The influence of extreme weather conditions on the magnitude and spatial distribution of crime in Tshwane (2001-2006)

FRANCOIS H SCHUTTE[a] & GREGORY D BREETZKE[b]

[a] Francois H. Schutte

Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria, 0002, South Africa (E-mail: u12002217@tuks.co.za)

Corresponding author:

[b] Gregory D. Breetzke

Associate Professor, Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria, 0002, South Africa (Tel: +27 12 420 4318; Fax: 0027 12 420 6385; E-mail: greg.breetzke@up.ac.za)

Abstract

This article examines the influence of extreme weather conditions on the magnitude and spatial distribution of violent, sexual and property crime in Tshwane, South Africa from 2001 to 2006. Analysis of variance (ANOVA) is initially used to identify whether there are significant differences in the mean amount of crimes (violent, sexual and property) committed on days stratified by temperature and rainfall extremes. Next, a spatial point pattern test is used to determine the spatial similarity of violent, sexual and property crime on temperature and rainfall days classified as low, random, and high. Results indicate a strong association between temperature and criminal activity, and a less significant association between rainfall and crime. The spatial distribution of all types of crime are found to differ significantly depending on the type of weather extreme observed. The results of this study has the potential to assist law enforcement agencies to better understand how weather affects crime patterns in urban areas in South Africa and develop and implement appropriate crime prevention measures.

Keywords: crime, rainfall, temperature, spatial point pattern test, Tshwane

1. Introduction

Over the past few decades there has been a growing worldwide interest in examining the relationship between weather and various types of crime (see Breetzke & Cohn, 2012; Ceccato, 2005; Cohn, 1993; Xiaofeng & Peng, 2017). This interest has grown rapidly over the past number of years due to the increasing availability and accuracy of recorded crime information coupled with the proliferation and use of geographical information systems (GIS). Much of the research examining the nature of the relationship between climatic variability and crime has however produced inconsistent and often paradoxical results. For example, some studies have found no seasonal fluctuations in crime (Pittman & Handy, 1964; Yan, 2004), while others have found an increase in crimes during either the colder winter months or warmer summer months (Breetzke & Cohn, 2012; Cohen, 1942; Morken & Linaker, 2000). The reasons for these conflicting findings are largely uncertain, but Landau and Fridman (1993) suggested that they are related to the different ways in which seasons are measured by different countries, whereas Yan (2004) considered them to be related to the varying geographical locations under investigation.

Although some research has been done examining the relationship between seasonality and crime worldwide, very little is known about how the magnitude and spatial distribution of criminal activity in South Africa is impacted by climatic conditions. The aim of this research is to determine whether there is an association between criminal activity and climate in Tshwane. Specifically, we are interested in examining whether the magnitude of crime changes depending on extreme weather conditions, notably temperature and rainfall. For example, do extremely hot days experience higher or lower rates of violent, property or sexual crime in the city? Do extremely high rainfall days experience higher or lower rates of violent, property or sexual crime in the city? Moreover, does the spatial distribution of violent, property or sexual crime change depending on the type of extreme weather event? The study site of this research is the city of Tshwane located in the Gauteng province of South Africa. The City of Tshwane Metropolitan Municipality (CTMM) houses the local government of the Gauteng Province and covers approximately 6, 298 km^2 and is home to approximately three million residents.

2. Theoretical framework

The notion that there is a relationship between criminal activity and climate is nothing new. Over a century ago Quételet (1842) observed that crimes against people reach a maximum during the warmer summer months, while crimes against property reached a peak during winter. He later developed the temperature-aggression or T/A theory. The T/A theory provides a psychological explanation for the increase in crime during warmer months as it suggests that warmer temperatures will lead to an increase in an individual's frustration and discomfort levels and, thus, increase the likelihood of aggression, which could in turn result in interpersonal crimes such as assault. Essentially, the relationship between an aversive event (such as an extremely hot day) and aggression is facilitated by these emotions that generate negative effects. Over the years several versions of T/A theory have emerged, which differ in terms of the nature of the shape of the relationship between temperature and aggression. The first version by Anderson and Bushman (2002) suggest that the relationship between aggression and temperature is linear and that aggression increases during warmer days, months and seasons. However, when Rotten and Cohn (1999) examined the effects of temperature on aggression on a smaller time scale (such as 3-6 hour time intervals), they found that the function becomes curvilinear. That is, moderately high temperatures can cause negative effects (increased aggression among individuals due to increased temperatures), but if temperatures continue to increase, a critical threshold is reached. Thus, at extremely high and uncomfortable temperatures, individuals are more likely to attempt to escape the high temperatures and less likely to seek conflict with others.

