Open Peer Review on Qeios

How Urban Heat Islands Effect Crime: Understanding the Implications of Temperature, Population Density, and Green Canopy Cover in Shaping Built Environments

Emil Eugen Jonescu[1], Chamil Erik Ramanayaka[2], Oluwole Olatunji[3]

1 Edith Cowan University
2 Central Queensland University
3 University of Southern Queensland

Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.

Abstract

Emergent evidence shows micro and macro-climates influence criminal behaviour; a complex phenomenon that is still incipient in theory development. A mixed method research, this study starts with a systematic review of literature on theorical premises that urban heat islands amplify aggressive behaviour and crime. Further, it discusses potential implications of the relationship between the environment and social outcomes on design and planning of urban environments. A meta-synthesis was conducted to explain the correlations between patterns of criminal behaviour and thermal (dis) comfort. This correlation is to relate fundamental urban design principles to socially sustainable communities that dissuade violence and crime, and otherwise show poorly designed spaces do propagate criminal behaviour. Cross-validation was undertaken using a case study of Midland, a suburb of Perth, Western Australia. Data involve population demographics, temperature, and crime statistics relating to Offences against the Person. Analysis focused on homicide, assault, threatening behaviour, and robbery. Findings show limited positive correlations between long-term temperature, crime, population density, and green canopy cover. Variables of climate (e.g., short-to-long-term climate-related stressors) and crime types also show non-linear association. Nonetheless, forecasting the future of violence and trends of crime through attributes or potential impacts of heat and urban canopy cover on the built environment will inform sustainable social development policy, environmental planning, development strategy, designers, and planners. Recommendations are made around these in relation to making urban communities adaptive to the impacts of global warming and future densification.

Emil E. Jonescu[1,2*], **Chamil Erik Ramanayaka**[3], **Oluwole A. Olatunji**[1]

[1] *School of Surveying and Built Environment, University of Southern Queensland, Springfield, QLD 4300, Australia.*

[2] *Hames Sharley, Perth, Western Australia 6000, Australia.*

[3] *Central Queensland University, School of Engineering and Technology, Brisbane, Australia.*

Keywords: Climate, Criminal Behaviour, Sustainable urban design, Urban heat island, Global warming.

Introduction

Normative studies agree on how climate change impacts various aspects of city life. Evidence in a study of the Maldives by Moosa *et al.* (2020) shows there is significant disparity in location-based climate change outcomes. They emphasised the implications of their study to culture, employment, food production, economic output, and mobility patterns. Su, Li, and Qiu 2023, posit that mobility may increase propensity for opportunistic urban crimes resulting from density, mixing, and movement of a diversity of people public transport nodes (Brantingham & Brantingham, 1995; Felson, 2003; Madensen & Eck, 2012), with existing research finding that the impact to the surrounding increasingly urbanised environments was not inconsequential (Loukaitou-Sideris et al., 2002; Moreira & Ceccato, 2021; Newton et al., 2014).

Yet, as urbanisation continues to accelerate to meet the demands of growing populations, frequently they result in unintended and complex consequences. The impact of the constructed environment on the severity of criminal activities is a significant factor (Silva and Li 2020), and has been the subject of increasing scholarly attention within the realm of crime place studies (Hipp, Kim, and Kane 2018; Sohn 2016). For example, excessive heat in localised areas, referred to as the urban heat island effect (UHIE), occurs when an urban area has significantly disparate temperatures to that of its surrounding rural belt, caused by heat absorption (Aguiar 2012). Accordingly, it is incumbent on governments across the world to improve long-term decisioning in respect of regional planning and development to mitigate unintended community harms. This must be done with cognisance of paucity of arable land and spikes in resource demand and in relation to population growth.

Moreover, giving up spaces through development and densification pressures agricultural fringes. This also affects long-term sustainability of natural ecosystems and biodiversity (Armstrong 2001). In addition, exposed areas required to replenish underground water supplies is impacted, as well as other environmental and socio-economic issues. Criminal activities are influenced by demographic and socioeconomic variables as well as the built environment, which serves as an external factor that impacts an individual's attitudes and behaviors (Cozens 2011; Davies and Johnson 2014; Eck and Weisburd 2015). Thus, under such circumstances, maximising the potential use of all—even seemingly insignificant spaces, and pedestrianising hard infrastructure towards to active transportation modalities—reverting the vehicular-dependence paradigms which fuels current societal norms—to mitigate HIE, it has been suggested, may contribute to reducing microclimates, improving perception of safety, and concurrently reducing the propensity for crime.

Many scholarly works have examined the role of genetics (a person’s biological nature) and the environment (the natural and built environment a person exists within, including society and its institutions) in shaping or triggering criminal behaviour (Benson 2013; Mednick and Volavka 1980; Rafter 2008). Most studies suggest that criminality is influenced by both factors, with the environment shaping an individual while their biological nature sets the boundaries of their behaviour (Boyanowsky 2020; Mehta and Binder 2012; Wilson and Herrnstein 1998).

The identification of key factors that contribute to criminality in society has been a focus of previous research. Gaining an understanding of the factors that exert influence on criminal activities is paramount in reducing the detrimental and expensive consequences they can have on society (Twinam 2017). These factors include population density (Watts 1931), mental health (Fleischman et al. 2014), substance abuse (Grann and Fazel 2004), mobility (Kelly 2000), law enforcement (Fafchamps and Moser 2003), public perception (Gaubatz 1995), quality of governance (Curran 1998), and Oscar Newman's (1977) defensible space theory. The present study aims to evaluate existing literature and theories that relate criminality to climate in order to determine whether increasing urban expansion and densification, and diversity of people such as that which occur in ecotones (Kark 2013) is likely to lead to opportunities for an increased propensity for crime. Ecotones are regions where different ecological communities, ecosystems, or biotic regions overlap. Typically, ecotones occur in areas where there is a sharp environmental transition or along environmental gradients. Within these transitional areas, the environment can quickly shift from one type to another as a result of various factors, including both abiotic factors such as climate and biotic factors such as community structure. (Holland et al., 1991; Kent et al., 1997).

