimes had the highest count and contribute 29% while contact related crimes contribute 6% of reported crimes in Gauteng. The police districts with the highest crimes (maximum values) are; Johannesburg Central for contact crimes (5301 recorded incidents), Hillbrow police district for contact related crimes (832 incidents), Eldorado Park in the category crime detected as a result of police action (with 2515 incidents), Johannesburg Central in the category of other serious crimes (with recorded 4603 incidents), and Honeydew in the category property related crimes (with 3655 incidents). The police districts with the lowest crimes count are Kliprivier in contact related crimes with 9 crimes and Wedela in other serious crimes with 16 incidents. Vaal Marina has the lowest crime counts in three types of crimes namely, property related crimes (45), contact crimes (40) and crime detected as a result of police action (4). The crime category with the largest variation is contact crimes (901.37) and the crime category with the lowest variation is contact related crimes (168.50).

Table 4.1 Descriptive summary for crime counts in 2016

Crime Category	Count	Min	Max	Mean	Standard Deviation
Contact Crimes	171 466	40	5301	1199	901.37
Contact Related Crimes	34 023	9	832	238	168.5
Property Related Crimes	154 761	45	3655	1082	740.75
Other Serious Crimes	142 974	16	4603	1000	814.13
Crime detected as a result of police action	95 403	4	2515	667	519.81

4.1.2 Correlation analysis for Crime Counts

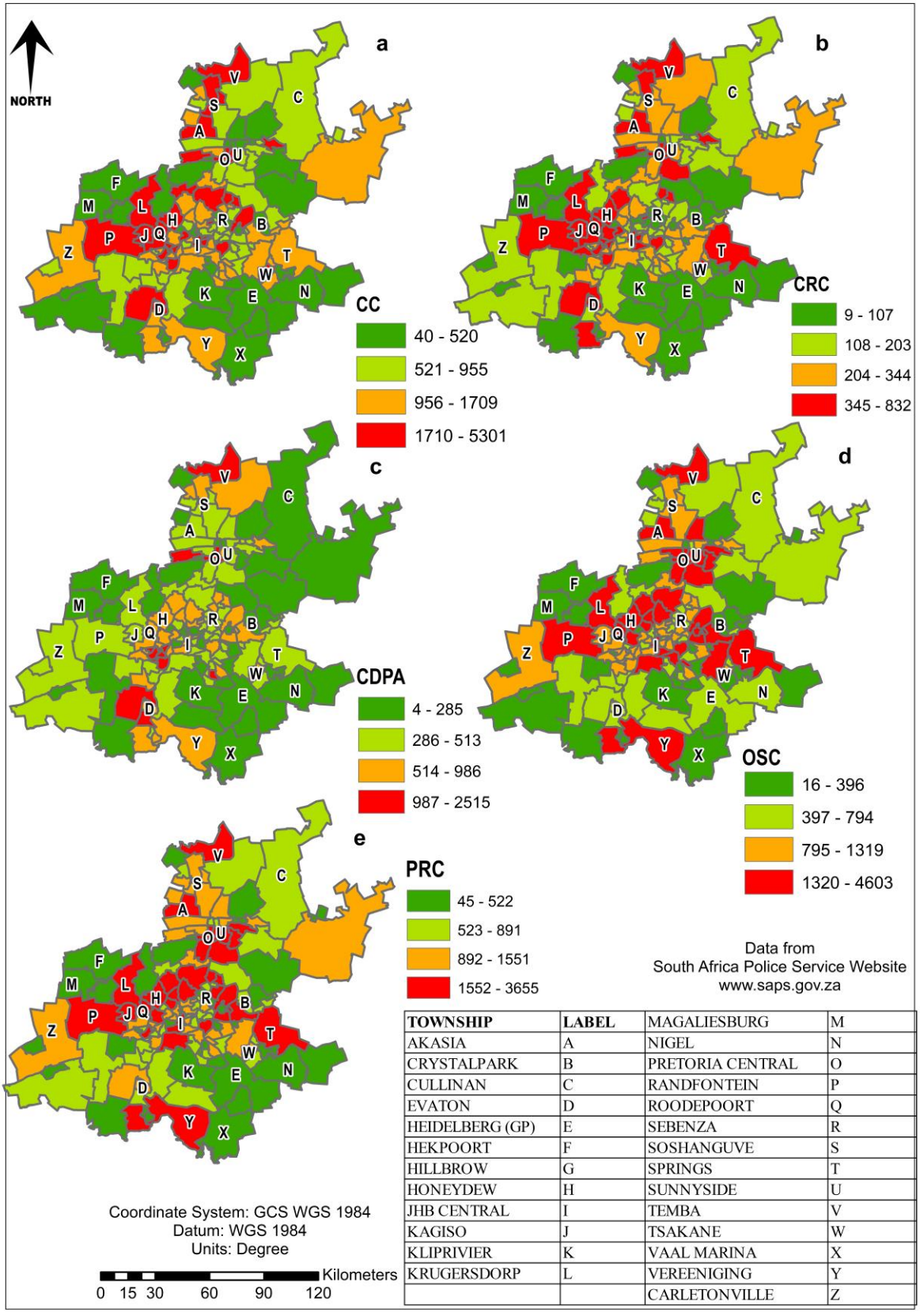
The Pearson's correlation analysis found that contact related crimes are strongly related to contact crimes (r=0.88) and other serious crimes are strongly related to crime detected as a result of police action (r=0.87). Other serious crime and property-related crimes yielded a Pearson correlation coefficient of 0.44 which shows the two crimes have average to little bivariate relationship. Other bivariate relationships reveal moderate positive relationships between the pairs of variables which means when one variable increases as the other variable also increases.

Table 4.2 Pearson's bivariate correlation for types of crimes (2016 crime counts)

	Contact crimes	Contact related crimes	Property related crimes	Other serious crimes	Crime detected as a result of police action
Contact Crimes	1.00				
Contact Related Crimes	0.88	1.00			
Property Related Crimes	0.61	0.64	1.00		
Other Serious Crimes	0.59	0.61	0.44	1.00	
Crime detected as a result of police action	0.64	0.64	0.40	0.87	1.00

4.1.3 Spatial distribution of Crime Counts

Figure 4.1 shows the distribution of crime counts using the quantile classification, the quantile classification is a data classification method that distributes a set of values into groups that contain an equal number of values. Four classes have been controlled to display the distribution of crime counts and this approach has been used throughout the report unless otherwise stated. Figure 4.1 show that police districts with the highest crime counts (colour red) in all the five crime types of crime are mostly can be found throughout the province with a few clusters of high values appearing in the City of Johannesburg municipality and the police districts with low crime count (green colour) are mostly located in the Sedibeng District. When comparing the distribution of the five types of crimes, Hekpoort (F) and Vaal Marina(X) which have low crime counts for all the five types of crimes. Some police districts such as Honeydew (H) and Temba (V) had high counts for two or more crime types. The Honeydew police district had high crime contact crimes, contact related crimes, other serious crimes and property related crimes, while Temba (V) is affected by all five types of crimes types.



TOWNSHIP	LABEL	MAGALIESBURG	M
AKASIA	A	NIGEL	N
CRYSTALPARK	B	PRETORIA CENTRAL	O
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure 4.1 Spatial Distribution of Crime counts. (a) : contact crimes, (b) : contact-related crimes, (c) : crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes

4.1.4 Global Autocorrelation for Crime Counts

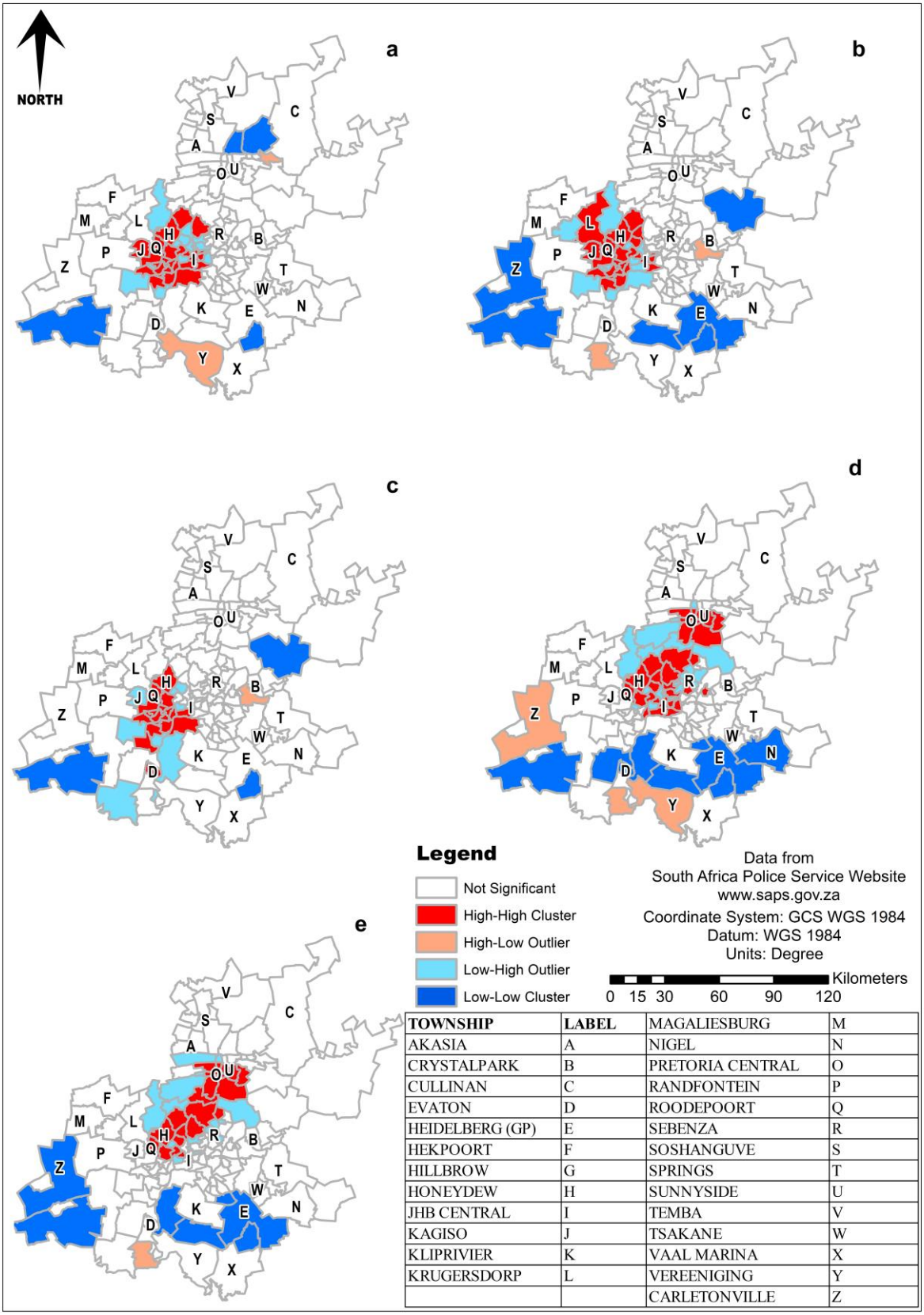
The overall tendency of values to cluster as observed in Figure 4.1 could be real or may appear as a function of map classification. Moran's, I was used to analyse if spatial autocorrelation is present in the five types of crimes using crime counts (Table 4.3). The Moran's I test the hypothesis that spatial autocorrelation is not present. The null hypothesis is rejected if the p-value is less than 0.05. The alternative hypothesis to be accepted is that spatial autocorrelation is present. Using a *p*-value of 0.05, we can conclude that all values are significant and positive spatial autocorrelation is present in all the five types of crimes. The Moran's I values achieved are low in general, with the highest value attributed to property related crimes (0.1858) and the lowest attribute to contact crimes (0.1089).

Table 4.3 Moran's I statistic, p-values and conclusion from test for spatial autocorrelation based on crime counts

Crime Category	Moran's I	p-value	Conclusion
Contact Crimes	0.1089	0.001	Autocorrelation present
Contact-Related Crimes	0.1277	0.001	Autocorrelation present
Property Related Crimes	0.1858	0.001	Autocorrelation present
Other Serious Related Crimes	0.1295	0.001	Autocorrelation present
Crime Detected as a Result of Police Action	0.1642	0.001	Autocorrelation present

4.1.5 Local Autocorrelation for Crime Counts

The Moran's I values in Table 4.3 only give an idea of the global autocorrelation. Figure 4.2 shows the police districts that are hot spots (high-high) and cold spots (low-low) clusters. Clusters of high-high and low-low values are present in all the five types of crime. The results show that contact crimes have 25 police districts which are clusters of high-high (hot spots) values, contact related crimes have 23 police districts which are hot spots, crime detected as a result of police action have 19 police districts action which are hot spots, other serious crimes have 29 police districts which are hot spots and property related crimes have 20 police districts which are clusters of hot spots. The spatial distribution of the five types of crimes, show that most of the high-high (hot spots) clusters are located in the City of Johannesburg municipality. Police districts such as Honeydew (H) and Roodepoort (Q) are hot spots for all the crimes while districts including Vaal Marina (X) and Heidelberg GP (E) are cold spots for all the crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
AKASIA	A	NIGEL	N
CRYSTALPARK	B	PRETORIA CENTRAL	O
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure 4.2 LISA maps for crime counts. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.