Later Cohn and Rotton (2005; 2006) suggested that the nature of the relationship between temperature and aggression may be linear or curvilinear depending on other factors including time of day, day of week, season of the year as well as the setting in which the crime occurs. For example, they suggested that during specific times of the day the relationship between temperature and aggression can be curvilinear however, during other times of the day (like during early evening hours) the relationship might be linear or even non-existent because that critical threshold where temperatures become unbearable is not reached. Although the exact nature of the T/A curve is still a subject to much debate, most researchers agree that there is a general positive relationship between temperature and aggression.

A second theory commonly used to explain seasonal variations of crime is the routine activities (RA) theory of Cohen and Felson (1979). In contrast to the psychological explanation advocated by T/A theory, the RA theory employs a more social explanation. It focuses on opportunities and risks and is based on the notion that in order to understand criminal behaviour, one must first understand how individuals routinely use their time. RA theory states that individuals generally follow strict daily, weekly and even monthly routines, which affects opportunities for crime to occur (Brunsdon, Corcoran & Higgs, 2009). While some of these activities are compulsory with a fixed duration (such as school or work), other more flexible activities (such as socialising) leave individuals with a greater amount of choice as to when or where they will occur.

According to RA theory, for a crime to occur three fundamental factors need to coincide in time and space – namely, a motivated offender, a suitable target and the absence of a capable guardian (Cohen & Felson, 1979). Changing weather conditions can play an important role in altering the routine activities of individuals, particularly those who are more flexible, which may in turn impact the likelihood of the convergence of the three required elements required to increase the likelihood for a crime to occur. For example, a sunny day might encourage individuals to leave their homes and engage in social outdoor activities, which would increase the likelihood of contact between victims and potential offenders, resulting in more opportunities for interpersonal criminal offenses to occur. A rainy day may limit social interaction and result in reduced contact crime.

3. Literature review

The influence of a variety of meteorological parameters on crime has been the focus of a plethora of studies across a number of geographic locales. In China, Xiaofeng and colleagues (2017) examined the effect of temperature as well as relative humidity on crime and found a strong, positive association between temperature and both violent and property crimes. Relative humidity in particular was also found to be positively associated with a variety of crimes including rape and robbery. In the United States Cohn (1993) examined the short-term effect of weather variations on calls for police service in Minneapolis and found that the occurrence of domestic violence was positively associated with ambient temperature. Later, Rotton and Cohn (2003) examined the association between annual temperatures and crime rates across the whole US and found annual temperatures to be associated with an increase in assault, rape, robbery, burglary, and larceny, but not with murder or motor vehicle theft. Their results were consistent with RA theory's interpretation of everyday and criminal behaviour. Finally Mares (2013) used 20 years of monthly data to show how most major crime types in St Louis were positively associated with rising temperatures. Results indicated that the relationship between climate and crime was significant for most crime categories, and that potential future temperature increases may significantly impact future crime rates.

In Canada, Linning (2015) investigated whether seasonal variation existed across different types of property crime in Vancouver and Ottawa and found that property crimes exhibited distinct temporal peaks in humid continental climates like Ottawa but not in temperate ones like Vancouver. Linning and colleagues (2017) later examined crime seasonality across eight cities in British Columbia, Canada between 2000 and 2006 and found that temperature impacted assault levels but that few weather variables affected the occurrence of robberies. Their findings suggest that changes in weather patterns modify people's routine activities and, in turn, influence when crime is committed.

In Europe, Brunsdon et al. (2009) considered the effect of various weather parameters on the spatial distribution of crime within an urban city in the United Kingdom. The researchers found that the spatial distribution of crime changed depending on the temperature and humidity but found no effect from rainfall, wind speed, and wind direction. In particular, they found that at higher temperatures and humidity levels a greater proportion of incidents occurred outside of the city centre. Also in Europe, Morken and Linaker (2000) examined seasonal variation of violence in Norway, and found significant temporal variations between months with a minimum of violent incidences occurring in March (winter) and a maximum of incidences occurring in June (summer). Finally, in Brazil, Ceccato (2005) evaluated the influence of weather variations on homicide in Sao-Paulo and found an increase in homicide in warmer months. Of particular interest was the fact that central and more deprived areas showed the highest increase in homicide in summer. Overall, the results showed that temporal variables are far more powerful for explaining levels of homicide than weather variability, at least in a Brazilian context.