Furthermore, the study seeks to provide guidance for development policy, resulting in improved urban design decisions, policing infrastructure, and operational planning. Ultimately, the goal of this study is to encourage a regenerative systems thinking approach to development. To achieve these objectives, the present chapter focuses on analysing crime types and statistics, climate factors and patterns, tree canopy cover in urban areas, and population density. A systematic literature review of shared variables across existing studies was conducted, with methodological frameworks, data collection, and analysis focusing on criminality and climatic conditions. Gaps and limitations in previous research are also considered, highlighting the current study's contribution and face validity. Based on these findings, a meta-synthesis of select studies was conducted to identify scholarship at the intersections of heat and urban crime studies, with a specific focus on highly urbanised areas (urban heat islands) in general and in the Australian environment.

This study differs from many other studies in the literature in several ways. It examines the relationship between criminality and climate, with a specific focus on the potential impact of urban expansion and densification on crime rates. Moreover, the study provides a unique perspective on this topic by focusing on a specific case study location, the City of Midland in Western Australia, and analysing the interplay between population growth, crime rates, demography, density, vegetation cover, and temperature. This case study approach offers valuable insights into the complex relationship between urbanization and crime that are context-specific and could inform more effective urban design decisions and policing strategies. Finally, the study uses a systematic literature review and meta-synthesis approach, which helps identify gaps and limitations in the existing literature and offers a more comprehensive and integrated view of the current state of knowledge in this field. Overall, the study's unique focus, methodology, and contribution to the literature make it a valuable addition to the existing body of research on crime prevention and urban design.

Urban Heat Island Studies

Sustainability is a necessity for survival, therefore design strategies that improve sustainability outcomes take precedence

over other political and economic motivations. Rad and Afzali (2021) highlight that urban morphology plays an important role in mediating immediate micro-climate and localised thermal comfort. Buildings are an example of this, and their form and orientation can further impact on urban heat island effect. Moreover, materiality, such as extensive masonry and road infrastructure is likely to exacerbate the condition as they add to thermal mass. Applying ENVI-met 3D simulations, Rad and Afzali highlights how different models of urban development provide improved conditions for thermal comfort over other alternatives. They found high-rise buildings affect micro-climate that impact outdoor thermal comfort.

Chakraborty et al. (2019) found green vegetation in urban neighbourhoods moderate HIE. 72% of cities sampled in their study showed disproportionate impact between affluent and vulnerable communities. An inference from this is that climatic events and the HIEs attributed to “urban structures which is then later radiated back into the environment” (Aguiar 2012, p. 2), are not equitably distributed amongst communities. Aguiar’s description suggests heat island conditions are aggravated in the evening due to thermal lag, or the rate at which heat that was absorbed by a material is released. High thermal mass such as hard surfaces that have absorbed solar radiation will retain the heat for longer and thus have a large thermal lag with implications for social, economic and health related outcomes. Other studies cited by the author suggest greener urban environment is gaining popularity amongst prospective urban dwellers.

Dew point is interface between dry heat and humidity. This is important in body’s ability to cool itself. because it is an element of thermal dis-comfort. Wet-bulb temperature is the measure of heat and humidity in keeping with how a human might experience heat. This is also important as it helps to evaluate the relationship between heat and humidity beyond human tolerance, as they interact in some parts of the world much faster than expected under global climate change (Raymond et al., 2020). O'Connor (2020) maintains "most climate scientists believed wet-bulb temperatures never rose above 35°C, and never would until the effects of global warming grew stronger later in the 21st century”. Sherwood and Huber (2010) extrapolate this further. They suggest a human body will overheat if heat and humidity combine to stop sweat from cooling the skin below 35°C irrespective of health, level of activity, or whether in shade or not, and with unlimited drinking water supply. Therefore, wet-bulb temperature at this rate and lower can be uncomfortable and dangerous to health.

Climate and Crime

Some studies highlight a positive correlation between the age of dwellings and suburbs with tree canopy coverage and socioeconomic markers (Troy, Morgan Grove and O’Neil-Dunne, 2012: Donovan and Prestemon, 2010). They also link this to population vulnerability, and propensity for crime. However, other disparate and stratified studies focus on specific locations and homogenous groups. To control variables in these studies, many observed variables impact on urban landscape, density, and crime relationships (Nieuwenhuijsen, 2020). Extant literature that examines northern hemisphere case studies suggests vegetation influences crime in both positive and negative ways. Examples of positive impact include mitigating the likelihood of crime through cooling of the immediate environment and community temperament, the appearance of maintenance and perception of care. Examples of negative impact include increasing the likelihood of

crime when it provides subterfuge. These are discussed further in this section.

Muggah (2021) reports a non-linear association between variables of climate and crime. Their observations include climate-related stressors that cause significant variances in violent and non-violent forms of crimes “ranging from homicides and assaults to robberies and burglaries”. Such weather events have become more commonplace, and although the extent to which these links apply, varies, Anderson and Anderson (1984), Anderson, Bushman and Groom (1997) and Rotton and Cohn (2004), who linked climate-related stressors and extreme temperature events with crime, and distinguished between “short-term shocks (cyclones, tornadoes, forest fires and floods), and long-term stressors (droughts and sea level rise)” (Muggah, 2021, p.3) generally imply that rising temperatures can cause a significant rise in crime.

Ranson (2012) predicted a dire situation based on a survey of over 3,000 counties in the United States. The study anticipates a dramatic increase in crime by 2100, with an estimated 35,000 additional homicides, 216,000 more rapes, and 1.6 million aggravated assaults. Assaults with a deadly weapon, 409,000, and 3.1 million annual robberies. Further, Harp and Karnauskas (2020) evaluated 42 global climate models across 16,000 US cities and estimated an increase of between 2.3 and 3.2 million more violent crimes by 2100. These events can be attributed to high density populations and susceptible locations.