4.1.6 Summary of analyses based on Crime count

The descriptive statistics found that different types of crimes have can affect the same police district. According to the Pearson's correlation coefficient analysis, the five types of crimes either have a strong or moderate bivariate relationship. The choropleth maps revealed variations in the distribution of crime counts for the five types of crimes in the Gauteng. The Moran's I statistic showed that positive spatial autocorrelation was present in all the five types of crimes. All the five types of crimes had a significant value for the Moran's I statistic. The LISA showed that clusters of high-high crime counts (hot spots) where mostly found in the central part of the province, in the City of Johannesburg municipality and the clusters of low-low (cold spots) being situated at the south eastern part of the province, which is the Sedibeng District.

While the crime counts analyses showed that the five types of crimes are differently distributed in the province of Gauteng, the results do not tell us which crimes are specialised in each district. The sections that follow focus on using alternative measures of crime to study the spatial patterns and other characteristics of the five types of crime.

4.2 Alternative measures of crime

4.2.1 Summary statistics

The summary statistics for the alternative measures of crime is shown in Table 4.4.

Table 4.4 Summary statistics for the alternative measures of crime

Measure	Crime Type	Min	Max	Mean	Standard Deviation
LQ	Contact Crimes	0.02	1.70	0.90	0.32
	Contact Related Crimes	0.09	1.60	1.00	0.29
	Property Related Crimes	0.19	1.70	1.00	0.30
	Other Serious Crimes	0.19	3.30	0.90	0.39
	Crime detected as a result of police action	0.13	3.40	1.00	0.57
TI	Contact Crimes	0.06	0.49	0.29	0.09
	Contact Related Crimes	0.01	0.09	0.06	0.02
	Property Related Crimes	0.02	0.56	0.16	0.09
	Other Serious Crimes	0.05	0.80	0.23	0.09
	Crime detected as a result of police action	0.05	0.46	0.27	0.08
HHI	Contact Crimes	0.12	0.98	0.18	0.13
	Contact Related Crimes	0.09	0.56	0.10	0.10
	Property Related Crimes	0.11	0.73	0.13	0.13
	Other Serious Crimes	0.11	0.73	0.13	0.13
	Crime detected as a result of police action	0.11	0.73	0.13	0.13
SI	Contact Crimes	0.03	0.25	0.14	0.05
	Contact Related Crimes	0.00	0.05	0.03	0.01
	Property Related Crimes	0.03	0.23	0.13	0.04
	Other Serious Crimes	0.02	0.40	0.11	0.05
	Crime detected as a result of police action	0.01	0.28	0.07	0.05
EI	Contact Crimes	0.06	0.49	0.29	0.09
	Contact Related Crimes	0.01	0.09	0.06	0.02
	Property Related Crimes	0.05	0.46	0.27	0.08
	Other Serious Crimes	0.05	0.80	0.23	0.09
	Crime detected as a result of police action	0.02	0.56	0.16	0.09

4.2.1.1 Summary statistics for LQ

According to the LQ statistic, the police districts with the highest values are, Diepsloot for contact crimes with a value of 1.7, Vaal Marina in contact related crimes category with a value of 1.6, Garsfontein for property related crimes with a value of 1.7, OR Tambo Intern Airport for other serious crimes with a values of 3.3 and Sharpeville in crimes detected as a result of police action with a value of 3.4. The police districts with the lowest LQ values are the OR Tambo Intern Airport in contact crimes with a value of 0.02, the Sebenza police district in contact related crimes with a value of 0.09, the OR Tambo Intern Airport in crimes detected as a result of police action with a value of 0.19, the Boipatong police district in other serious crimes and Boschkop in property related crimes with a values of 0.19. The means are generally close to 1 which means that on average police districts almost specialise in that crime type. Contact related crimes have highest mean of 1.00 and a standard deviation of 0.29. Contact crimes have the lowest mean of 0.90 and a standard deviation of 0.32.

4.2.1.2 Summary statistics for TI

The TI were analysed, with values ranging from 0 to 1, with values closer to 0 showing a little or no specialisation and values close to 1 showing the presence of specialisation. According to the TI values the police districts with the highest values are, Diepsloot in contact crimes with a value of 0.49, Vaal Marina in contact related crimes with a value of 0.09, Garsfontein in property related crimes with a value of 0.56, Sandton in other serious crimes with a values of 0.80 and Sharpeville in crimes detected as a result of police action with a value of 0.46. The police districts with the lowest TI values is the OR Tambo International Airport in contact crimes with a value of 0.06, the Sebenza police district in contact related crimes with a value of 0.01, Boschkop in crimes detected as a result of police action with a value of 0.05, the Boipang police district in other serious crimes with a value of 0.05, and OR Tambo International Airport in property related crimes with a values of 0.05. Contact crimes have the highest mean of 0.29 and a standard deviation of 0.09. Contact related crimes have the lowest mean of 0.06 and a standard deviation of 0.02.

4.2.1.3 Summary statistics for HHI

The summary of the statistics of the HHI of crime is shown in Table 4.4. The HHI were, with values ranging from 0 to 1, with values closer to 0 showing little specialisation and values closer to 1 showing specialisation of crime in that police district. According to the HHI values the police districts with the highest values are, Johannesburg Central in contact crimes with a value of 0.98, Hillbrow in contact related crimes with a value of 0.56, Garsfontein in property related crimes with a value of 0.73, Johannesburg Central in other serious crimes with a values of 0.73 and Honeydew in crimes detected as a result of police action with a value of 0.74. The police districts with the lowest HHI values are the Vaal Marina in contact crimes with a value of 0.12, the Kliprivier police district in contact related crimes with a value of 0.09, the Vaal Marina in crimes detected as a result of police action with a value of 0.11, the Wedela police district in other serious crimes with a value of 0.11 and Vaal Marina in property related crimes with a values 0.11. The descriptive summary of statistics of the TI identifies that one police district can have two types of crimes dominating or specialising in it. The Johannesburg Central police district has the highest TI (maximum value) of contact crimes (0.98) and other serious crimes (0.73).Vaal Marina has the lowest TI value in three types of crimes namely, property related crimes (0.02), contact crimes (0.06) and in crime detected as a result of police action (0.05). Contact crimes have the highest mean of 0.18 and a standard deviation of 0.13. Contact related crimes have the lowest mean of 0.10 and a standard deviation of 0.10.

4.2.1.4 The summary statistics for SI

According to the SI values the police districts with the highest values are, Diepsloot in contact crimes with a value of 0.25, Vaal Marina in contact related crimes with a value of 0.05, Garsfontein in property related crimes with a value of 0.23, OR Tambo Intern Airport in other serious crimes with a values of 0.40 and Sharpeville in crimes detected as a result of police action with a value of 0.28. The police districts with the lowest SI values are the OR Tambo Intern Airport in contact crimes with a value of 0.03, the Sebenza police district in contact related crimes with a value of 0.002, the OR Tambo Intern Airport in crimes detected as a result of police action with a value of 0.01, the Boipatong police district in other serious crimes with a SI value of 0.02 and Boschkop in property related crimes with a values of 0.03. Contact crimes have the highest mean of 0.14 and a standard deviation of 0.05. Contact related crimes have the lowest mean of 0.03 and a standard deviation of 0.01.

4.2.1.5 Summary Statistics for EI

The summary of the statistics of the EI of crime is shown in Table 4.4. The EI were analysed using the quantile classification, with values ranging from 0 to 1, with values closer to 0 showing a little or no specialisation and values close to 1 showing the presence of specialisation. According to the EI values the police districts with the highest values are, Diepsloot in contact crimes with a value of 0.49, Katlehong North in contact related crimes with a value of 0.09, Garsfontein in property related crimes with a value of 0.46, OR Tambo Intern Airport in other serious crimes with a values of 0.80 and Sharpeville in crimes detected as a result of police action with a value of 0.56. The police districts with the lowest EI values are the OR Tambo Intern Airport in contact crimes with a value of 0.06, the Kliprivier police district in contact related crimes with a value of 0.01, the Boschkop in crimes detected as a result of police action with a value of 0.02, the Wedela police district in other serious crimes with a value of 0.05 and OR Tambo Intern Airport in property related crimes with a value of 0.05. Contact crimes have the highest mean of 0.29 and a standard deviation of 0.09. Contact related crimes have the lowest mean of 0.06 and a standard deviation of 0.02.

4.2.2 Correlation analysis for alternative measures

Table 4.5 Pearson's bivariate correlation: crime count and alternative measures of crime by types of crime

Crime Type	Measure	Crime Count	LQ	TI	HHI	SI	EI
Contact Crimes	Crime Count	1					
	LQ	0.42	1				
	TI	0.40	0.97	1			
	HHI	0.73	0.92	0.35	1		
	SI	0.42	0.93	0.97	0.37	1	
	EI	0.40	0.94	0.97	0.36	0.99	1
Contact Related Crimes	Crime Count	1					
	LQ	0.34	1				
	TI	0.34	1	1			
	HHI	0.85	0.58	0.60	1		
	SI	0.35	1	0.58	0.58	1	
	EI	0.35	0.98	0.98	0.55	0.98	1
Property Related Crimes	Crime Count	1					
	LQ	0.27	1				
	TI	0.27	1	1			
	HHI	0.75	-0.7	0.75	1		
	SI	0.27	1	1	-0.75	1	
	EI	0.27	0.99	0.99	-0.75	0.99	1
Other Serious Crimes	Crime Count	1					
	LQ	0.51	1				
	TI	0.52	1	1			
	HHI	0.87	-0.8	-0.82	1		
	SI	0.52	1	1	0.99	1	
	EI	0.52	0.99	0.99	0.8	0.99	1
Crime detected as a result of police action	Crime Count	1					
	LQ	0.54	1				
	TI	0.54	1	1			
	HHI	0.83	0.71	0.72	1		
	SI	0.54	1	1	0.71	1	
	EI	0.55	0.99	0.99	0.71	0.72	1

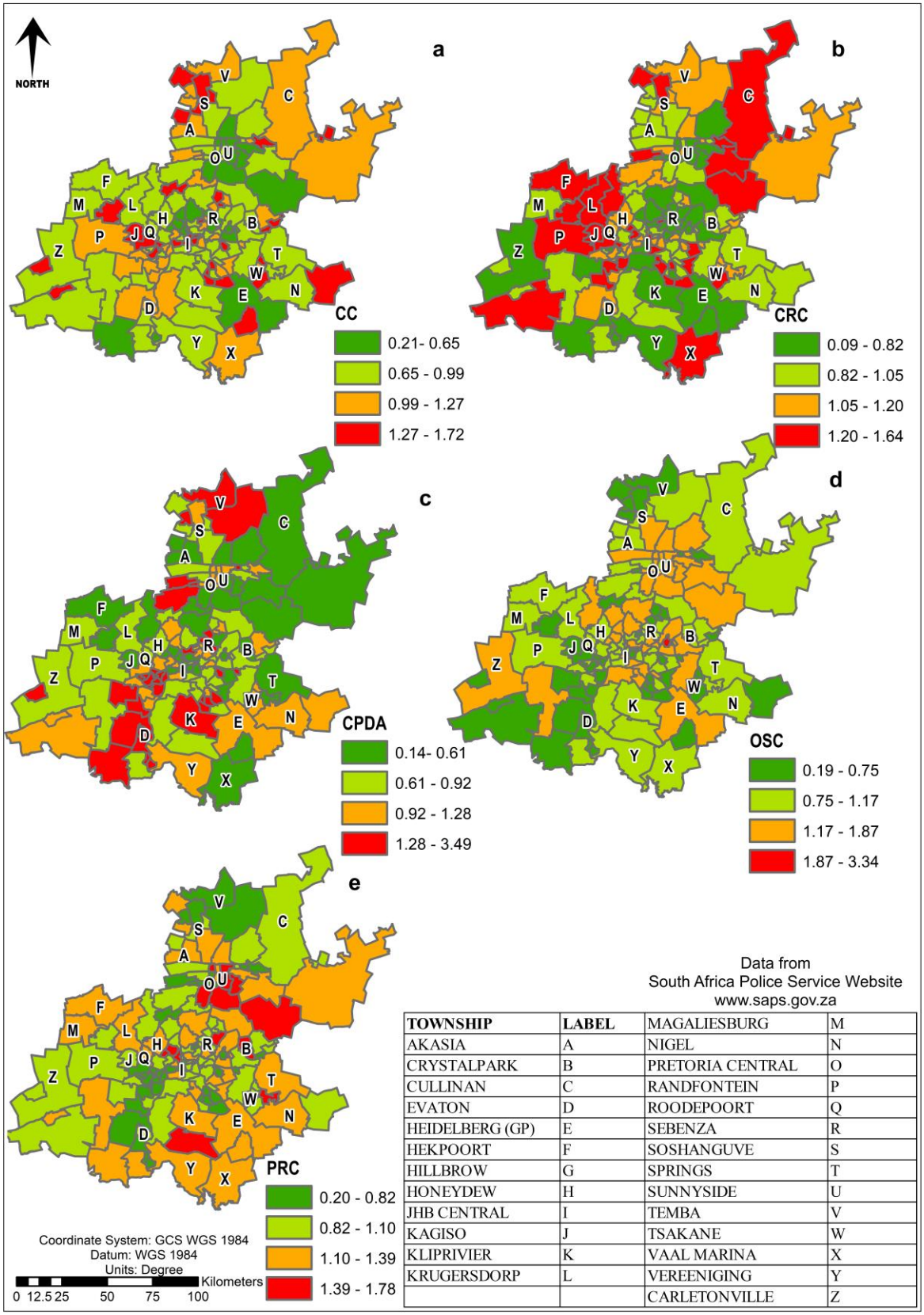
Table 4.5 displays the results of correlation analysis of "crime count" and the five alternative measures of crime (LQ, TI, HHI, SI and EI) for all the five types of crimes. The five alternative measures show significant positive relationships with some moderate values and a few negative bivariate associations. Correlation can take any value in the range of -1 to +1. Correlation coefficient of 0 indicates that there is no relationship between the variables. Correlation coefficient of 0.34 indicates a small or weak correlation. Correlation coefficient of 0.7 indicates that there is a medium or moderate correlation and a correlation coefficient of 0.99 indicates that there is a large of strong correlation between the variables. The direction of the correlations can be either positive or negative, a negative correlation corresponds to a decreasing relationship, while and a positive correlation corresponds to an increasing relationship. In general, the five alternative measures of crime show similar bivariate analysis results for all five-crime types. In all five types of crimes the crime counts are strongly related to the HHI. The relationship of the LQ , TI, SI and EI are different in the crime types ranging from weak to strong relationships. For this reason and considering that the LQ is the most widely used of the alternative measures focus is given to the LQ in the rest of the report and highlights of the other alternative measure are provided where necessary.