Within crime seasonality research, a much smaller set of literature has examined inter-neighborhood variations in seasonal crime rates. That is, do all neighbourhoods within a city or region experience seasonal increases or decreases in crime uniformly or do city-wide statistics mask sub-city trends? The limited literature generally indicates that seasonal crime rates are more pronounced in areas with lower socioeconomic wealth. For example Harries and Stadler (1983) found that the relationship between temperature and assault in Dallas was stronger in more deprived neighborhoods. Later, Stadler and Zdorkowski (1984) showed that the hot summer effects on aggressive crime rates were most pronounced in neighborhoods where air conditioning was scarce. In Brazil, Ceccato (2005) found considerable differences in spatial patterns of seasonal homicide in São Paulo and found clusters of seasonal homicide occurring more often in the disadvantaged areas of the city. Relatedly, Andresen and Malleson

(2013) found that the spatial patterns of crimes in Vancouver shifted depending not only on the socioeconomics of the neighbourhood under investigation but on where people spent more of their time. For example, they found that crime increased in summer at the location of the Vancouver summer fair.

Although these and other studies have enhanced our understanding of the impact of climate variability on crime throughout much of the world, very little is known about how seasonal variations impact the levels and distribution of crime in Africa in general, and South Africa specifically. Moreover, the focus of much of the past local and international seasonal crime research has been at examining broader meteorological parameters rather than examining the effect of extreme meteorological events on crime patterns. Locally, we aware of only two studies that have specifically examined the seasonal variation of crime in a South African context. These include Collings (2008), who found that incidences of child rape peaked during the summer and reached their lowest levels during the winter months in an analysis in KwaZulu-Natal and Breetzke and Cohn (2102), who found that assault is seasonal in Tshwane, with higher incidences of assault in summer. They also found that assault rates were more equably split in winter over neighbourhoods ranging from high to low deprivation. To our knowledge, there has been no research examining the impact of extreme weather events on crime in South Africa, and none examining the inter-neighbourhood variation and differences of crime in relation to extreme weather events within a single city.

The aim of this study is to examine the effect of extreme weather conditions on the magnitude and spatial distribution of violent, sexual and property crime incidences in Tshwane, South Africa from 2001 to 2006. This is done using statistical analysis, GIS as well as a novel analysis technique, the spatial point pattern test.

4. Data and methods

Climate data

Climate data for Tshwane was obtained from the South African Weather Service for a five year period from 2001/09/01 to 2006/08/31. The data included the daily temperature and precipitation records for the five year duration of the study period and was aggregated and averaged to represent the Tshwane metropolitan area[1]. Daily temperature averages were calculated for each day over the five year study period (n = 1826) and the top ten highest mean daily temperature days per year were extracted from the dataset. These 10 days per year were then combined to yield a dataset containing the 50 highest daily mean temperature days over the five year study period. This process was repeated for low temperature days where the top ten lowest mean daily temperature days were extracted per year and combined to yield a data set containing the 50 coldest days over the five year period. Finally, ten random temperatures days per year were selected using a random number generator. This yielded a data set containing 50 random mean daily temperature days. These 50 random days were selected from the dataset after the 50 warmest or coldest days were extracted to avoid duplication. Of course, it was possible to simply select the top 50 highest/lowest mean temperature days over the five year study period overall without extracting the top ten days year-on-year but we wanted to have consistency over time both in terms of the climatic and crime parameters.

In terms of rainfall, again three categories were extracted from the dataset (i.e. high rainfall days, no rainfall days and random rainfall days). High rainfall days were obtained by extracting the ten days per year over the five years which received the highest amount of rainfall. This yielding a data set with the 50 highest rainfall dates over the five year period. Random rainfall

[1] In this study, we used the pre-2011 municipal boundary for Tshwane. This includes 371 neighbourhoods. In May 2011, the boundary for the city of Tshwane expanded to incorporate the Metsweding District Municipality in the east of the city.

days per year were extracted using a random number generator, which yielded 50 days (ten per year) that experienced either some or no rainfall over the five year period. Ten days per year in which there was no recorded rainfall was also randomly extracted from the dataset. High rainfall days had a very high daily average amount of precipitation (30.7 mm), random rainfall days received substantially less rainfall (4.3 mm) while no rainfall days obviously had no rainfall.