Many vulnerable communities are already impacted by extreme weather events and are dealing with severe economic and social impacts resulting from these. Inequities and ability to adapt exist across geographic locations. Examples include District 4 Vietnam, Copenhagen, Calcutta, Venice, Vancouver, The Maldives, The Torres Strait, and Australian States of New South Wales and Queensland. These are but a few amongst many more which underscore community divisions relating to approach, response, and adaptation issues, highlighting the challenge of seeking unification in mitigation planning (Moosa, Do and Jonescu, 2020). Notwithstanding this, scalable studies at the individual, local, and regional levels remain critical in Australia, even as most populated metropolitan centres are in proximity to areas most vulnerable to imminent pressures of extreme weather events. To this end, further cross-sectoral leadership will be necessary to coordinate an industry-led collaborative research approach and action a cohesive adoption of adaption strategies to enable a resilient and sustainable approach at local and national levels.

Mares and Moffett (2015) assessed the link between climate change on levels of violence across 57 countries, sampling both western and non-western countries with regression results suggesting an increase in 1 degree Celsius in annual temperatures equated to an approximate 6% average increase in homicides. The authors later examined the impact of climate change on crime at specific times of the year. They had utilised monthly crime statistics in the United States, set against historical weather data that were collected by the Global Historical Climatology Network. Findings from these highlights a positive correlation between climate and crimes, with evidence supporting monthly variance clearly (Mares and Moffett, 2019).

Amati et al. (2017) undertook a study across 139 metropolitan local government areas in Australia between 2015 and 2016. They established an estimated canopy cover and several socio-economic disadvantage benchmarks. Their calculation highlighted “heat island intensity” using satellite imagery, where they identify “hotspots” or heat islands across Australia through readily available data. The study also developed a vulnerability index that show areas of socioeconomic

and health disadvantage which coincide with a lack of green cover and a high incidence of heat. Notwithstanding this, both global and local analyses have demonstrated that median household income to be one of the strongest determinants of urban crime incidence with other demographic variables such as homogeneity, prevalence of specific typologies (such as tobacco retailers), and the number of abandoned properties were also positively associated with urban crime (Yu and Fang 2022).

Kuo and Sullivan (2001) also undertook studies on Ida B. Wells, a large highly densified public housing development in Chicago. The case study shows a “homogeneity” representation that is disproportionately high, with a lack of diversity evidenced in female residents (65%), African American (97%) and unemployment (93%). In addition, the study also sought to evidence a link between vegetation and crime, whether the former persuaded criminal behaviour based on passive surveillance and sentiment of ownership and safety. This is an important addition to knowledge as other research have only sought to link vegetation to urban heat islands where the heat itself is the subject of study in its effect on criminal behaviour. Donovan and Prestemon (2010) also consider the impact of vegetation density by relating it to limiting visibility and natural surveillance, in ways that advance the conversation on perceived safety through prevention e.g., inclusion of street lighting, security bars and systems, and the physical structures themselves.

The environment, psychological health, and safety are examined in Branas et al. (2011). The authors used incivility and broken windows theories to frame their research. They discovered that health and safety results relate to perceived attitudes of managed urban greening of empty spaces in Philadelphia, cared for and considered as "orderly" (as though someone had "power" over them). Greening's physiological and temperature effects on health and safety were not examined in the study. However, some associations imply major statistical decreases in some crimes, while others show the contrary, such as disorderly conduct, which grew dramatically, and unlawful dumping, which only increased in specific city regions.

Poorly constructed urban places where people are exposed to human tendencies constitute a safety risk. People avoid poorly lighted, low-traffic places that may attract crime (Jacobs 1961, 89). Oc and Tiesdell (2007) argue that public spaces become socially sustainable due to increased occupancy and activity, passive surveillance, and extended habitation through "fortification approaches". These involve physical segregation and territorial defence, spatial governance within fortified and controlled spaces, and "regulatory approaches" that regulate public spaces and protect local municipal assets. Jonescu et al. (2018) demonstrate how surveillance technology might be integrated into urban environments to govern public places. These important planning principles reduce crime by encouraging occupancy, territorialization, and social involvement in urban places. They also deter inhabitants from disruptive behaviours, vandalism, and other minor offences that affect personal and spatial safety. However, permeability, sightlines, and visual access are necessary for beneficial community interactions and social behaviours that improve safety perception and reality (Jacobs 1961, Newman 1977).

Newman (1977) argues that a sense of ownership over a person’s immediate urban environment empowers them for greater accountability and responsibility. In addition, according to Oc and Tiesdell's (2007), in an "animated approach" to urban design, public spaces must be socially sustainable through increased use, passive surveillance, occupation, and

activation. When communal places lack critical components of good urban design, lighting and activities that encourage participants to venture outside and stimulate community interaction, safety perception becomes crucial. Passive monitoring of a section of the population will lead to an increased sentiment of safety for communities to act in coordination with collective power to prevent undesirable behaviours (Jacobs 1961, Cozens and Grieve 2009, Jonescu 2013). These elements address observations against key criteria outlined by Gehl (2011). The elements are protection, comfort, environment, urban density, level of activity, increased physical participation, decreased volume, traffic noise, pedestrianisation, and occupation of spaces. Other authors also agree these variables shape fundamental principles for designing urban environment that are socially sustainable (Cozens 2011; Jonescu et al., 2020).

Methodology

Case Study Development

This study utilised the *Australian Real Estate Search, Suburb Reviews, and Local Q&A* website (www.homely.com.au) to understand residents' sentiments throughout a cross-section of north, south, east, and western suburbs across Perth. Inclusion criteria included suburbs with a mix of land-use and are well-established, within 50 to 100 years of existence. Uses considered include infrastructure, spaces, and buildings, that have, or are in the process of regeneration, including a blend of residential infrastructure, commercial, industrial, urban spaces, public transport and nodes, and civic infrastructure such as town halls, leisure, community and cultural centres, and theatres. Healthcare, childcare, police, and justice (courts), and primary to tertiary education facilities were also included. Essentially, the study focused on a township that has grown substantially and is pressured to densify and regenerate. From investigation, the study selected eastern suburb of Midland as suitable for a detailed analysis.