4.2.3 Spatial distributions based on alternative measures of crime

4.2.3.1 Spatial distribution of LQ

Figure 4.3 shows how the LQ values for the five types of crimes are spatially distributed using the quantile classification and 4 classes. The LQ shows that the five alternative measures of crime are differently distributed across Gauteng, indicating that police districts are affected by different crimes. The areas shaded in red are areas that have far more incidents for that crime type than the province as a whole. The police districts such as Kagiso (J) and Soshanguve (S) highly specialise in contact crimes. Contact related crime is also dispersed over the province. The police districts which highly specialise in contact related crimes are Krugersdorp (L) and Hekpoort (F). The crimes detected as a result of police action are highly dominant in police districts such as, Temba (V), Evaton (D), and Kliprivier (K). Edenvale police district specialises in other serious crimes, while Pretoria Central (O) and Sunnyside (U) specialises in property related crimes. The spatial distribution shown in Figure 4.3 show that there is potential clustering of specialisation in contact related crimes and the crimes detected as a result of police action.

The spatial distribution of the other alternative measure of crime are presented in Appendix A (Figure A1 to Figure A4). Crime counts (Figure 4.1) have similar distribution to the HHI (Figure A2). The LQ (Figure 4.3), TI (Figures A1), SI (Figures A3) and the EI (Figures A4) also have a similar distribution to each other. Although the five alternative measures may show different spatial distribution with the crime counts, they have common districts of concentration of specialisation.



TOWNSHIP	LABEL	MAGALIESBURG	M
AKASIA	A	NIGEL	N
CRYSTALPARK	B	PRETORIA CENTRAL	O
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure 4.3 Spatial Distribution of LQ of Crime. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.

4.2.4 Global Autocorrelation tests for Alternative Measures of Crime

Table 4.6 Moran's I statistic from tests for spatial autocorrelation based on alternative measures of crime

Crime Category[+]	LQ	TI	HHI	SI	EI
Contact Crimes	0.1253	0.0818	0.0743	0.1266	0.1258
Contact-Related Crimes	0.1254	0.0932	0.1057	0.1113	0.0109
Property Related Crimes	0.1238	0.1169	0.0984	0.1235	0.1245
Other Serious Related Crimes	0.1516	0.0936	0.0719	0.0153	0.1534
Crime Detected as a Result of Police Action	0.2575	0.0281	0.1552	0.2571	0.2562

[+]All results are statistically significant (*p-value* < 0.05)

Moran's I was used to analyse if spatial autocorrelation is present in the five types of crimes using the LQ (Table 4.6). We can conclude that all values are positive and significant as the values range from -1 to +1. The closer the value to 0, the weaker it is, while the close it is to +/-1, the stronger it is. The spatial autocorrelation is present in all five alternative measures of crime and in all the five types of crimes. The conclusion is similar for the Moran's I statistics related to all the five crime categories base on the LQ, TI, HHI, SI and EI (Table 4.6). The Moran's I values are all positive, with the highest value attributed to LQ for crimes detected as a result of police action (0.2575) and the lowest attribute to the EI for contact related crimes (0.0109).

4.2.5 LISA for Alternative Measures of Crime

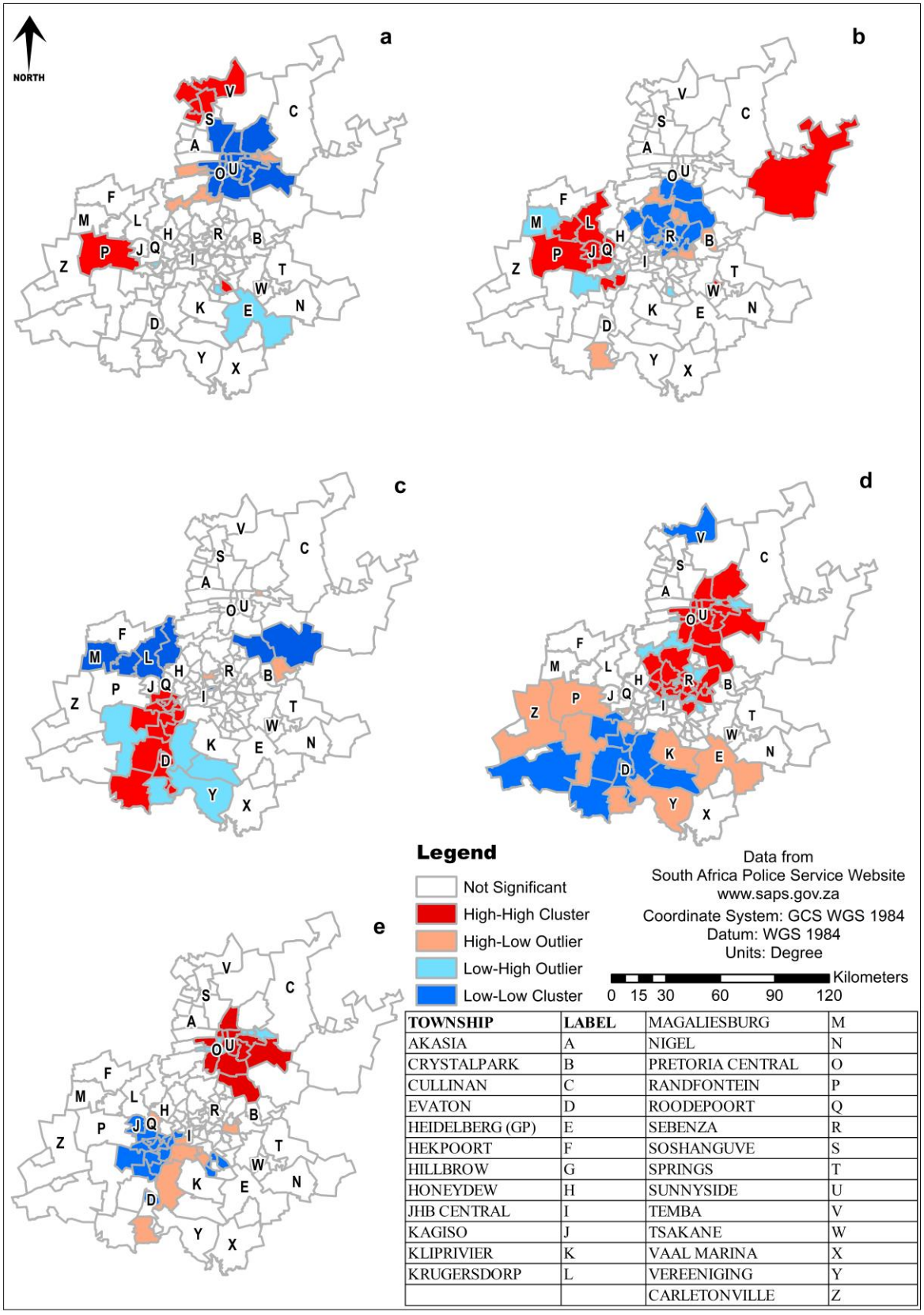
4.2.5.1 LISA for the LQ

Figure 4.4 shows the police districts that are hot spots (high-high) and cold spots (low-low) clusters and hot spot (high-high) and cold spots (low-low) outliers and Table 4.7 outlines how many clusters and outliers each crime type has. Figure 4.4 (A) and Table 4.7 show that contact crimes have 6 police districts which are clusters of hot spots and 15 police districts are clusters of low-low(cold spots). Figure 4.4 (B) and Table 4.7 reveal contact related crimes have 7 police districts which are clusters of high-high LQ values (cold spots) and 16 police districts which are cold spots. Figure 4.4 (C) and Table 4.7 show that property related crimes have 14 police districts which are clusters of high-high (hot spots) values and 22 police districts which are clusters of low-low (cold spots) values. Figure 4.4 (D) and Table 4.7 show that for other serious

crimes 14 police districts are clusters of high-high (hot spots) and 21 police districts are clusters of low-low values (cold spots). The hotspots for contact crimes are clustered in the north western part of the City of Tshwane municipality and in the West Rand district whereas cold spots are concentrated in the central part of the City of Tshwane municipality. The hotspots for contact related crimes are clustered in the central of West Rand district whereas coldspots are clustered in the City of Johannesburg municipality. The hotspots for crimes detected as a result of police action are clustered in the southern part of the Sedibeng District where as coldspots are clustered in the West Rand District and the City of Ekurhuleni municipality. The hotspots for the other serious crimes are clustered in the City of Tshwane municipality whereas coldspots are clustered in the West Rand district. The hotspots for the property related crimes are clustered in the central of the City of Tshwane municipality whereas coldspots are located in the West Rand District.

Table 4.7 show that contact crimes have 6 police districts which are clusters of high-lows and 3 police districts are clusters of low-high. Contact related crimes have 9 police districts which are clusters of high-lows and 8 police districts are clusters of low-high. Crimes detected as a result of police action have 3 police districts which are clusters of high-lows and 5 police districts are clusters of low-high. Other serious crimes and property related crimes have 9 police districts which are clusters of high-lows and 5 police districts are clusters of low-high.

The police districts with the hot spots are all located in the metropolitan municipalities which are the City of Tshwane and the City of Johannesburg municipality which are high density areas as they have high numbers of population in the country. The City of Tshwane being the municipality that has the capital city of the country and the City of Johannesburg being the municipality that has the biggest economic hub in the county. The cold spots are mostly located in the West Rand and Sedibeng Districts which are low density areas and are not economic hubs as compared to the metropolitan area. The West Rand and the Sedibeng District are mostly composed of residential and industrial uses whereas the metropolitan which have hot spots are mostly a mix use of business, industrial and residential uses.



TOWNSHIP	LABEL	MAGALIESBURG	M
AKASIA	A	NIGEL	N
CRYSTALPARK	B	PRETORIA CENTRAL	O
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure 4.4 LISA Maps for showing spatial clusters and outliers based on LQ of crime. (a): contact crimes, (b): contact-related crimes, (c) crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.

Finally, Figure 4.4 (E) and Table 4.7, show that crime detected as a result of police action have 18 police districts which are clusters of high-high values (cold spots) and 9 police districts which are clusters of low-low (cold spots). In addition, the hotspots of crime based on the LQ appear to cluster in different parts of the province.

Table 4.7 Summary of LISA classes for the five types of crimes by alternative measures of crime

Measure	Crime Type	LISA Class				
		HH	HL	LH	LL	NS
LQ	Contact Crimes	6	6	3	15	113
	Contact Related Crimes	7	9	8	16	103
	Property Related Crimes	14	9	5	22	93
	Other Serious Crimes	14	9	5	21	94
	Crime detected as a result of police action	18	3	5	9	108
TI	Contact Crimes	6	6	2	17	112
	Contact Related Crimes	7	10	7	20	99
	Property Related Crimes	13	6	5	23	96
	Other Serious Crimes	19	5	10	19	90
	Crime detected as a result of police action	12	4	6	12	105
HHI	Contact Crimes	15	1	17	3	107
	Contact Related Crimes	18	1	13	8	103
	Property Related Crimes	17	0	8	8	110
	Other Serious Crimes	12	1	15	9	106
	Crime detected as a result of police action	16	3	8	14	102
SI	Contact Crimes	5	6	2	16	114
	Contact Related Crimes	8	8	6	16	105
	Property Related Crimes	12	8	5	20	98
	Other Serious Crimes	33	9	14	14	73
	Crime detected as a result of police action	19	3	5	9	107
EI	Contact Crimes	7	6	2	17	111
	Contact Related Crimes	12	11	5	12	103
	Property Related Crimes	15	9	5	22	92
	Other Serious Crimes	34	9	13	16	71
	Crime detected as a result of police action	19	2	5	8	109

The spatial distribution of LISA values for the TI (Figure A5), HHI (Figure A6), SI (Figure A7) and EI (Figure A8) are in Appendix A. The LISA distributions of the five types of crimes based on the LQ (Figure 4.4), TI (Figure A5) and the EI (Figure A8) have similar spatial distributions of LISA values. The SI (Figure A7) and the HHI (Figure A6) have similar spatial distribution of LISA values. Table 4.7 show that the five measures of crimes have different

numbers of HH and LL values. For some crime type such as contact crime and contact related crime, the number of districts with High-High (HH) LISA values are similar when LQ, TI and SI while the HHI have a higher number of HH LISA clusters for these two crime types. The TI and the EI have the same pattern as the LQ hot spot and cold spot clusters. Their hotspots in contact crimes are clustered in the north western part of the City of Tshwane municipality and in the West Rand district while cold spots are clustered in the City of Tshwane municipality. Their hotspots in contact related crimes are clustered in the central of West Rand district while the coldspots are clustered in the City of Johannesburg municipality. Their hotspots in crimes detected as a result of police action are clustered in the southern part of the Sedibeng District whereas coldspots are clustered in the West Rand District and the City of Ekurhuleni municipality. The hotspots for the other serious crimes are clustered in the City of Tshwane municipality while coldspots are clustered in the West Rand district. The hotspots for the property related crimes are clustered in the central of the City of Tshwane municipality whereas coldspots are located in the West Rand District.