Crime data

Crime data for the research project were obtained from the Crime and Information Analysis Centre (CIAC) of the South African Police Service (SAPS) for the same five year period. The data provided by the SAPS included the geographical location of each crime (x; y coordinate); the date and time of day that each crime was committed; and the specific type of crime committed. A total of 1,361,220 crimes were reported in the five year period across 32 different categories. All crime was then categorised into either violent, sexual or property crimes and a count of crime per type per day calculated over the five year period. Violent crimes consisted of murder, attempted murder, assault grievous bodily harm (GBH), and common assault; sexual crimes consisted of rape, attempted rape, and indecent assault; while property crimes consisted of house burglary, house robbery and common robbery. In this study, common robbery was categorised as property crime due to the fact that this types of crime shares a common motive with most other property crimes, namely economic benefit (Indermaur, 1995).

Empirical approach

Both descriptive and analytical methods were used in this study. Descriptively, the amount of violent, sexual and property crime occurring on the extracted temperature and rainfall days was calculated and combined into a single dataset. Descriptive statistics of the amount of violent, property and sexual crime occurring on different types of temperature and rainfall days were then calculated. Analytically, two main methods were employed. The first method uses an analysis of variance (ANOVA) to determine whether or not there is a significant difference between the mean amount of crimes (violent, sexual or property crimes) committed on temperature and rainfall days by category (i.e., high, low/no, and random).

Next, we used a recently developed spatial point pattern test (see Andersen, 2009) to determine whether the spatial distribution of crime on the three types of days changes. That is, does the spatial patterning of crime in Tshwane change depending on certain rainfall and temperature conditions? Andresen's spatial point pattern test allows for the identification of similarity between two spatial point patterns. In order to implement the spatial point pattern test, the first step is to identify a base data set. The base data set is the data used as the reference point for change. In this analysis, the random temperature and rainfall days were selected as the base data set, as this category represents the mildest or typically everyday weather conditions. The test data set is then randomly sampled with replacement at a rate of 85%, this process is then repeated 100 times, with the percentage of events calculated for all samples. These percentages are then rank ordered with the top and bottom 2.5% removed in order to create a 95% confidence interval. The test then produces global and local output results. The global statistic is calculated as a percentage of test sample points that had been similar to the base data set points. The similarity index, *S-index*, ranges from 0, no similarity, to 1, perfect similarity, and is calculated using the following equation:

$$S = \frac{\sum_{i=1}^{n} s_i}{n}$$

A value of S = 0.8 is deemed by Andresen (2009) as indicating spatially similar point distributions where any value less than 0.5 indicates significant spatial dissimilarity. Spatial point pattern tests were performed in this study to compare the spatial similarity of violent, sexual and property crime committed on different days by temperature/rainfall. The spatial point pattern test had been used in a number of crime related studies including testing for the spatial similarity of crime patterns for different crime types (Andersen & Linning, 2012), identifying changing patterns of crime resulting from police foot patrols (Andersen & Malleson, 2014) and comparing the spatial similarity of actual police data with open source crime data (Tompson, 2015).

5. Results

Table 1 shows the descriptive statistics of violent, property and sexual crimes on days stratified by temperature (high, low, random) (*n*=50). The mean amount of violent, sexual and property crime is highest on high temperature days. The mean amount of violent crimes are substantially higher on high temperature days (171.1 rate per 1000 population) compared to low (91.9 rate per 1000 population) and random (133.1 rate per 1000 population) temperature days. The mean amount of sexual crimes are also higher on high temperature days (16.6 rate per 1000 population) compared to low (9.6 rate per 1000 population) temperature days. Although less in magnitude, property crime is also higher on high temperature days (110.58 rate per 1000 population) compared to low (97.88 rate per 1000 population) and random (95.52 rate per 1000 population) days.