Further literature published by the City of Swan, the municipality in which Midland resides, further substantiates this position. Midland was established in 1832, with a paucity of development until the Midland Railway Company commenced operations in 1886. This set forth a rapid expansion with a development of diverse mix of services and buildings to serve the growing community, including the Town Hall in 1923 where a clock is an iconic landmark. The State Abattoirs had operated in Midland from 1914 until its recent renewal, now a large commercial precinct. The 1960s and 70s bought with it shopping centres, the merging of the Town of Midland with the Swan-Guildford Shire to become the Shire of Swan (now the City of Swan). Further developments in the 80s included a new Police Station, Court house, another shopping centre, and leisure centres. Midland Redevelopment Authority (established in 2000) has significantly influenced the historical town's revitalisation, and boosted its economic growth, tourism potential and business investments. Midland Authority became part of the Metropolitan Redevelopment Authority in 2012 (City of Swan, 2022).

Drawing from *Suburb Reviews* of the *Australian Real Estate Search,* Midland received mixed online reviews. The suburb was described as a place that has a little bit of everything. It is situated on the outskirts of Swan Valley, thus a beautiful town with some amazing old buildings and a great place for walks, and the Swan River. Moreover, Midland provides a choice of public and private schools and hospitals, shopping centres and services within walking distance. It is located

near Perth Hills, with a high-rated public transportation system. Not only these, but Midland is also multicultural and had weekly community events such as Sunday Fresh Farmers Market, and several other family gatherings that benefited the community. The quality of its new oval development is high. However, criminality and certain undesirables were raised a significant concern (Homely 2022). Whilst some reviewed only expressed a positive sentiment towards Midland's ease and convenience for shopping, critical concerns have been reported. Numerous abandoned places have attracted a fear response. Violence and excessive 'hoon' driving were common. Shopping trolleys were an eyesore. Drugs and wanton damage to almost metal fencing was rife. Some reviews said verge grass was knee-high, and that signages and parks were in disarray. Taking a night-time walk alone was dangerous. Some review comments also described Midland as a historic town with a tarnished reputation – although, this is not entirely true, the motivation for such a conclusion is unclear.

Some reviewers also think Midland was not a place where anyone would want to settle down permanently, nor was it ideal for families with children because of the possibility of being confronted with drug usage. Nonetheless, some reviewers recommended it as the ideal location for people looking to buy or rent an apartment due to its strong investment hub – proximity to train station, shopping centre, local restaurants, hospital, and a soon-to-be university campus were an advantage. Rental properties were described as plentiful, some offering excellent value, while many older properties are being demolished and rebuilt with condominiums and townhouses (Homely 2022). The sentiments outlined appear to be consistent with Midland being a place that has a little bit of everything for everyone. The study then undertook a review of temperature, vegetation cover, population, and crime statistics data for the case study location.

Method Design

This study applies three research methods. Figure 1 presents a relationship diagram between the research methods applied in this study.

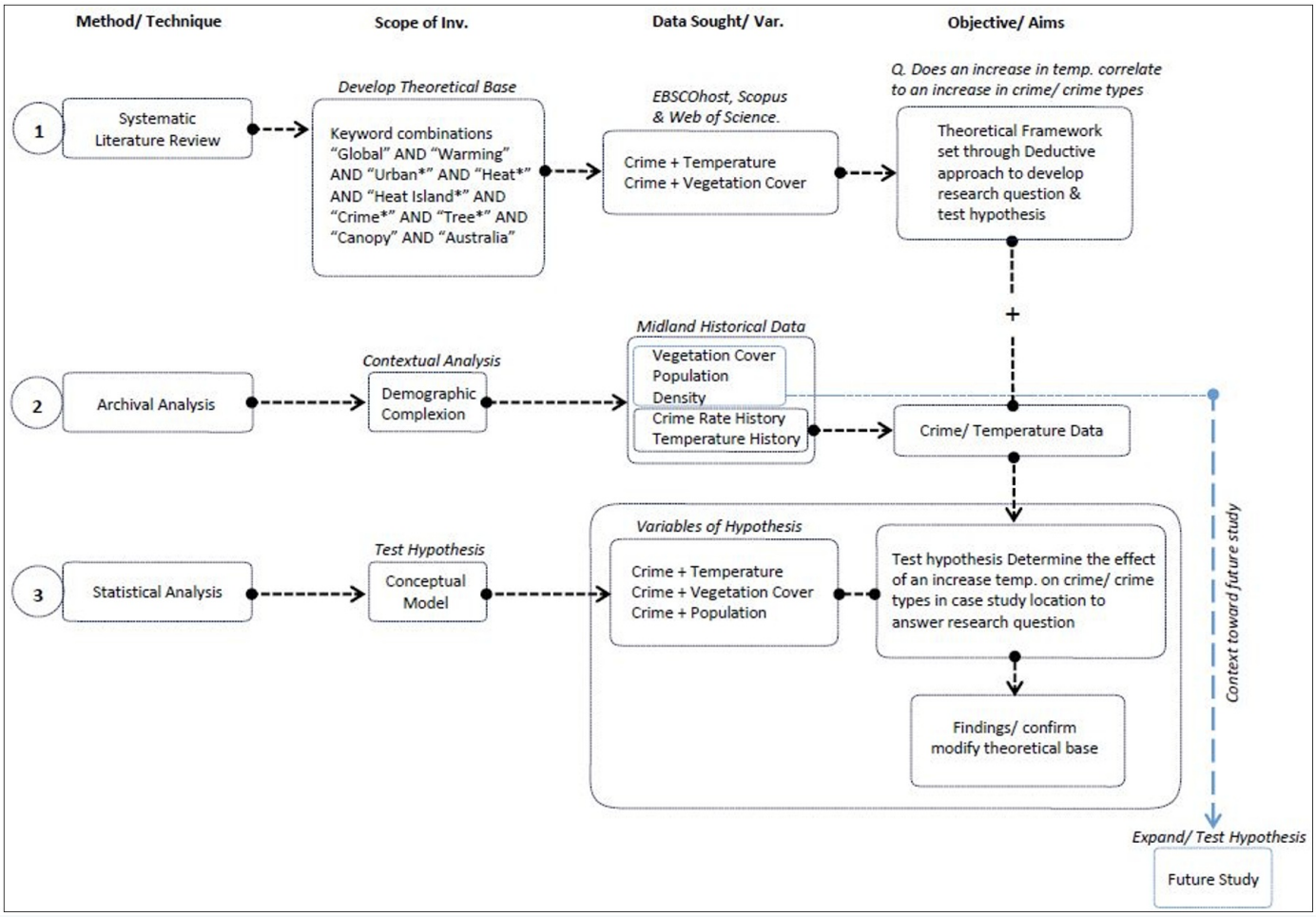


Figure 1. Diagram of research methods and their relationships.