The SI and the HHI have the same pattern of cold spots and hot spots clustering, which is different from the LQ, TI and the EI. The hotspots of SI and TI, in contact crimes are clustered in the central part of the City of Johannesburg municipality whereas the coldspots are clustered in the West Rand district. The hotspots of contact related crimes are clustered in the central of the City of Johannesburg municipality and the cold spots are clustered in the Sedibeng district and the West Rand district. The hot spots for the crime detected as a result of police action are clustered in the City of Johannesburg municipality while the cold spots are clustered in the City of Ekurhuleni municipality. The hotspots for the other serious crimes and the property related crimes are clustered in the City of Johannesburg municipality while the coldspots are concentrated in the Sedibeng and the West Rand district.

The hotspots of all the five types of crimes seem to be located in the City of Johannesburg municipality. The clustering townships in the municipality are the Johannesburg Central, Hillbrow, Jeppe, Yoeville, Holeydew, Roodeport, Sandton and Roodeport townships. These townships are the mostly highly dense as they have large population numbers of people either residing or working in them. The City of Johannesburg is the economic and financial hub of South Africa. The city also faces high levels of unemployment hence crime is bound to concentrate in its townships.

4.3 Shift-share analysis

The short-term spatial temporal changes in the patterns of crime using the shift-share analysis was calculated with a focus on the changes between 2014 and 2016. The analyses were based only on crime counts and were done to consider the components that contribute to crime increase or decrease of crime. Results from the shift-share analysis (Table 4.8) show that there are positive and negative changes in crimes from 2014 to 2016. Contact crimes increased in recorded counts, while the contact related crimes, property related crimes, other serious crimes and crimes detected as a result of police action decreased over the 2-year period. The contact crimes increased by 4202 incidents or 2% whereas the highest decrease in the other categories can be attributed to other serious crimes which decreased by 12846 incidents (a decrease of 9%) between 2014 and 2016. The results for these two categories are presented in the following paragraphs to illustrate how the spatial patterns of an overall positive and that of an overall negative change can be interpreted.

Table 4.8 Shift-share analysis from year 2014 to 2016

	2014	2016	National Share	Industry Mix	Regional Shift	Total Change in Crime 2014-2016
Contact Crimes	167264	171466	-4482.15	8684.15	1.07E-13	4202
Contact-Related Crimes	35847	34023	-960.59	1861.13	-2724.55	-1824
Other Serious Crimes	155820	142974	-4175.48	-8670.52	-6.6791E-13	-12846
Property-Related Crimes	155912	154761	-4177.95	3026.95	2.91323E-13	-1151
Crime Detected as A Result of Police Action	100267	95403	-2686.84	-2177.16	-6.96332E-13	-4864

The national share of all the five types of crimes decreased, while the industry mix increased in contact crimes, contact related crimes and property related crimes. The industry mix decreased in other contact crimes and crimes detected as a result of police action. The regional shift also increased in contact crimes and property related crimes while decreasing in contact related crimes, other serious crimes and in crimes detected as a result of police action . The national share explains how much crime growth in a region can be attributed to overall growth rates in the national crime statistics. The industrial mix effect represents the portion of a police district's growth that can be attributed to that industry's national level growth. The regional

competitive effects represent the unique characteristic a particular police district has in a given industry. Sometimes a police district's growth in a given industry outpaces both national crime growth trends and national level growth trends for the industry. This behaviour indicates that there is something unique about the police district causing it to experience a regional competitive effect in that industry. Regional competitive effects can be generated by factors such as geography, legislation or regulation and population characteristics.

The spatial temporal changes in the patterns of crime using the shift-share analysis for contact crimes

Figure A9 displays the spatial temporal changes in contact crimes from 2014 to 2016. It identifies the police districts with the greatest positive and negative change from year 2014 to 2016. The police districts in red (Figure A9 D), are police districts with high positive values which means they have greatly increased in contact crime, while the police districts in green (low values) depict those with great decreases in contact crime from 2014 to 2016. There are 61 police districts that decreased in contact crime and 82 police districts that with increased contact crimes. The police districts that had very high increases in the number of incidents of contact crimes are Vereeniging (Y), Temba (V), Honeydew (H), Randfontein (P) and Krugersdorp (L). The national (Figure A9 A), sectoral (Figure A9 B), and regional effects (Figure A9 C) show the police districts with large increases in red. There are 35 police districts that increased in national effect, 37 police districts that increased in sectoral effect and 36 police districts that increased in regional effect.

The spatial temporal changes in the patterns of crime using the shift-share analysis for other serious crimes

Figure A10 displays the spatial temporal changes from 2014 to 2016 in other serious crimes. The police districts in red (69 police districts) are police districts with high positive values which means they have greatly increased in other serious crimes while the police districts in green (74 police districts with low values) depict a great decrease in other serious crimes from 2014 to 2016 (Figure A10 D). Sandton police district had a high increase while Akasia (A) showed the most decrease. The national (Figure A10 A), sectoral (Figure A10 B), and regional effects (Figure A10 C) show the police districts which strongly increased in them in red. There are 38 police districts that increased in national effect, 35 police districts that increased in sectoral effect and 37 police districts that increased in regional effect.

5 Discussion

5.1 Summary of results

The aim of the research was to analyse the spatial distribution of five types of crimes (contact crimes, contact related crimes, property related crimes, other serious crimes and crimes detected as a result of police action) using traditional and alternative measures of crime analysis and to identify temporal changes in the distribution of crime by analysing the change in crime statistics using the shift-share analysis for the years 2014 and 2016.

The five types of crimes are differently distributed in the province. The contact crimes are scattered in the province with a cluster situated in the City of Johannesburg and the City of Tshwane municipality. The contact related crimes and property related crimes are also scattered in the province with a cluster in the City of Johannesburg and the West Rand District. The other serious crimes are mostly clustered in the City of Ekurhuleni municipality while the crimes detected as a result of police action specialisation clusters were found in West Rand District. The property related crimes, other serious crimes, contact crimes are clustering in the City of Johannesburg municipality in the province. There were crime police districts that showed the prevalence of more than one types of crime. The Pearson's correlation analysis found that four types of crimes (contact crimes, contact related crimes, property related crimes, other serious crimes) are strongly related to each other with a positive strong Pearson value, while crimes detected as a result of police action is related to them with a moderate positive Pearson value.

The alternative measures of crime to analyse show how the five types of crimes are differently distributed in the province. The alternative measure of crime demonstrated that they distribute crimes similarly in the province. The LQ, TI, SI and the EI also have a similar distribution to each other, where they show similar clusters and outliers. The HHI has a similar distribution to the LQ and the crime counts. The five alternative measures show significant positive relationships with some moderate values and a few negative bivariate associations. The HHI have a strong negative relationship towards the LQ and the TI, the crime counts are strongly related to the HHI, while the LQ is strongly related to TI, and the SI strongly related to EI. A decision was made to focus on the LQ in the rest of the report.

The Moran's I statistic showed that positive spatial autocorrelation was present in all the five types of crimes. The LISA showed that clusters of high-high (hot spots) and clusters of cold spots (low-low) where found in all the five types of crimes and in all the alternative measures of crimes. The Moran's I statistic showed that positive spatial autocorrelation was present in all the five types of crimes based on the LQ statistic. The LQ for the different types of crimes also exhibited clusters of hot spots, cold spots. Hot spots show the police districts that are affected by the same crimes which are close to each other, cold spots show the police districts and its surrounding police districts which are not affected by the type of crime. This is similar to the decision that was made in Andresen (2014), when measuring specialisations and concentration using these five alternative measures of crime. The LQ, TI and the EI showed a similar spatial distribution of their LISA values, while the SI and the HHI had similar spatial distribution of LISA values.

Figure 5.1 shows how each police district specialises in a particular type of crime (the dominant crime, based on the largest value of the LQ). Based on visual inspection, contact crimes exhibit some clustering in the City of Tshwane municipality. Contact related crimes are mostly located in the City of Johannesburg and the West Rand District. Property related crimes exhibits some clustering in the City of Johannesburg as well as in police districts located in the City of Tshwane municipality. Other serious crimes are mostly clustered in the City of Ekurhuleni municipality. Crimes detected as a result of police action cluster in the Sedibeng District.

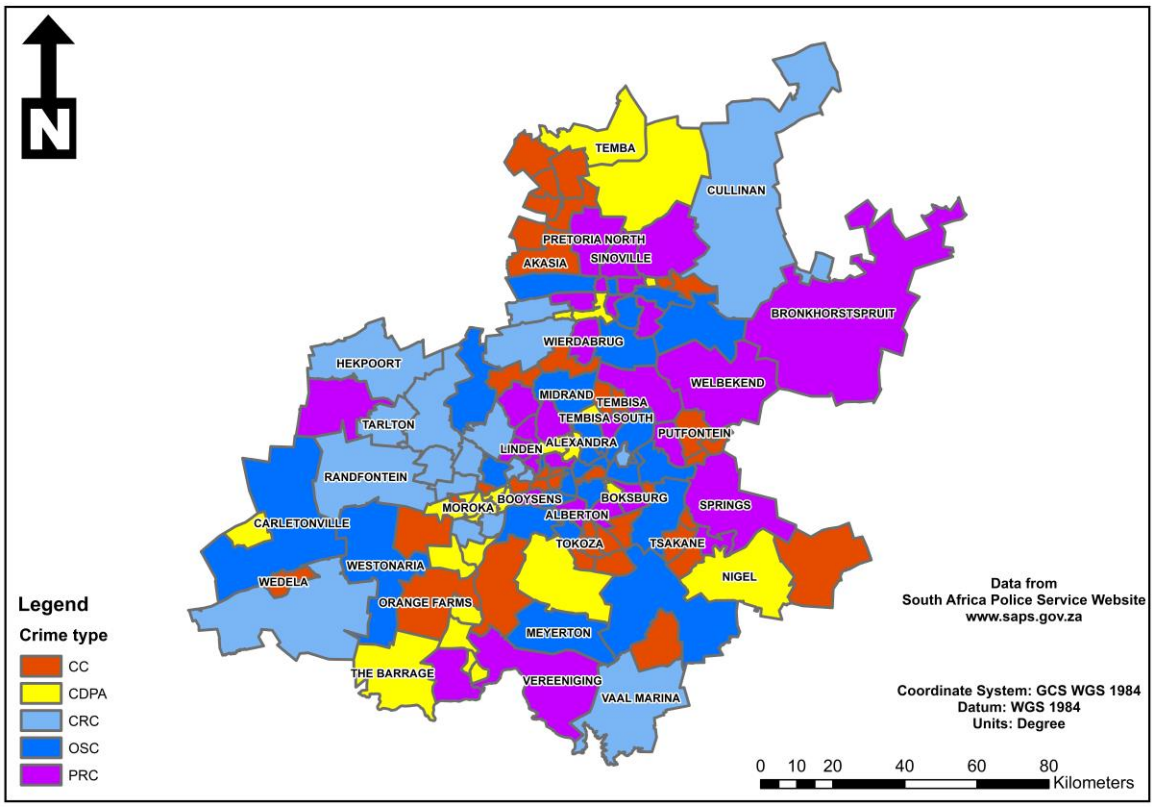


Figure 5.1 The dominant crimes categories in each police districts in Gauteng (CC=Contact Crimes, CRC=Contact Related Crimes, CDPA=Crimes Detected as a Result of Police Action, OSC=Other Serious Crimes, PRC=Property Related Crimes, TI=Theil Index)

5.2 Focus areas for intervention

The traditional and the five alternative measures showed how the five types of crimes are spatially distributed in the province. Table 5.1 shows that similar police districts are included in the top 5 across most crime categories and of for most of the alternative measures of crimes. In other words, Figure 5.1 show the police districts where crime concentrate or specialise and where attention is needed.

Table 5.1 shows the top five police districts in Gauteng for five crime types by alternative measures of crime. The alternative measures of crime show the five top police districts that are dominant in each type of crime. The alternative measures show common district being in the top five, for example in contact crimes, Diepsloot police district is found in the top five of crime counts, LQ, TI, SI and EI measures. Zonkizizwe police district is also in the top five of the alternative measures LQ, EI, SI and EI. In contact related crimes, the Kagiso police district is found in the top five of all the five alternative measures of crime. In Crime detected as a

result of police action, Sharpeville police district is found in the top five of alternative measures LQ, TI, SI and EI. In other serious crimes, the Or Tambo Airport police district is found in the top five of alternative measures LQ, TI, SI and EI. In property related crimes, the Parkview police district is found in the top five of alternative measures LQ, TI, SI and EI.

The alternative measures LQ, TI, SI and EI, have common police district being in their top five , while the crime counts and the HHI share common police district. This shows that the four (LQ, TI, SI and EI) alternative measures of crime show a similar spatial distribution of crime over Gauteng and the crime counts and the HHI also show a similar spatial distribution of crime.