Table 2 provides descriptive statistics on the amount of violent, sexual and property crimes on different rainfall days. The differences in the rate of violent, sexual and property crime on the various rainfall days are more subtle than on the various temperature days. The mean rate of violent crime on high rainfall days (108.6 rate per 1000 population) is found to be less than on low (140.5 rate per 1000 population) and random (125 rate per 1000 population) rainfall

Table 1: Descriptive statistics for violent, sexual and property crimes on days stratified by temperature (*n*=50)

	Violent crime					Sexual crime					Property crime				
	N	Min	Mean	Max	SD	N	Min	Mean	Max	SD	N	Min	Mean	Max	SD
High temperature days	8591	73	171.1	462	102.7	829	4	16.6	69	11.9	5527	57	110.6	195	29.9
Low temperature days	4596	45	91.9	208	37.4	480	4	9.6	20	4.4	4894	66	97.9	155	22.9
Random temperature days	6655	49	133.1	330	59.7	736	7	15.3	37	7.1	4776	51	95.9	158	22.2

Table 2: Descriptive statistics for violent, sexual and property crimes on days stratified by rainfall (*n*=50)

	Violent crime					Sexual crime					Property crime				
	N	Min	Mean	Max	SD	N	Min	Mean	Max	SD	N	Min	Mean	Max	SD
High rainfall days	5428	64	108.6	266	43.4	654	3	13.1	42	6.0	5416	56	108.3	193	29.3
No rainfall days	7024	58	140.5	309	66.7	690	4	13.8	28	6.5	5319	59	106.4	217	29.4
Random rainfall days	6250	42	125.0	347	70.0	707	2	14.1	33	8.5	5090	56	101.8	172	26.4

days. Similarly, mean sexual crime rates were lowest on high rainfall days (13.1 rate per 1000 population) compared to low (13.8 rate per 1000 population) or random (14.1 rate per 1000 population) days, however the differences are relatively minor. Interestingly, the opposite is true for property crime, with the mean rate of property crimes highest on high rainfall days (108.3 rate per 1000 population) compared to low (106.4 rate per 1000 population) and random (101.8 rate per 1000 population) days. Although, again, the differences are relatively small. Table 3 shows the results of an ANOVA used to assess whether the differences in crime by type of temperature day observed in Table 1 were significant. We found significant differences between all types of crimes by type of temperature day with crimes increasing across all categories (violent, sexual and property) on higher temperature days. Table 4 shows the results of an ANOVA used to assess whether the differences in the magnitude of crime by type of rainfall day observed in Table 2 were significant. In contrast to the results above we found only significant differences for violent crimes by type of rainfall day (p = 0.036). No significant differences were found for the amount of sexual (p = 0.745) or property crime (p = 0.502) by type of rainfall day.

Table 3: ANOVA of violent, sexual and property by type of temperature day

Violent crime				
High temp	171.1	3	12.92	0.000
Low temp	91.9			
Random temp	133.1			
Sexual crime	16.6	3	7.54	0.007
High temp	9.6			
Low temp	15.3			
Random temp				
Property crime				
High temp	110.6	3	3.48	0.017
Low temp	97.9			
Random temp	95.5			

Table 4: ANOVA of violent, sexual and property crime by type of rainfall day

	Mean	df	*F*	p value
Violent crime				
High rain	108.6	3	3.40	0.036
No rain	140.5			
Random rain	125			
Sexual crime				
High rain	13.1	3	0.30	0.745
No rain	13.8			
Random rain	14.1			
Property crime				
High rain	108.3			
No rain	106.4	3	0.69	0.502
Random rain	101.8			

Tables 5 to 7 provide the output of the spatial point pattern test (where a global *S* value of 1 indicates that the spatial point pattern distributions are identical; and a global *S* value of 0 indicates that the two point distributions are completely dissimilar) for violent, sexual and property crime on different days by temperature and rainfall. Table 5 illustrates the global *S*-values for violent crime by temperature and rainfall days. All *S*-index values for violent crime on days by temperature and rainfall are less than 0.5, indicating significant spatial dissimilarity in the distribution of crime between the various categories. This shows that the spatial distribution of violent crime in Tshwane differs by type of temperature days. Indeed, the high versus low temperature days had the smallest *S*-index value (0.4221), indicating that there is a considerable difference in the way that violent crime is spatially distributed on cold compared to warm days in Tshwane. Similarly, violent crime distribution also differs significantly between high and random temperature days (0.4363), also indicating a strong dissimilarity in the way that crime is spatially distributed on mild compared to very warm days. In terms of rainfall, violent crime distribution is the most dissimilar between no rainfall days and random