A review of extant literature reported in this study has provided an understanding of some of the variables to be analysed in the study. City of Midland is the case study location. In addition, the review has presented theoretical correlation between climate, temperature, vegetation cover, population, and crime statistics. An objective of this study is to undertake statistical correlation in relation to patterns of criminal behaviours and deviations from thermal comfort. Such an intersection between heat and urban crime is important in highly urbanised areas generally, not least the Australian environment. Archival data were explored using cross-referenced weather station temperatures near the case study area with ACORN-SAT used by the Australian Bureau of Meteorology to track long-term temperature changes nationwide. Scope of capture includes Perth Metro, Perth Airport, and Upper Swan, all 4-15km from Midland CBD. CSIRO's Urban Monitor was utilised to measure vegetation coverage, using Mesh Block Vegetation and Tree Canopy Cover. Relying on Caccetta et al. (2018), this technique uses "grass", "shrubs", and "trees" to characterise vegetation by height: 0.5m, 0.5–3m, and >3m. Canopy coverage is provided in square metres. Further contextual studies are conducted of the Midland suburb including population, age distribution, population density and anticipated growth. The overarching purpose of this research is to test a hypothesis on the relationship between temperature and crime behaviours:

- H1: higher temperatures increase crime rates.

Midland Police District (Figure 2) is the define catchment of the study, consisting of three local government areas: City of

Swan, City of Kalamunda, and the Shire of Mundaring. Mean monthly temperature data for the study were extracted from the Bureau of Meteorology (2022), with Perth Airport Station Number 9021 being the closest weather station. Crime statistics from the WA Police archives were extracted from the Western Australian Police (2021). They cover records of offences that are known to Midland Police within the relevant periods, excluding incidents categorised as no criminal offence, offence substituted, false report, mistakenly reported, or entered in error. Monthly crime statistics were taken from January 2007 - December 2020 (data for the study including the year 2020 was treated with caution because of COVID-19 pandemic and the social restrictions that came about in controlling it).

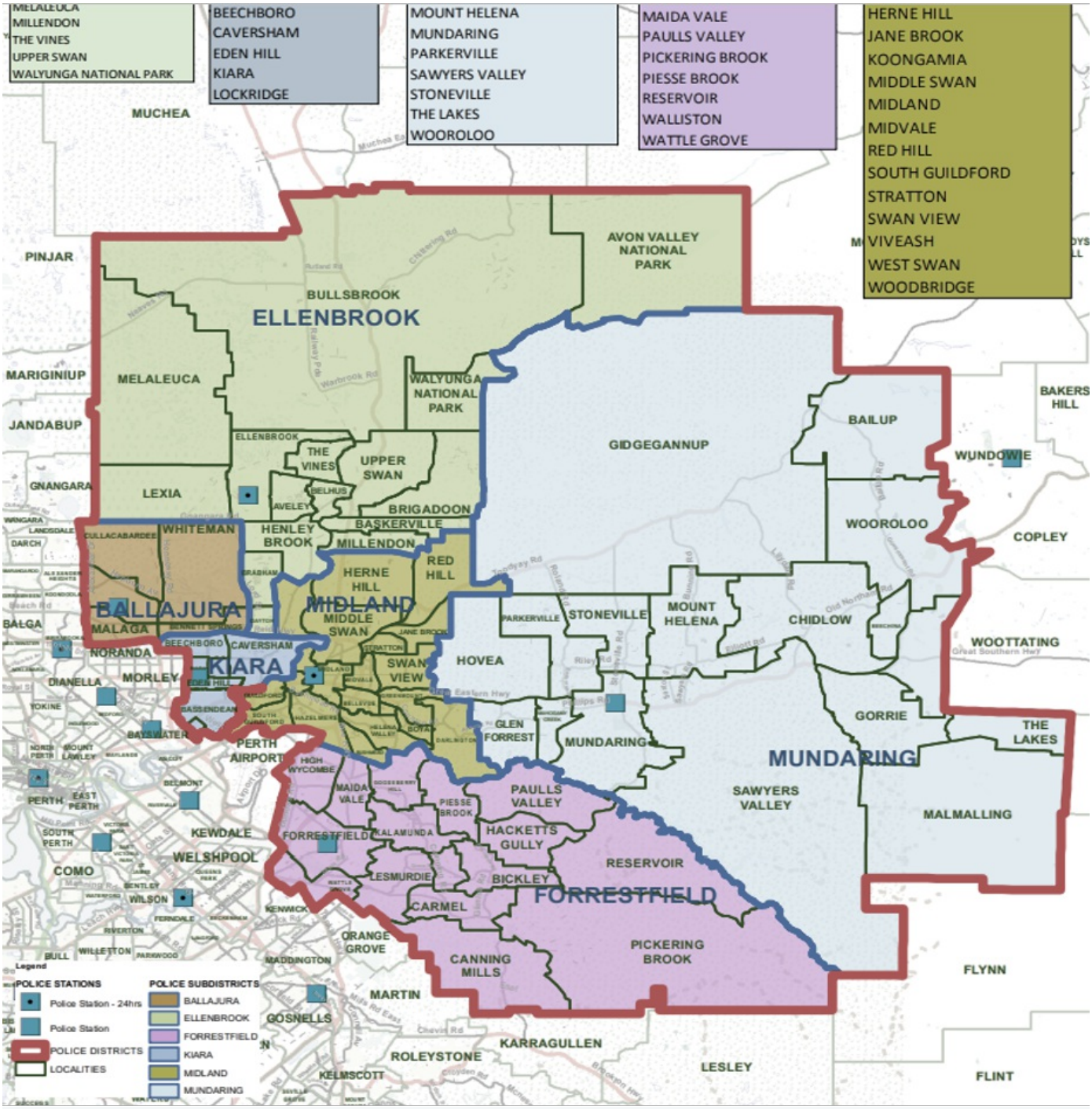


Figure 2. Midland Police District, Source: Western Australian Police Force, 2021.