Table 5.1 Top five police districts in Gauteng for five crime types by alternative measures of crime

Crime Type	Top 5 areas	Crime Count	LQ	TI	HHI	SI	EI
Contact Crimes	1	Edenvale (565)	Diepsloot (1.72)	Diepsloot (0.49)	Johannesburg Central (0.98)	Diepsloot (0.24)	Diepsloot (0.49)
	2	Olifantsfontein (549)	Zonkizizwe (1.64)	Zonkizizwe (0.47)	Hillbrow (0.94)	Zonkizizwe (0.23)	Zonkizizwe (0.47)
	3	Garsfontein (535)	Kagiso (1.59)	Kagiso (0.45)	Kagiso (0.91)	Kagiso (0.23)	Kagiso (0.46)
	4	Westonaria (530)	Jeppe (1.58)	Jeppe (0.44)	Honeydew (0.8)	Jeppe (0.22)	Jeppe (0.45)
	5	Ratanda (520)	Yeoville (1.54)	Etwatwa (0.44)	Moroka (0.8)	Etwatwa (0.22)	Etwatwa (0.44)
Contact Related Crimes	1	Hillbrow (832)	Vaal Marina (1.08)	Vaal Marina (0.09)	Hillbrow (0.27)	Vaal Marina (0.04)	Kaltehong North (0.09)
	2	Honeydew (827)	Zonkizizwe (1.63)	Zonkizizwe (0.09)	Honeydew (0.26)	Zonkizizwe (0.04)	Vaal Marina (0.09)
	3	Kagiso (704)	Kagiso (1.59)	Kagiso (0.08)	Kagiso (0.25)	Kagiso (0.04)	Hekpoort (0.09)
	4	Dobsonville (632)	Katlehong North (1.55)	Hekpoort (0.08)	Dobsonville ((0.24)	Hekpoort (0.04)	Zonkizizwe (0.09)
	5	Sunnyside (610)	Hekpoort (0.85)	Katlehong North (0.8)	Sunnyside (0.24)	Katlehong North (0.4)	Kagiso (0.09)
Crime detected as a result of police action	1	Eldorado Park (2515)	Sharpville (0.62)	Sharpville (0.55)	Eldorado Park (0.73)	Sharpville (0.27)	Sharpville (0.56)
	2	Pretoria Central (2285)	Boipang (3.31)	Boipang (0.52)	Pretoria Central (0.73)	Boipang (0.26)	Boipang (0.53)
	3	Kliptown (2189)	Katlehong (2.5)	Katlehong (0.3)	Kliptown (0.68)	Katlehong (0.19)	Katlehong (0.4)
	4	Moroka (2066)	Sebokeng (2.46)	Sebokeng (0.3)	Moroka (0.67)	Sebokeng (0.18)	Sebokeng (0.39)
	5	Temba (2007)	Kliptown (2.32)	Kliptown (0.3)	Temba (0.66)	Kliptown (0.17)	Kliptown (0.37)
Other Serious Crimes	1	Johannesburg Central (4603)	Or Tambo Airport (3.34)	Or Tambo Airport (0.79)	Johannesburg Central (0.73)	Or Tambo Airport (0.39)	Or Tambo Airport (0.8)
	2	Sandton (3763)	Rosebank (1.680	Rosebank (0.49)	Sandton (0.73)	Rosebank (0.22)	Rosebank (0.45)
	3	Pretoria Central (3544)	Sandton (1.68)	Sandton (0.4)	Pretoria Central (0.68)	Sandton (0.20)	Sandton (0.40)
	4	Midrand (1741)	Bedford view (1.65)	Bedford view (0.3)	Midrand (0.67)	Bedford view (0.19)	Bedford view (0.39)
	5	Honeydew (3206)	Brooklyn (1.63)	Brooklyn (0.3)	Honeydew (0.68)	Brooklyn (0.19)	Brooklyn (0.39)
Property Related Crimes	1	Honeydew (3655)	Parkview (1.78)	Parkview (0.46)	Honeydew (0.73)	Parkview (0.23)	Parkview (0.46)
	2	Brooklyn (3146)	Garsfontein (1.78)	Garsfontein (0.46)	Brooklyn (0.73)	Garsfontein (0.23)	Garsfontein (0.46)
	3	Sandton (2835)	Wierdaburg (1.77)	Wierdaburg (0.45)	Sandton (0.68)	Wierdaburg (0.22)	Wierdaburg (0.45)
	4	Midrand (2778)	Fairland (1.73)	Fairland (0.44)	Midrand (0.67)	Fairland (0.21)	Fairland (0.44)
	5	Wierdabrug (2771)	Norkempark (1.7)	Norkempark (0.44	Wierdabrug (0.66)	Norkempark (0.20)	Norkempark (0.44)

5.3 Temporal changes in the patterns of crime

The spatial temporal changes in the patterns of crime using the shift-share analysis was calculated over two years from 2014 to 2016. The shift-share analysis found that there were positive and negative changes in crimes in the 2-year period. Contact crimes increased by 4202 recorded crimes from 2014 to 2016. Property related crimes, contact related crimes, other serious crimes and crimes detected as a result of police action all experience short-term decreases between 2014 to 2016.

The five types of crimes are mostly clustered in the central police districts in the City of Johannesburg municipality. The City of Johannesburg municipality has the largest population (4.4 million) in the Gauteng province and the City of Johannesburg Municipality was affected by urbanisation when thousands moved to its cities. The municipality is composed of many buildings particularly in high-density areas, such as Hillbrow, Jhb Central and Marshalltown. Whereas the coldspots are situated in the West Rand and the Sedibeng district which have the lower population and also lower economic opportunities as compared to the City of Johannesburg municipality.

Regarding contact crimes, the top three police districts that increased in crime are Vereeniging, Temba, and Krugersdorp. The police districts that decreased in crime are Heidelberg, Springs, and Nigel police district. With respect to other serious crime, the top three police districts that increased in other serious crimes are Ivory Park, Diepsloot and Midrand police districts. The top police districts that decreased in other serious crimes is Sandton, Jhb Central and Akasia police district. In crime detected as a result of police action, the top three police districts that increased in crime detected as a result of police action crime are namely Sunnyside, Evaton and Randfontein police districts. The top police districts that decreased in crime detected as a result of police action crime are Eldorado Park, Daveyton and Sophia Town police district.

In contact crimes the shift share reveals a decrease at the national level, and an increase on the industry mix and on the regional effect. In contact related crimes the shift shares reveal a decrease at national level, increase on the industry mix and a decrease on the regional level. In property related crimes the shift shares reveal a decrease at national level, increase on the industry mix and an increase on the regional level. In other serious crimes there is a decrease at the national level, regional effect, and the industry mix. In crime detected as a result of police action crime the shift share reveals a decrease at the national level, regional effect and on the industry mix.

6 Conclusions

The analysis shows that contact crimes, contact related crimes, property related crimes and other serious crimes are strongly related to each other and moderately related to crimes detected as a result of police action. The five alternative measures of crime show similar bivariate analysis results for all five-crime types such that crime counts are strongly related to the HHI, while the LQ is strongly related to TI, SI and EI. The alternative measures of crime show similar spatial distribution for the five types of crimes. Contact crimes, property related crimes and contact related crimes were found to cluster in the City of Johannesburg municipality. In addition, some police districts were affected by more than one type of crime e.g. the Honeydew and Sandton police district is affected by contact crimes, other serious crimes and property related crimes. The LQ, TI, SI and the EI exhibited similar spatial patterns in terms of where clusters and outlier police districts are located, while the HHI has a similar distribution to the crime counts.

In terms of spatial temporal changes, both negative and positive changes where observed from the year 2014 to 2016. Contact crimes increased in recorded crimes, while the contact related crimes, property related crimes, other serious crimes and crimes detected as a result of police action decreased. The five types of crimes decreased in national effect. For contact crimes and property related crimes, decreases were observed at the national level, and increases on the regional and industry mix. Contact related crimes decreased at national level, increased on the industry mix and decreased regionally. For other serious crimes and the crimes detected as a result of police action there is were decreases at the national level, industry mix and the regional shift.

6.1 Recommendations and policy implications

The alternative measures of crime help to identify where a particular crime type specialises in a province or country. Identifying districts where a particular crime specialises help improve the fight against crime as it helps the police services to correctly allocate resources to fighting crime in the district and also helps them with developing measures and policies to prevent crime. Once police districts which specialise in a particular crime have been further analysis can be conducted to identify the causes of crime in the district.

As stated in the literature review, crime can occur due to two theories, the social disorganisation theory, and the routine activity theory. When the police districts where a particular crime specialises have been identified, research can be conducted based on the two theories so that strategies of combating crimes can be identified. When correct measures of fighting crime are in place, crime has the possibility of decreasing tremendously (Ratcliffe, 2007).

Based on the results of this research, the traditional and alternative measures can be used in conjunction to further display the spatial distribution of crime in a place, district, or country. The traditional measure crime count seems to show similar results as the HHI measure, while the LQ, TI, SI and EI display similar results of spatial distribution. This shows that other researchers can use these measures in conjunction to understand spatial distribution in a certain given place. When measuring crime spatialisation using the tradition measures and the alternative, the crime counts are best used with the LQ, TI, SI and SI, and HHI excluded as it portrays similar results as the traditional measure. The HHI is best used with the LQ,TI,SI and EI as it will portray result that are similar to the traditional measure and different from the other alternative measures of crime. Crime Counts and HHI can be used separately, a researcher can choose to use both or choose one as they will display similar results, a researcher can also choose to use one of these measures LQ, TI, SI and SI, as they also portray similar results. For example a researcher can use either crime counts and LQ, crime counts and TI, crime counts and EI or use crime counts or SI, or use HHI and LQ, HHI and SI, HHI and EI and HHI and TI to measure spatial distribution using a traditional measure and an alternative measure. HHI can replace crime counts "a traditional measure" as they show similar results.

The social disorganisation theory and the routine activity theory.

The crime counts, and the alternative measures of crime help to identify where a particular crime type specialises in a province or country. Identifying districts where a particular crime specialises help improve the fight against crime as it helps the police services to rightfully allocate resources of fighting crime in the district and also helps them with developing measures and policies to prevent crime. Once police districts which specialise in a particular crime have been identified we can analyse the population which stay within the area to identify the causes of crime in the district. As stated in the literature review, crime can occur due to two theories, the social disorganisation theory and the routine activity theory. The social disorganisation theory and the routine activity theory both analyse the structure of a neighbourhood in relation to criminal activities. The social disorganisation theory states that

socio-economic distresses which include unemployment, poverty and racial issues exclude social cohesion which then results in high volumes of crime (Zhang and Peterson, 2007).

Four of the types of crime; contact crimes, contact related crimes, property related crimes and other serious crimes are clustered in the central police districts in the City of Johannesburg municipality. The City of Johannesburg municipality has the largest population (4.4 million) in the province. The City of Johannesburg Municipality was affected by urbanisation when thousands of people move to its cities to seek for greener pastures. The municipality is composed of many buildings particularly in high-density areas, such as Hillbrow, Jhb Central and Marshalltown.

When the police districts which specialise in a particular crime have been identified, research can be conducted based on the two theories so that strategies of combating crimes can be identified. When correct measures of fighting crime are in place, crime will decrease tremendously.

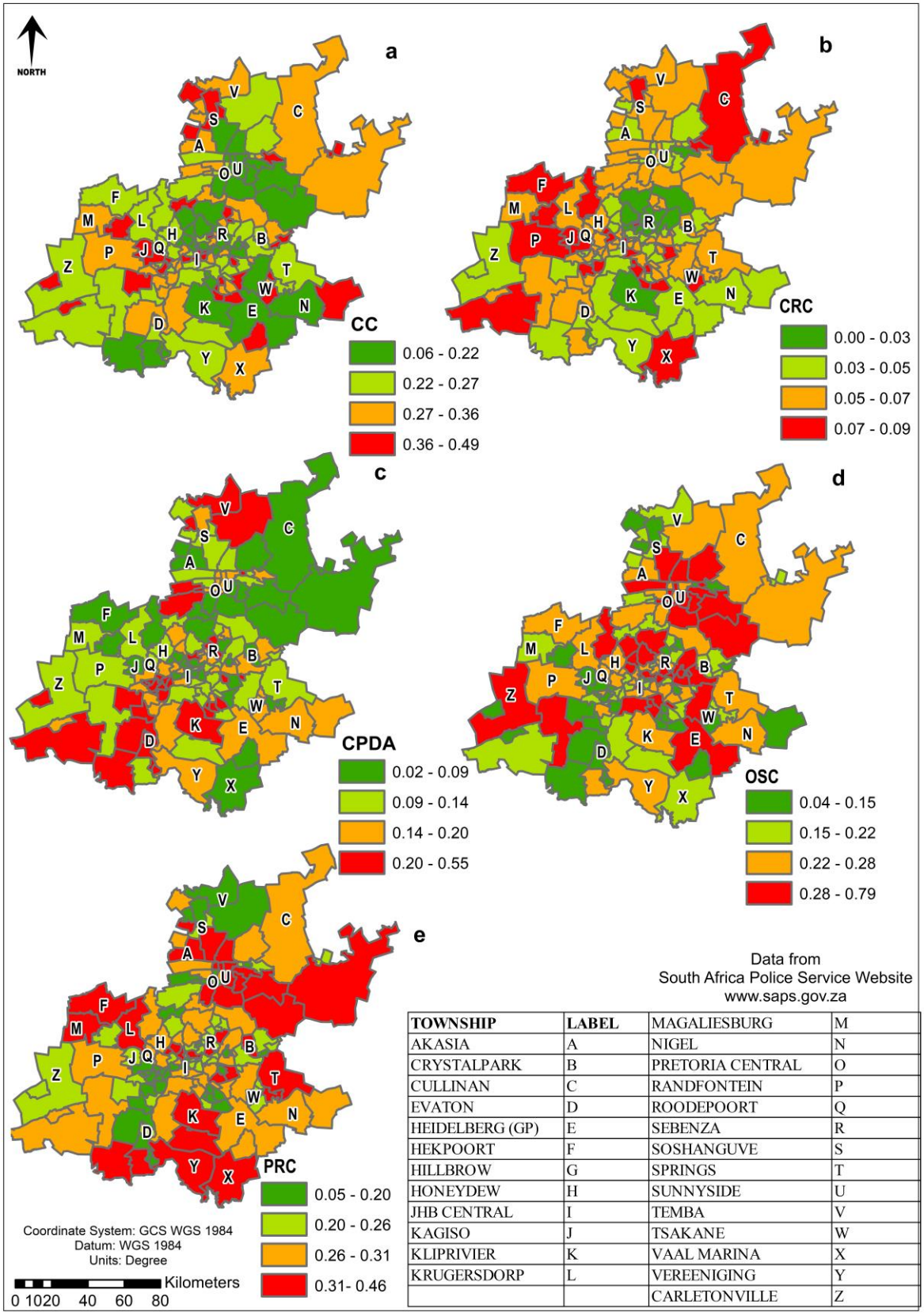
6.2 Limitations

The analysis focused on published aggregate crime data. Incidents that are not reported by victims to the SAPS remain unknown and unrecorded and efforts should be made to include such data when conducting a similar analysis. The research used the five alternative measures of crime to analyse spatial distribution of crime in the province. It is a challenge to compare the five alternative measures as they have different interpretations and ranges. In addition, the quantile classification that was used to display the maps was chosen for convenience and for ease of displaying and comparing mapped values. Future research must consider ways of standardising and mapping alternative measures of crime. In addition, short-term changes considered in this research was conducted based on availability of comparable data and may not show the true dynamics. Future research should consider conducting the shift-share analysis by exploring long-term changes.