Table 5: Spatial point pattern test for violent crimes by temperature and rainfall

Violent crime							
	High temp	Low temp	Random temp		High rain	No rain	Random rain
High temp	-	-	-	High rain	-	-	-
Low temp	0.4221	-	-	No rain	0.3711	-	-
Random temp	0.4363	0.4476	-	Random rain	0.3401	0.2774	-

Table 6: Spatial point pattern test for sexual crimes by temperature and rainfall

Sexual crime							
	High temp	Low temp	Random temp		High rain	No rain	Random rain
High temp	-	-	-	High rain	-	-	-
Low temp	0.6771	-	-	No rain	0.6657	-	-
Random temp	0.6629	0.6856	-	Random rain	0.6855	0.7054	-

Table 7: Spatial point pattern test for property crimes by temperature and rainfall

Property crime							
	High temp	Low temp	Random temp		High rain	No rain	Random rain
High temp	-	-	-	High rain	-	-	-
Low temp	0.3938	-	-	No rain	0.3966	-	-
Random temp	0.4108	0.4136	-	Random rain	0.3994	0.3938	-

rainfall days (0.2774). As one would expect, violent crime on high rainfall days versus no rainfall days also differs significantly (0.3711) in spatial distribution.

Table 6 illustrates the global *S*-index values for sexual crime on different days by temperature and rainfall. Sexual crime was found to be the most similar of all crime types across all categories. The *S*-index values on different temperature days ranged from 0.67 – 0.69, whilst the *S*-index values for rainfall ranged from 0.67-0.71. On different temperature days, sexual crimes were found to be the least similar in spatial distribution on high temperature versus random temperature days (0.6629), while on different rainfall days, high versus no rainfall days were the least similar (0.6657). Sexual crime on random versus high rainfall days had the highest similarity (0.7054) of all crime types over all the categories.

Table 7 illustrates the global *S*-index values for property crime on different days by temperature and rainfall. Similar to violent crime, property crime was also found to differ significantly over all categories on different temperature and rainfall days. Although the distribution of property crime differs significantly, the range within temperature and rainfall categories is very small. On different days by temperature, the *S*-index values for property crime range from 0.39-0.41, similarly on different days by rainfall, *S*-index values range from 0.39-0.40.

Finally, while not a main aim of this work, an examination of the localised mappable output produced by the spatial point pattern test indicated relative uniformity in the dissimilarity of crime patterns across the city by temperature and rainfall extremes. That is, spatial crime distributions across all three categories (violent, property and sexual) certainly changed to varying extents depending on temperate and rainfall type but no clear socio-demographic pattern or gradient emerged from the spatial results. No region of the city experienced greater dissimilarity than another for most combinations of crime (by category) and temperature, and rainfall (by type). Previous crime seasonality research in Tshwane has shown how more deprived neighborhoods experienced higher assault rates in summer, whereas in winter, assault rates were more equably split over neighborhoods ranging from high to low deprivation (see Breetzke & Cohn, 2012). No such spatial patterning was observed here although it should be noted that the spatial point pattern test is more concerned with *where* point patterns differ at the neighbourhood level, than *why* patterns differ. Future research should aim to further explore these findings, or expand on them more generally, in order to explain the reasons for the spatial dissimilarity observed uniformly throughout the city.

6. Discussion

The results of this study shows statistically significant differences in the magnitude of crime occurring on temperature days classified as high, low and random. There is an increase in violent, sexual and property crimes occurring on high temperature days compared to low or random temperature days. These results support T/A theory which suggests that warmer temperatures may lead to an increase in crime by increasing an individual’s frustration and discomfort levels and thus increases the likelihood of aggression. In our research however we have found that this increase occurs across multiple types of crime and not just interpersonal crime as has been found in previous research (see Breetzke & Cohn, 2012; Rotton & Cohn, 2001). In terms of RA theory, warmer weather might encourage individuals to leave their homes, socialise, and consume alcohol which could increase the possibility of contact between victims and perpetrators, resulting in more opportunities for violent or sexual criminal offences to occur. This may explain the observed increase in violent and sexual crimes on hotter days. Moreover, we found an increase, although more subtle, in the amount of property crimes occurring on higher temperature days. In this instance it could be that warmer weather might encourage individuals to leave their homes leaving houses unguarded and susceptible to various types of property crime.