All data obtained for the purpose of the study are open source and publicly available from: City of Midland,

Australian Bureau of Meteorology, CSIRO's Urban Monitor, and Western Australian Police Force.

Data Classification

Crime classification is by the Australian and New Zealand Standard Offence Classification (2011), WA Legislation, and operational reporting requirements (Western Australian Police, 2021). From WA Police Crime statistics published online, current research considered 9 crime groups, including:

1. Offences against a Person (OaP), such as Homicide (Hom), Recent Sexual Offence (RSO), Historical Sexual Offence (HSO), Assault (Family) (A_Fam), Assault (Non-Family) (A_nFam), and Threatening Behaviour (Family) (TB_Fam). Others in this category include Threatening Behaviour (Non-Family) (TB_nFam), Deprivation of Liberty (DoL), and Robbery (Rob).
2. Selected Offences Against Property (OaPty_Sel),
3. Drugs (Drugs),
4. Receiving and Possession of Stolen Property' (RnP_SP),
5. Regulated Weapons (RWp),
6. Graffiti (G),
7. Fraud and Related Offences (Fraud),
8. Breach of Violence Restraint Order (BVRO), and
9. Selected Miscellaneous Offences (MiscO_Sel).

Contextually, *Family* means partner, ex-partner, parents, guardians of children, and children who reside or regularly stay with involved parties. *Non-Family* crimes are acts against people that are not included in the*Family* bracket. In addition, there are sub-category classifications of the WA Police that this current research did consider in its analysis. There were five of such sub-categories under OaPty_Sel. They include Burglary (Bug), Stealing Motor Vehicle (S_MV), Stealing (St) - including from motor vehicles, Property Damage (ProDmg) and Arson (Ars).

WA Police's crime categories and sub-categories were analysed by total crime rates per 100,000 people[1] Total population was based on the annual Estimated Resident Population (ERP) published by the Australian Bureau of Statistics (ABS 2021). The research assumes that population growth was linear between two consecutive years – as shown in Equation 1.

$$Crime\ per\ 100,000 = \frac{Crime\ Count}{ERP\ x\ 100,000} \quad \text{(Equation 1)}$$

Findings

Mean Monthly Temperature

From January 2007 to December 2019, there were 156 mean monthly temperature readings with mean (μ) = 25.50ºC and standard deviation (σ) = 5.22ºC. The median was 24.95ºC, and the minimum and maximum temperatures were 17.5ºC (August 2016) and 35ºC (January 2010) respectively. As shown in Figure 3, the mean monthly temperature histogram had two peaks, due to the seasonal effects. Since this data distribution was non-normal, non-parametric statistical tools were used to test H1.