Appendix A

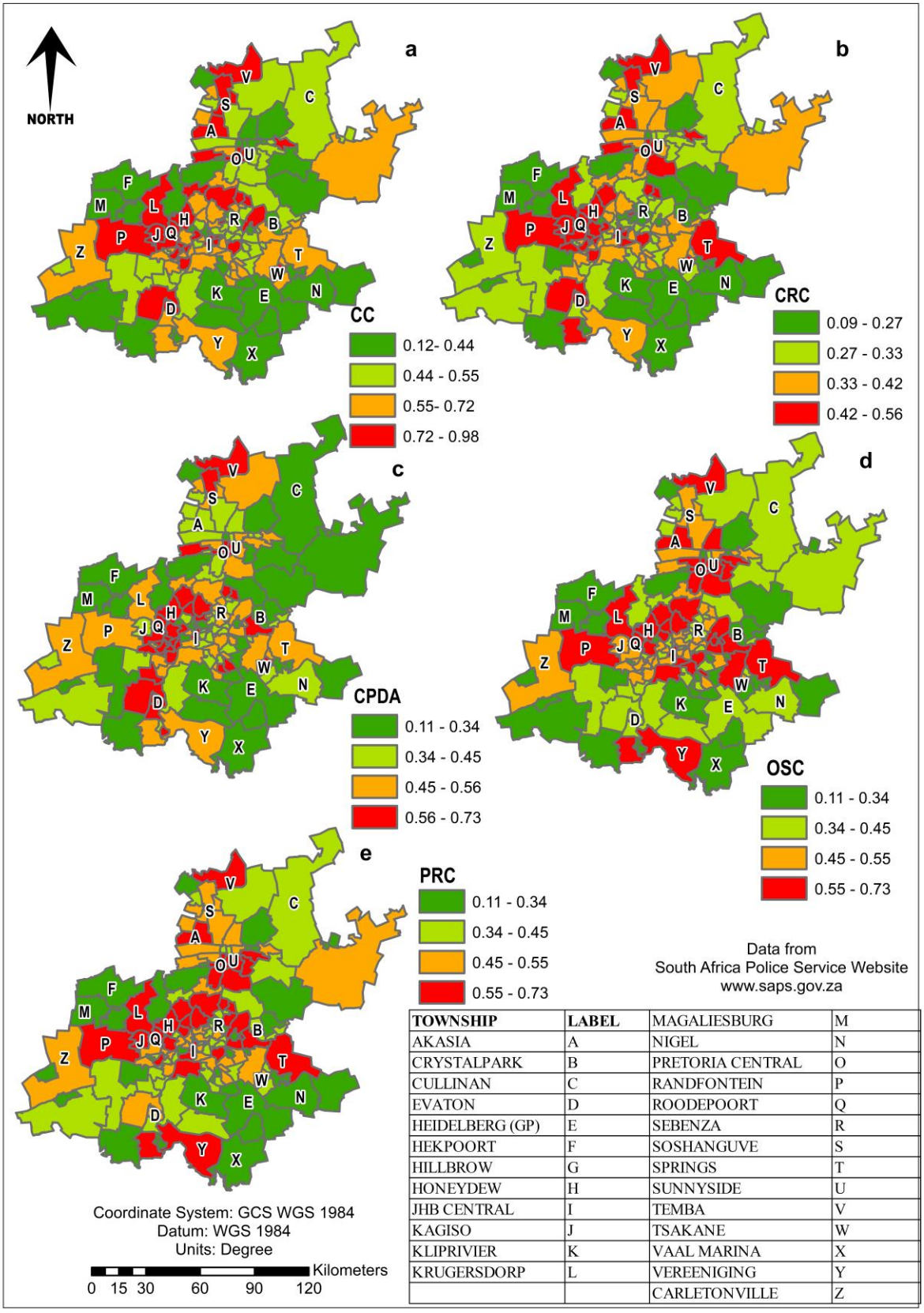
Table A 1 List of Police districts in Gauteng (SAPS, 2017)

City of Johannesburg	City of Tshwane	City Of Ekurhuleni	West Rand District	Sedibeng District
Alexandra	Akasia	Actonville	Bekkersdal	Boipatong
Booysens	Atteridgeville	Alberton	Carletonville	De Deur
Bramley	Boschkop	Bedfordview	Fochville	Evaton
Brixton	Bronkhorstspruit	Benoni	Hekpoort	Heidelberg
Diepkloof	Brooklyn	Boksburg	Magaliesburg	Heidelberg(GP)
Diepsloot	Cullinan	Boksburg North	Muldersdrift	Kliprivier
Dobsonville	Dube	Brackendowns	Randfontein	Meyerton
Douglasdale	Eersterust	Brakpan	Tarlton	Nigel
Eldorado Park	Ekangala	Crystalpark	Westonaria	Ratanda
Ennerdale	Erasmia	Daveyton		Sebokeng
Evaton	Ga-Rankuwa	Dawn Park		Sharpeville
Fairland	Garsfontein	Duduza		The Barrage
Florida	Hammanskraal	Dunnottar		Vaal Marina
Hillbrow	Hercules	Edenpark		Vanderbijlpark
Honeydew	Kameeldrift	Edenvale		Vereeniging
Jabulani	Laudium	Elsburg		Westonaria
Jeppe	Loate	Etwatwa		
Jhb Central	Lyttelton	Germiston		
Kagiso	Mabopane	Ivory Park		
Kliprivier	Mamelodi	Katlehong		
Kliptown	Mamelodi East	Katlehong North		
Krugersdorp	Muldersdrift	Kempton Park		
Langlaagte	Olievenhoutbosch	Kliprivier		
Lenasia	Pretoria Central	Kwa Thema		
Lenasia South	Pretoria Moot	Norkempark		
Linden	Pretoria North	Olifantsfontein		
Meadowlands	Pretoria West	Or Tambo Intern Airp		
Midrand	Rietgat	Primrose		
Moffatview	Silverton	Putfontein		
Mondeor	Sinoville	Rabie Ridge		
Moroka	Soshanguve	Reigerpark		
Naledi	Sunnyside	Springs		
Norwood	Temba	Tembisa		
Olievenhoutbosch	Villieria	Tembisa South		
Orange Farms	Welbekend	Tokoza		
Parkview	Wierdabrug	Tsakane		
Protea Glen	Wonderboompoort	Vosloorus		
Randburg		Zonkizizwe		
Rosebank				
Sandringham				
Sandton				
Sebenza				
Sophia Town				
Yeoville				