In terms of rainfall, the results are less clear as we found that only violent crimes differed significantly in magnitude on different type of rainfall days. That is, there are significantly less violent crimes occurring on heavy rainfall days than on other days. This could be as a result of the reduced likelihood of individuals leaving their homes and engaging in outdoor activities on rainy days, thus decreasing likely contact between victims and perpetrators, resulting in less interpersonal violent crimes. Results did however also show that sexual and property crimes do not differ significantly on days by rainfall. In fact, we found a slight increase in property crimes on high rainfall days. This latter finding is surprisingly as one would expect a reduction in property crime on high rainfall days based on the central tenets of the RA theory. Indeed, based on motivation, property crime can be categorised as an instrumental crime in that it involves behavior that has a specific tangible goal, such as the acquisition of property and would involve more planning. Plans can be adversely affected by high rainfall but this was found not to be the case in our study. Future research could investigate where crimes occur on high rainfall days as it could be that this global finding masks local spatial variations in the distribution of property crime that could potentially explain this finding.

The spatial distribution of violent and property crime was found to differ significantly on all type of days by temperature and rainfall. That is, spatial crime distributions changed significantly depending on daily temperature and rainfall measures. Unsurprisingly, the spatial distribution of violent crime on very cold days is significantly dissimilar to the spatial distribution of violent crime on very hot days (*S*-index value = 0.388). Similarly, the spatial distribution of crime on high rainfall days is significantly different to the spatial distribution of crime on low rainfall days (*S*-index value = 0.3711). These results can be partially explained by RA theory, as weather conditions change individuals' routine activities. A change in routine activities is likely to result in a change in the coming together in space and time of the three essential elements of RA theory: a motivated offender, a suitable target and the lack of a capable guardian. An individual's preference to participate in certain activities will vary depending on the weather conditions outside, which in turn will alter the distribution of where opportunities may arise for criminal offenses to occur. For example, if it was raining heavily outside an individual might rather stay home for warmth and comfort, whereas on a warmer night the same individual might be encouraged to go out socialising with friends, altering the potential location and/or possibility for a crime to occur, although more research is warranted to more fully explore this explanation.

7. Conclusion

The main aim of this study was to determine whether weather extremes influence the magnitude and spatial distribution of crime in Tshwane. We believe that we have achieved this aim and made a number of important contributions to the extant literature. First, the study demonstrates that the amount of violent, sexual and property crime in the city of Tshwane is significantly impacted by both temperature, and to a lesser extent, rainfall. The magnitude of violent, sexual and property crime was found to be higher on hot days compared to cold or random temperature days in Tshwane. Violent crimes increased by 50% on hot days compared to very cold days, while sexual crimes increased by 41% and property crime by 12%. Violent and sexual crimes in Tshwane also decreased on high rainfall days compared other rainfall days while property crime was surprisingly found to increase slightly on heavy rainfall days, though only by 2%.

Second, the spatial distribution of violent and property crime was found to differ on days by temperature and rainfall. That is, there is a considerable change in the way that particularly violent and property crime is spatially distributed in Tshwane depending on the weather conditions. We did however find that the distribution of sexual crime did not seem to differ significantly by temperature or rainfall. More research is needed to confirm these findings and to determine if the results can be generalised to other urban areas in South Africa, which could have positive practical applications for law enforcement in the country.

The results of this research have the potential to inform the practice and policy of law enforcement agencies and other relevant stakeholders in South Africa tasked with reducing crime. Indeed, our findings can be used to identify communities that are more prone to crime under certain meteorological conditions and allow stakeholders to target these neighbourhoods and plan interventions accordingly. It also allows stakeholders to adequately develop and implement suitable intervention practices in similar at-risk neighbourhoods. The South African Police Services and other role players that are responsible for specifically addressing long-term solutions to crime, crime pattern analysis can utilize the understanding of how weather events influence crime patterning and provide measures to take appropriate action.

Acknowledgements

The authors would like to thank the South African Weather Service who provided climate data for this study, as well as the Crime and Information Analysis Centre (CIAC) of the South African Police Service (SAPS), who provided crime data for the study.

References

Andresen, M. A., & Malleson, N. (2013). Crime seasonality and its variations across space. *Applied Geography*, *43*, 25-35.

Andresen, M. A., & Malleson, N. (2014). Police foot patrol and crime displacement: A local analysis. *Journal of Contemporary Criminal Justice*, *30*(2), 186-199.