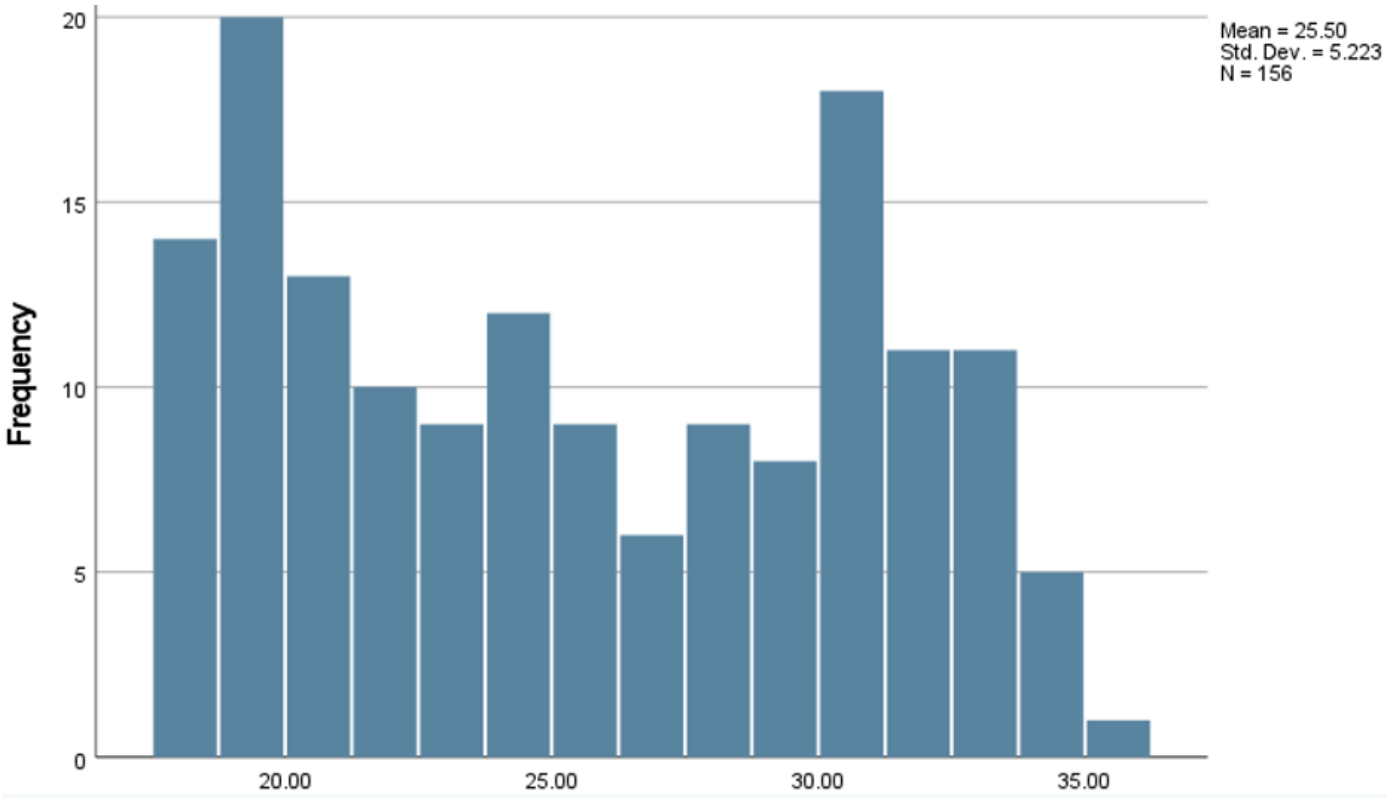


Figure 3. Mean Monthly Temperature Histogram

Monthly Crime Rates

Table 1 shows descriptive statistics for monthly crime rates for crime groups and sub-categories. Of the main groups, *OaPty* (μ=529.22; σ=71.25) has highest average crime rates, followed by *OaP* (μ=128.16; σ=26.12). In the sub-categories of *OaP*, *A_Fam* (μ=49.89; σ=16.77) and *A_nFam* (μ=38.07; σ=7.27) were the major crimes in Midland district. For Properties, stealing (μ=253.39; σ=28.47) was a main form of crime between 2007-2019.

Monthly mean temperature versus monthly crime rates

To test H1, this research set the null and alternative hypotheses as below:

- H_0: there is no significant correlation between monthly crime rates and mean monthly temperatures.

- H_a: there is a significant correlation between monthly crime rates and mean monthly temperatures.

Table 2 illustrates only the statistically significant associations at the 95% confidence level ($p \leq 0.05$). Three categories of crimes indicated significant statistical correlations. *OaP* shows the strongest correlation ($r=0.336$; $p<0.001$). The R-squared value shows about 12.5% of data fit the trendline. *Drugs* and *RnP_SP* indicts weak negative correlations with mean monthly temperature. Therefore, association between crime categories and monthly temperatures for Midland District is limited. Following these observations, sub-groups of *OaP* and *OaPty* were analysed further. Table 2 indicates *A_nFam* ($r=0.449$; $p<0.001$) and *Ars* ($r=0.485$; $p<0.001$) showed moderate positive relationships with monthly temperature. Since data distributions were non-normal, researchers relied on Spearman's correlation coefficients. IBM SPSS Statistics 28 was used to test the hypothesis.

Table 1. Descriptive Statistics for Monthly Crime Rates for Crime Groups and Sub-Categories

Crime Categories	N	Mean	Median	Standard Deviation	Kurtosis	Skewness
Main Categories						
OaP	156	128.16	123.23	26.12	0.6090	0.5534
OaPty	156	529.22	515.28	71.25	0.7408	0.1561
Drugs	156	64.84	61.82	24.69	0.5565	-0.1525
RnP_SP	156	10.27	9.51	5.41	1.3282	2.5762
RWp	156	11.61	11.18	5.06	0.7716	1.1155
G	156	38.31	8.50	54.43	1.7257	2.1405
Fraud	156	48.11	43.23	36.30	1.9564	7.6247
BVRO	156	25.72	23.87	11.98	1.9630	6.8435
MiscO_Sel	156	112.14	101.79	48.79	1.2623	1.9783
Sub-Categories - OaP						
Hom	61	0.78	0.52	0.56	4.0569	22.1440
RSO	155	9.64	8.30	7.87	7.9334	83.0057
HSO	156	7.30	5.64	6.80	3.4162	17.4099
A_Fam	156	49.89	48.47	16.77	0.3396	-0.5024
A_nFam	156	38.07	37.55	7.27	0.3819	0.2443
TB_nFam	156	9.75	9.64	3.15	0.3313	0.0466
TB_Fam	155	6.91	5.76	4.21	1.2871	1.9033
DoL	125	1.19	1.03	0.71	1.1729	1.7460
Rob	156	5.40	5.19	1.96	0.6717	0.5956
Sub-Categories - OaPty						
Bug	156	124.48	120.89	25.89	0.6347	0.0950
S_MV	156	27.78	26.61	7.02	1.0634	1.9481
St	156	253.39	253.06	28.47	0.3808	-0.0238
ProDmg	156	118.66	114.06	27.62	0.6054	0.0463
Ars	155	4.93	3.99	3.33	1.6182	3.4552

Table 2. Spearman's correlation coefficients between mean temperature and crime rates

Categories of Crimes	Mean Monthly Temperature	
	Correlation Coefficient (r)	Sig. (2-tailed)
OaP	0.336	<0.001
Drugs	-0.193	0.016
RnP_SP	-0.166	0.039
Sub-Categories - OaP		
A_Fam	0.201	0.012
A_nFam	0.449	<0.001
TB_nFam	0.167	0.037
Sub-Categories - OaPty		
Bug	0.208	0.009
S_MV	0.244	0.002
Ars	0.485	<0.001

Figure 4 shows about 20% of data fit the trendline. The positive correlation between*Ars* and temperature can be understood as hotter days leading to greater fire risks. This finding underlines the need to further study why higher temperatures increase assault rates towards non-family members.