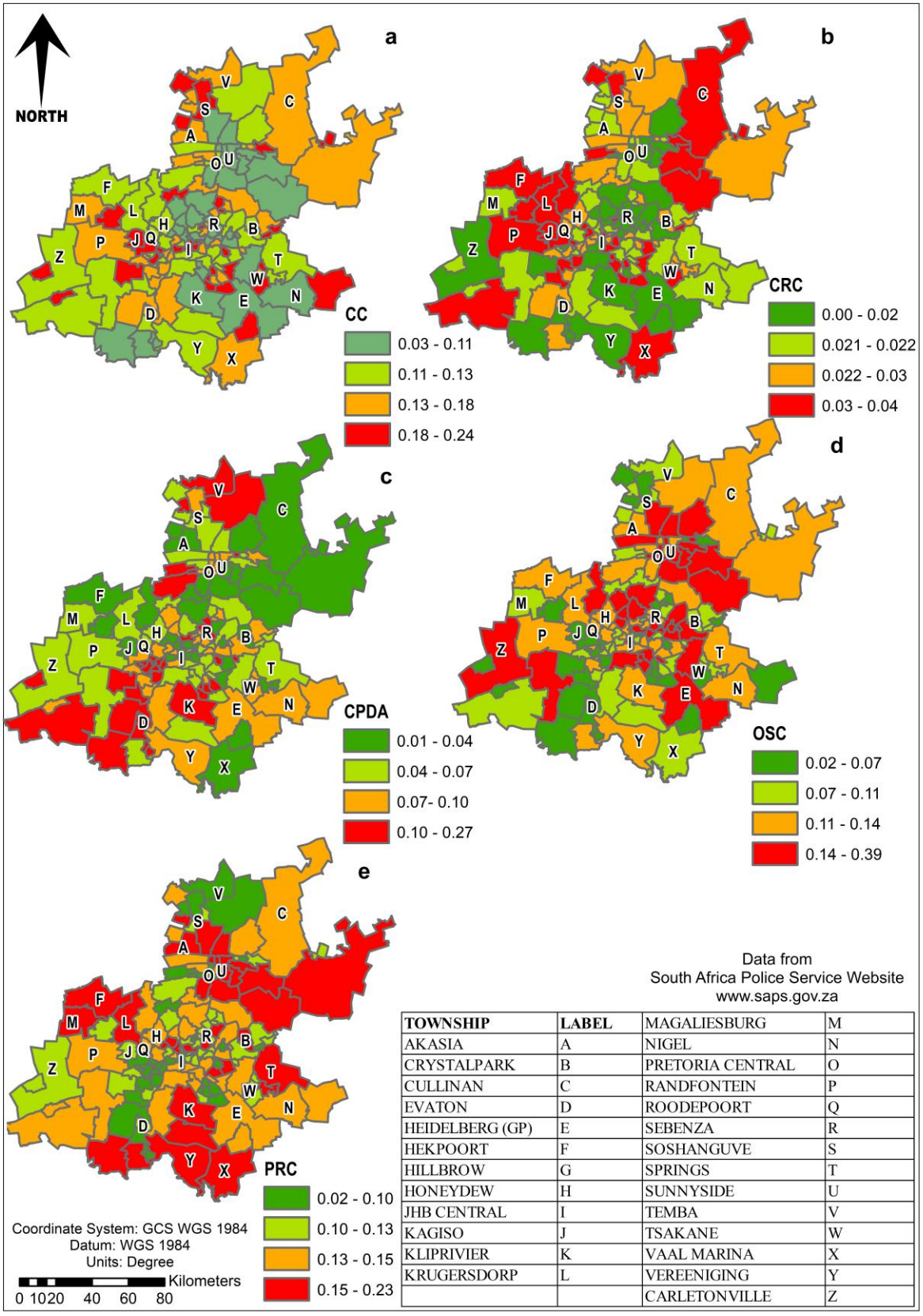
TOWNSHIP	LABEL	MAGALIESBURG	M
AKASIA	A	NIGEL	N
CRYSTALPARK	B	PRETORIA CENTRAL	O
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 1 Spatial Distribution of TI. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action (d): other serious crimes and (e): property-related crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
AKASIA	A	NIGEL	N
CRYSTALPARK	B	PRETORIA CENTRAL	O
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 2 Spatial Distribution of HHI. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
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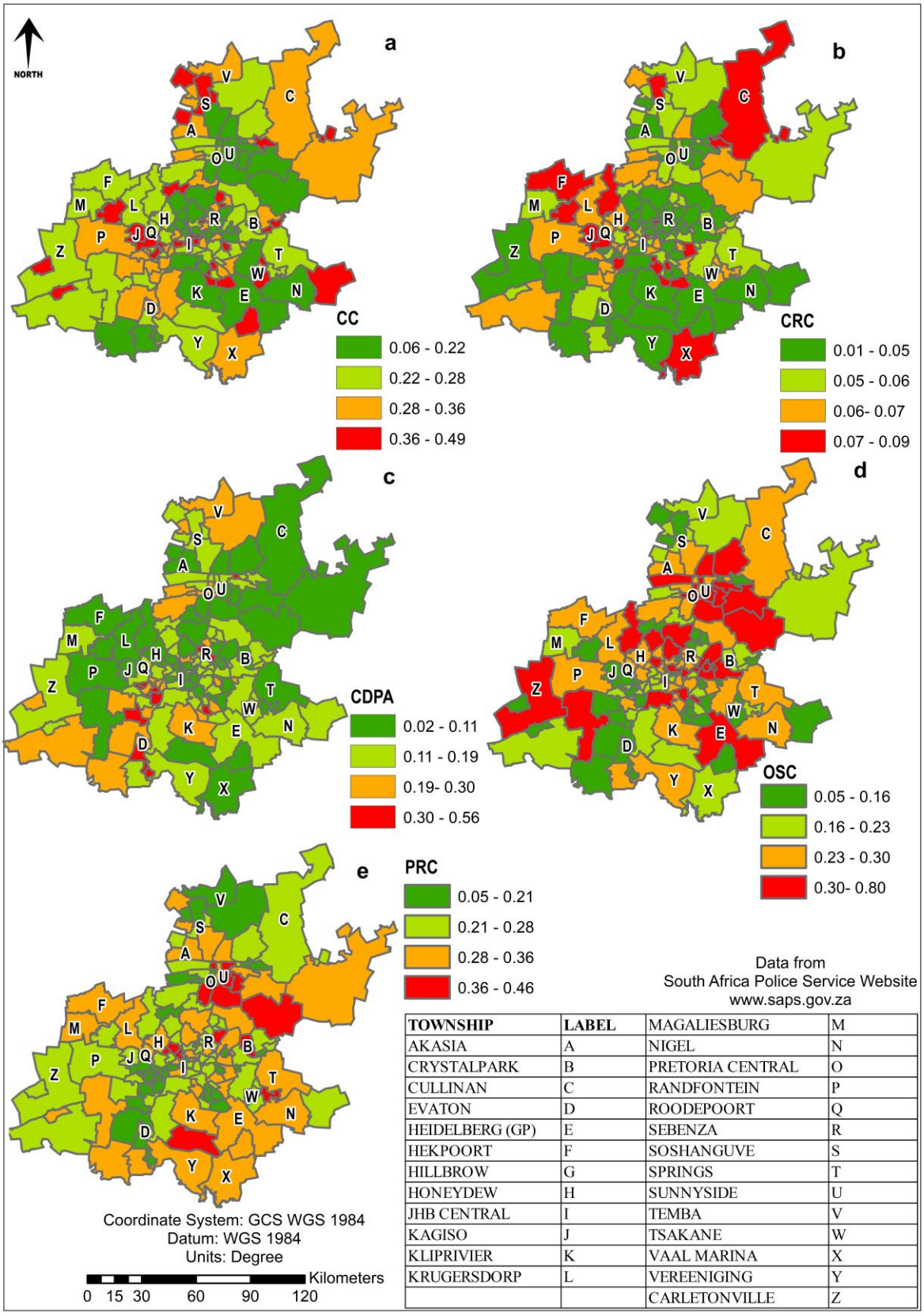
CRYSTALPARK	B	PRETORIA CENTRAL	O
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 3 Spatial Distribution of SI. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
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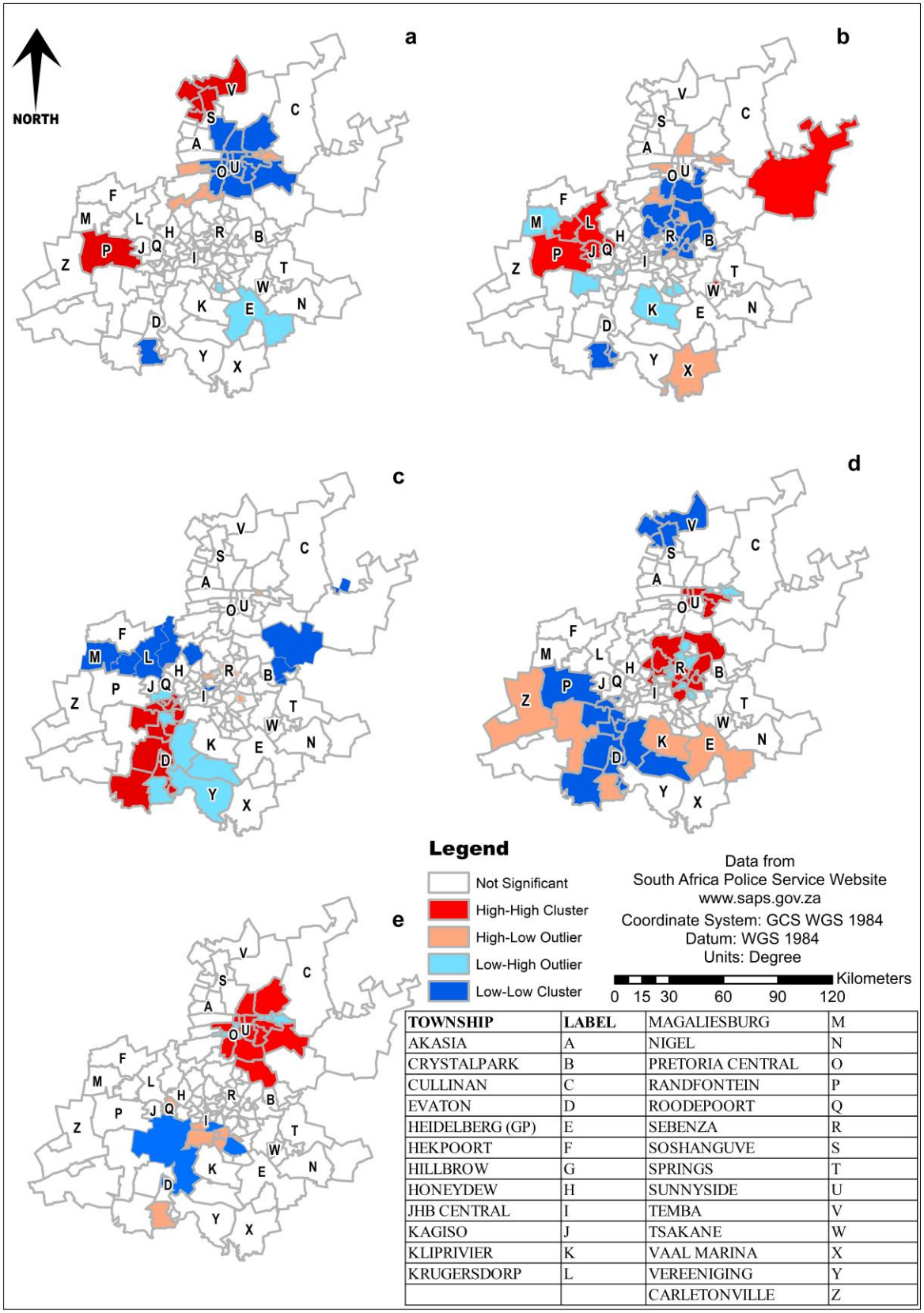
CRYSTALPARK	B	PRETORIA CENTRAL	O
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 4 Spatial Distribution of EI. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
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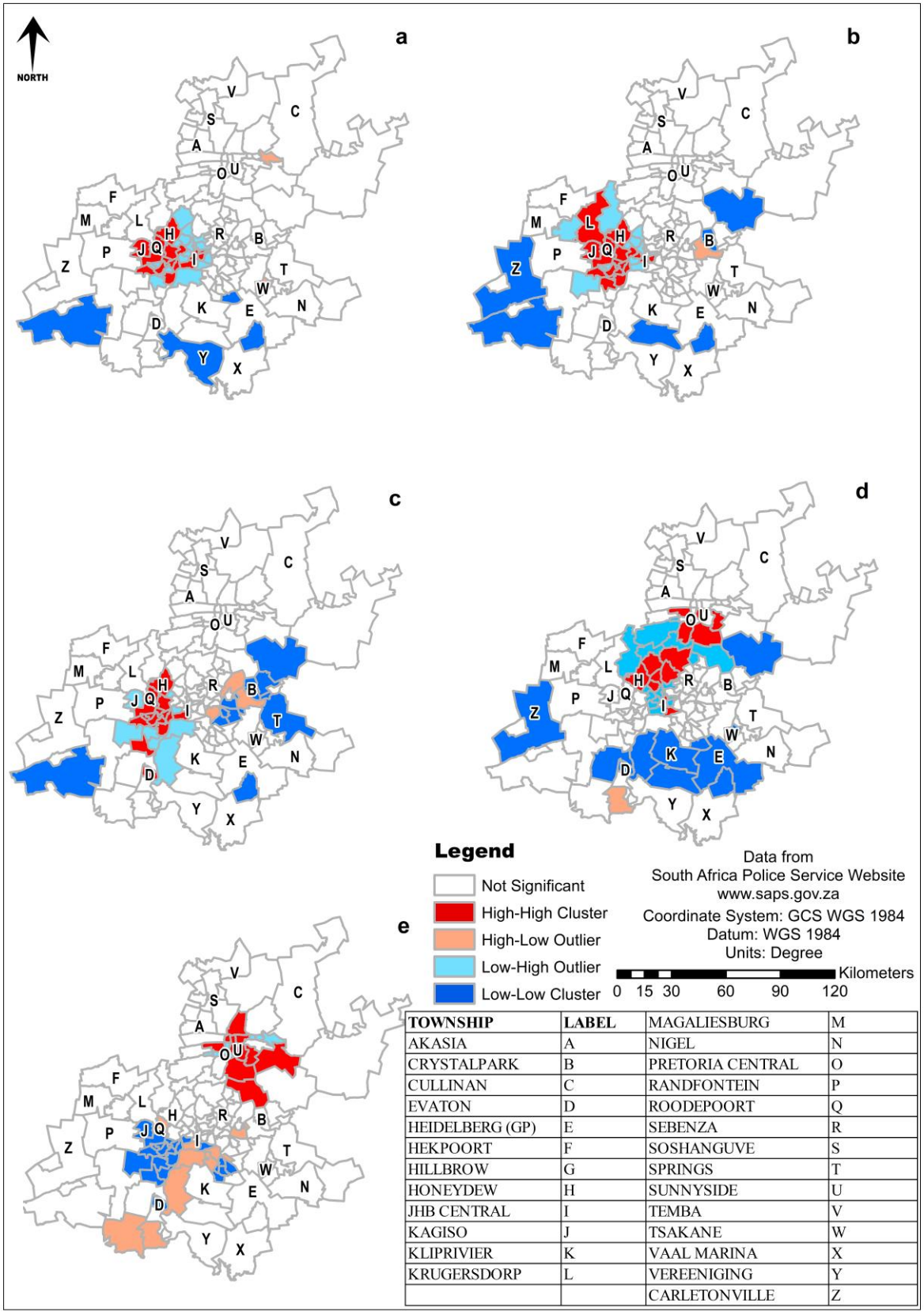
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 5 LISA Maps for showing spatial clusters and outliers for the TI. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
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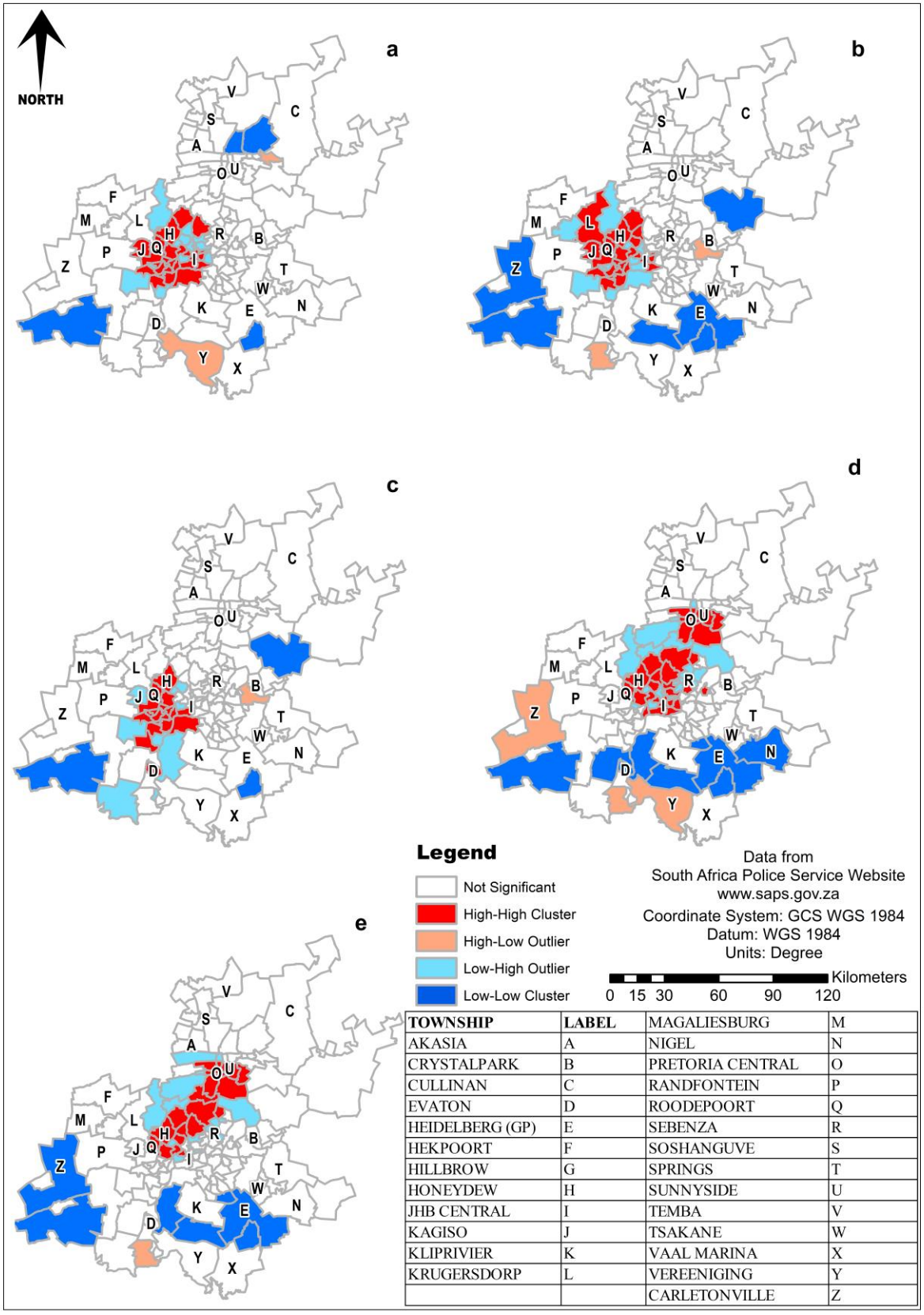
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 6 LISA Maps for showing spatial clusters and outliers for the HHI. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action (d): other serious crimes and (e): property-related crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
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CULLINAN	C	RANDFONTEIN	P
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HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
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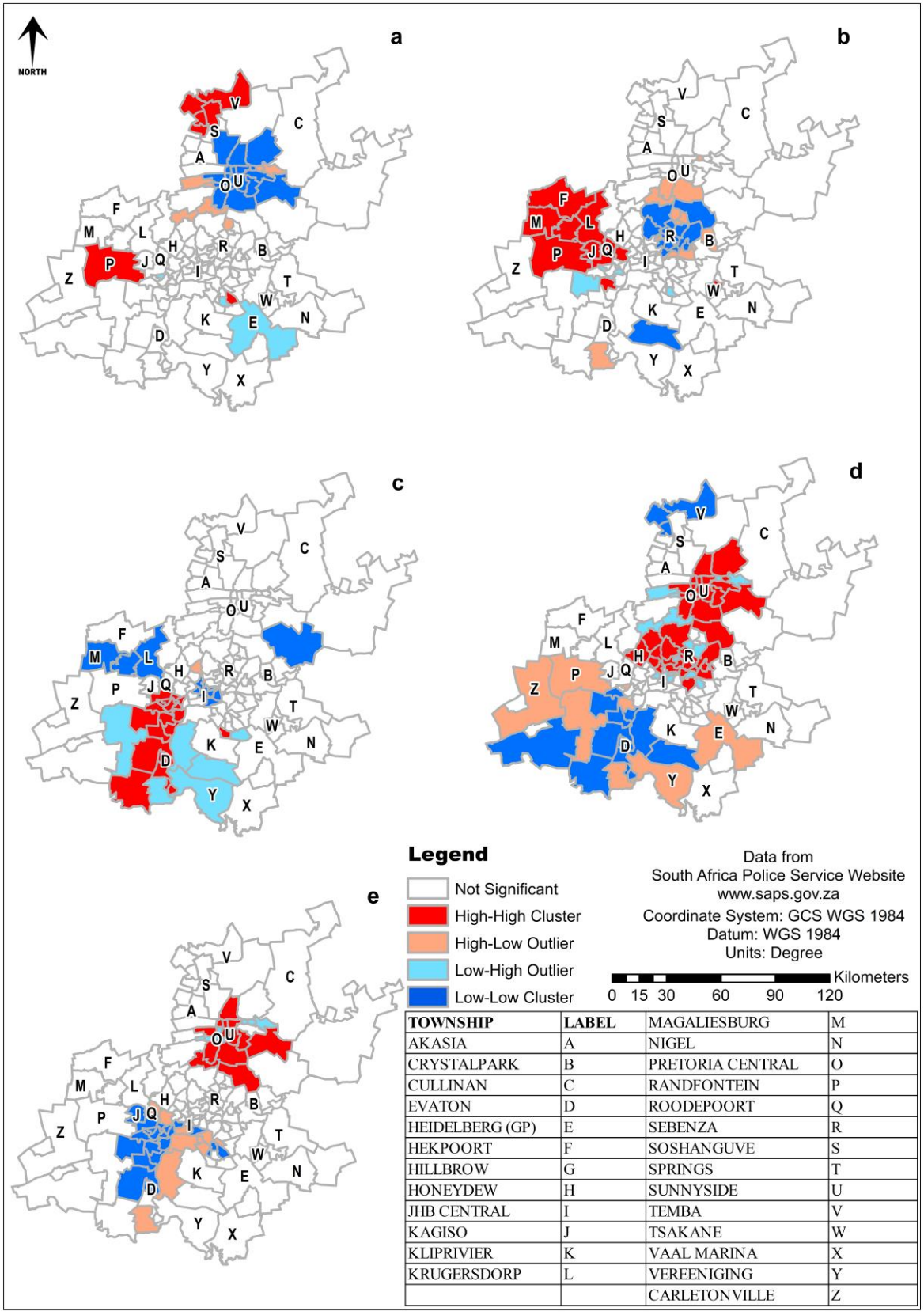
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 7 LISA Maps for showing spatial clusters and outliers for the SI. (a): contact crimes, (b): contact-related crimes,(c): crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
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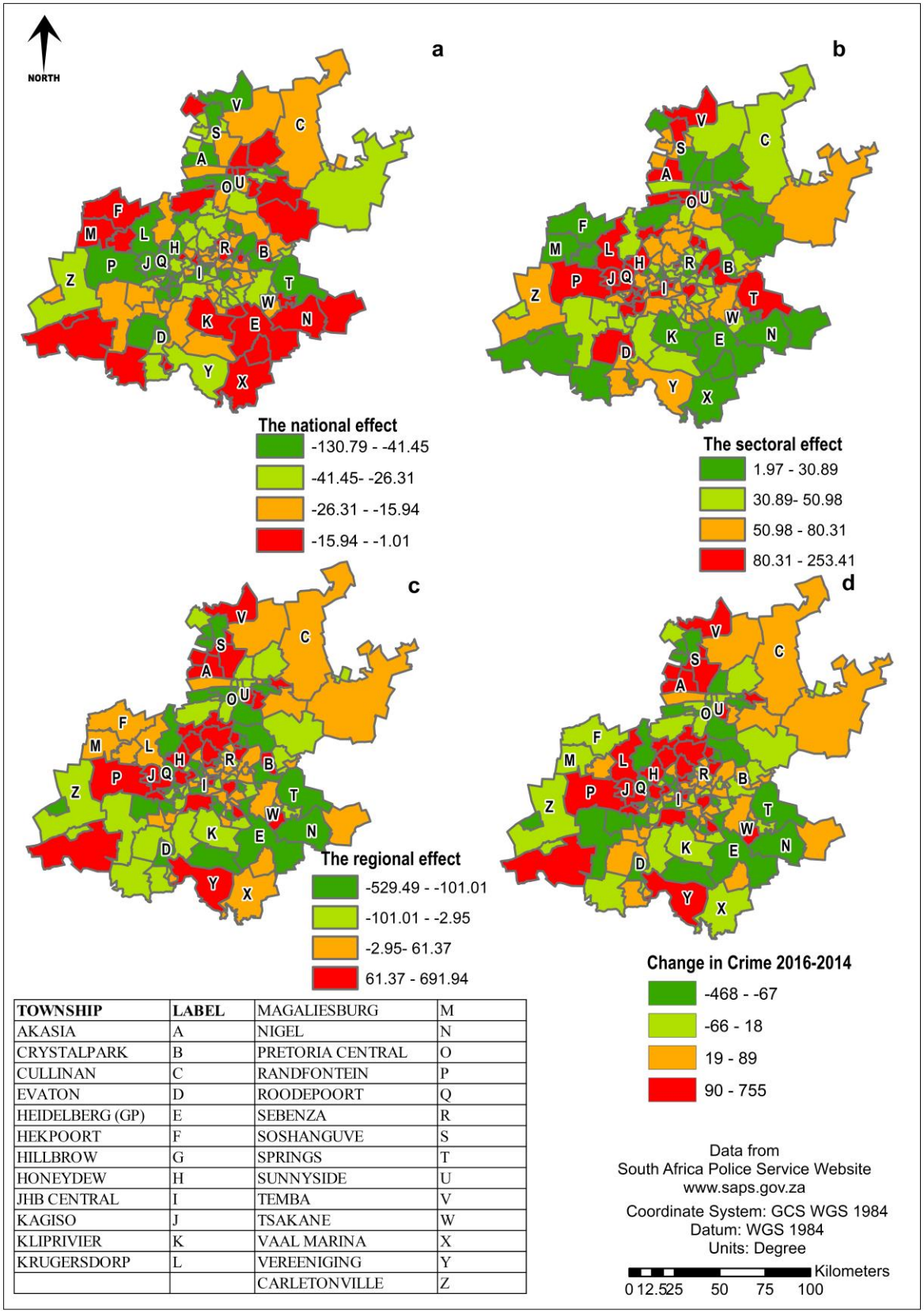
CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 8 LISA Maps for showing spatial clusters and outliers for the EI. (a): contact crimes, (b): contact-related crimes, (c): crime detected as a result of police action, (d): other serious crimes and (e): property-related crimes.