Anderson, C. A., & Bushman, B. J. (2002). Human aggression. *Annual Review of Psychology*, *53*, 27-51.

Anderson, M. A. (2016). An area based nonparametric spatial point pattern test: The test, its applications and the future. *Methodological Innovations, 9*, 1-11.

Breetzke, G. D., & Cohn, E. G. (2012). Seasonal assault and neighbourhood deprivation in South Africa: Some preliminary findings. *Environment and Behavior*, *44*(5), 641-647.

Brunsdon, C., Corcoran, J., & Higgs, G. (2009). The influence of weather on local geographical patterns of police calls for service. *Environment and Planning A*, *36*(5), 906-926.

Ceccato, V. (2005). Homicide in Sao Paulo, Brazil: Assessing spatial-temporal and weather variations. *Journal of Environmental Psychology*, *25*(3), 307-321.

Cohen, J. (1942). The geography of crime. *Annals of the American Academy of Political and Social Science, 217*(1), 29-47.

Cohen, L., & Felson, M. (1979). Social change and crime rate trends: A routine activity approach. *American Sociological Review*, *44*(4), 588-608.

Cohn, E. G. (1993). The prediction of polioce calls for service: The influence of weather and temporal variables on rape and domestic violence. *Journal of Environmental Psychology*, *13*(1), 71-83.

Collings, S. J. (2008). Seasonality of reported child rape in Kwazulu-Natal, South Africa. *Acta Criminologica*, *21*(3), 91-99.

Harries, K., & Stadler, S. (1983). Determinism revisited: Assault and heat stress in Dallas. *Environment and Behavior*, *15*(2), 235-256.

Harries, K., Stadler, S., & Zdorkowski, R. (1984). Seasonality and assault: Explorations in inter-neighborhood variation, Dallas 1980. *Annals of the Association of American Geographers*, *74*(4), 590-604.

Indermaur, D. (1995). *Violent Property Crime*. Sydney, NSW: Federation Press.

Linning, S. J. (2015). Crime seasonality and the micro-spatial patterns of property crime in Vancouver, BC and Ottawa, ON. *Journal of Criminal Justice*, *43*(6), 544-555.

Linning, S. J., Andresen, M. A., Ghaseminejad, A. H., & Brantingham, P. J. (2017). Crime seasonality across multiple jurisdictions in British Columbia, Canada. *Canadian Journal of Criminology and Criminal Justice*, *59*(2), 251-280.

Mares, D. (2013). Climate change and crime: Monthly temperature and precipitation anomalies and crime rates in St. Louis, MO 1990–2009. *Crime Law & Social Change*, *59*(2), 185-208.

Morken, G., & Linaker, O. (2000). Seasonal variation of violence in Norway. *American Journal of Psychiatry*, *157*(10), 1674-1678.

Pittman, D. J., & Handy, W. (1964). Patterns in criminal aggravated assault. *Journal of Criminal Law, Criminology & Police Science*, *55*(4), 462-470.

Quételet, M. A. (1842). A treatise on man and the development of his faculties. Edinburgh: William and Robert Chambers.

Rotton, J., & Cohn, E. G. (1997). Assault as a function of time and temperature: A moderator-variable time-series analysis. *Journal of Personality and Social Psycholology*, *72*(6) 1322-1334.

Rotton, J., & Cohn, E. G. (2001). Temperature, routine activities and domestic violence: A reanalysis. *Violence and Victims*, *16*(2), 203-215.

Rotton, J., & Cohn, E. G. (2003). Global warming and U.S crime rates: An application of routine activity theory. *Environment and Behavior*, *35*(6), 802-825.

Tompson, L. (2015). UK open source crime data: accuracy and possibilities for research. *Cartography and Geographic Information Science*, *42*(2), 97-111.

van Koppen, P., & Jansen, R. (1999). The time to rob: Variations in the number of commercial robberies. *Journal of Research in Crime and Delinquency*, *36*(1), 7-29.

Xiaofeng, H., Jiansong, W., & Peng, C. (2017). Impact of climate variability and change on crime rates in Tangshan, China. *Scence of the Total Environment*, *609*, 1041-1048.

Yan, Y. Y. (2004). Seasonality of property crime in Hong Kong. *British Journal of Criminology*, *44*(2) 276–283.