TOWNSHIP	LABEL	MAGALIESBURG	M
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CULLINAN	C	RANDFONTEIN	P
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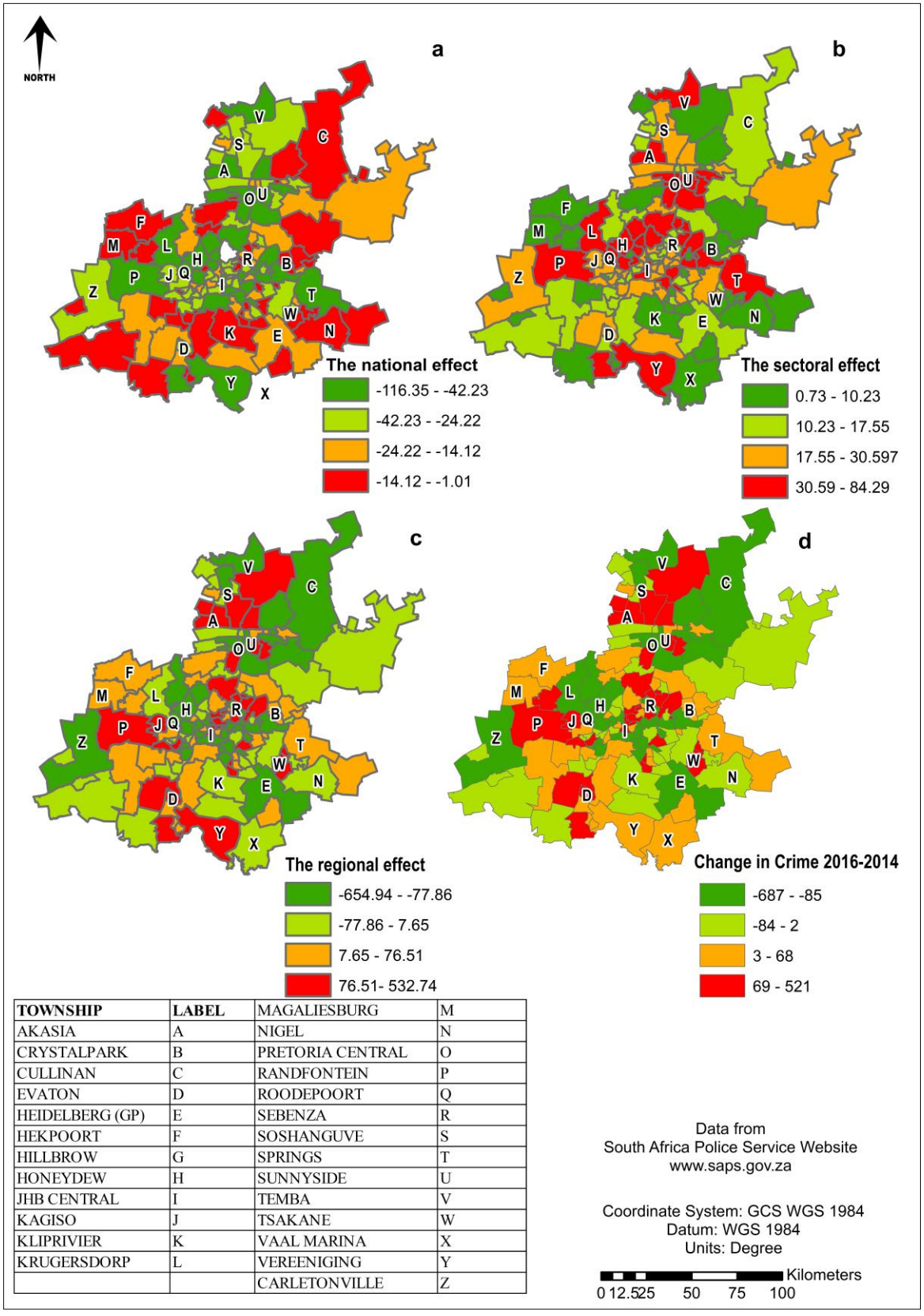
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 9 Spatial Distribution of changes in contact crime from 2014 to 2016 (d), B the national effect (a), sectorial effect b) and regional share of changes in crime (c).



TOWNSHIP	LABEL	MAGALIESBURG	M
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CULLINAN	C	RANDFONTEIN	P
EVATON	D	ROODEPOORT	Q
HEIDELBERG (GP)	E	SEBENZA	R
HEKPOORT	F	SOSHANGUVE	S
HILLBROW	G	SPRINGS	T
HONEYDEW	H	SUNNYSIDE	U
JHB CENTRAL	I	TEMBA	V
KAGISO	J	TSAKANE	W
KLIPRIVIER	K	VAAL MARINA	X
KRUGERSDORP	L	VEREENIGING	Y
		CARLETONVILLE	Z

Figure A 10 Spatial Distribution of changes in other serious crimes from 2014 to 2016 (d), B the national effect (a), sectorial effect (b) and regional share of changes in crime (c).

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