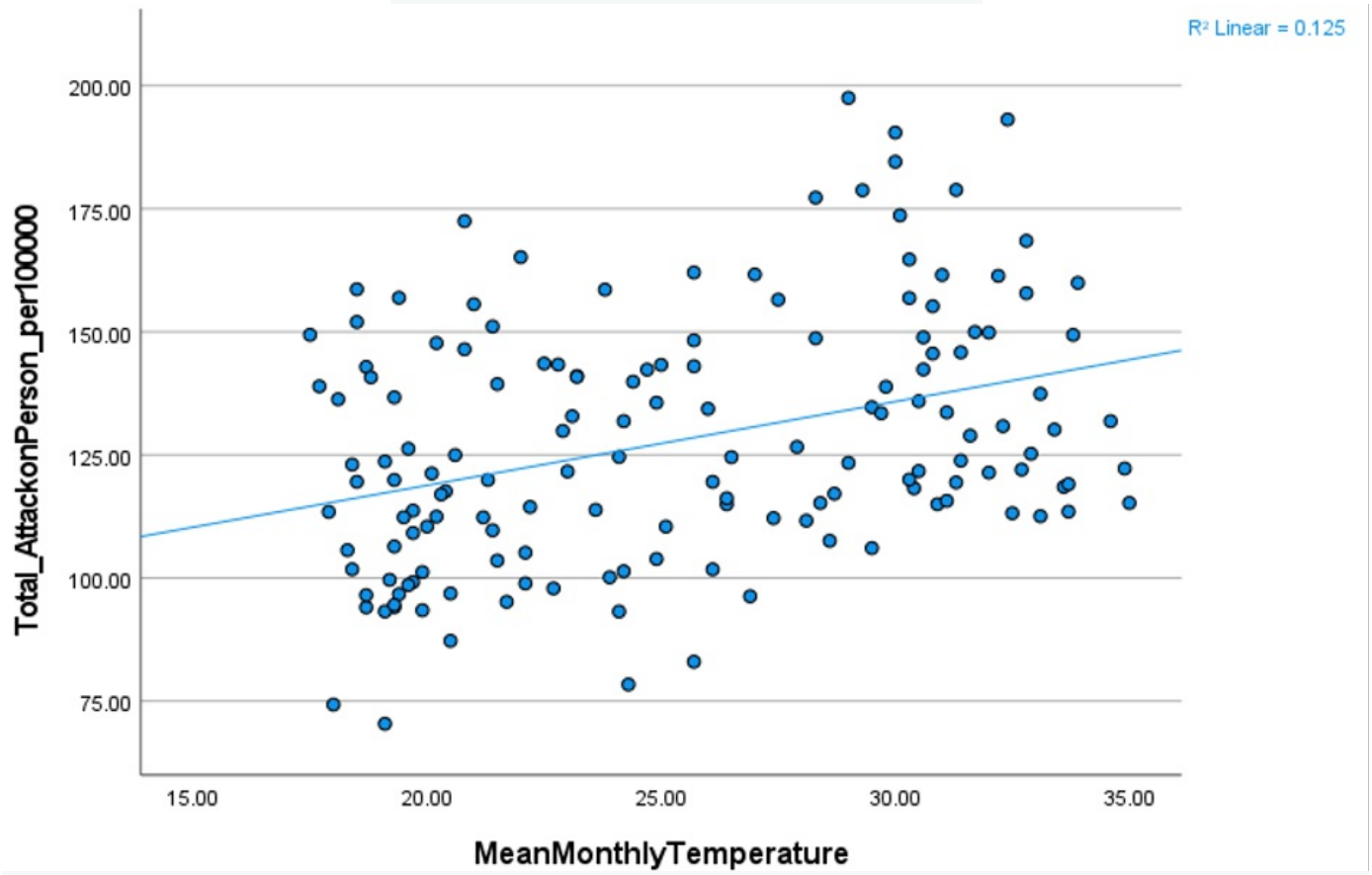
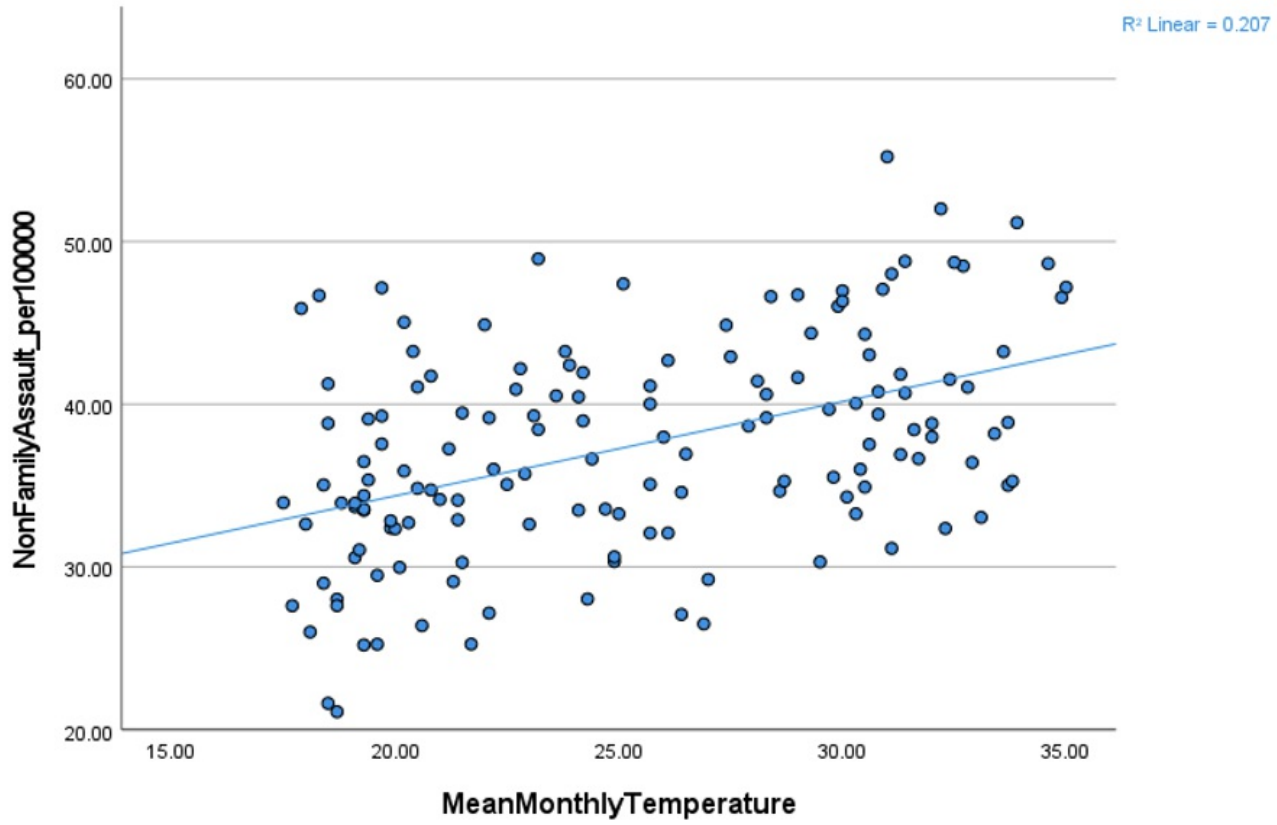
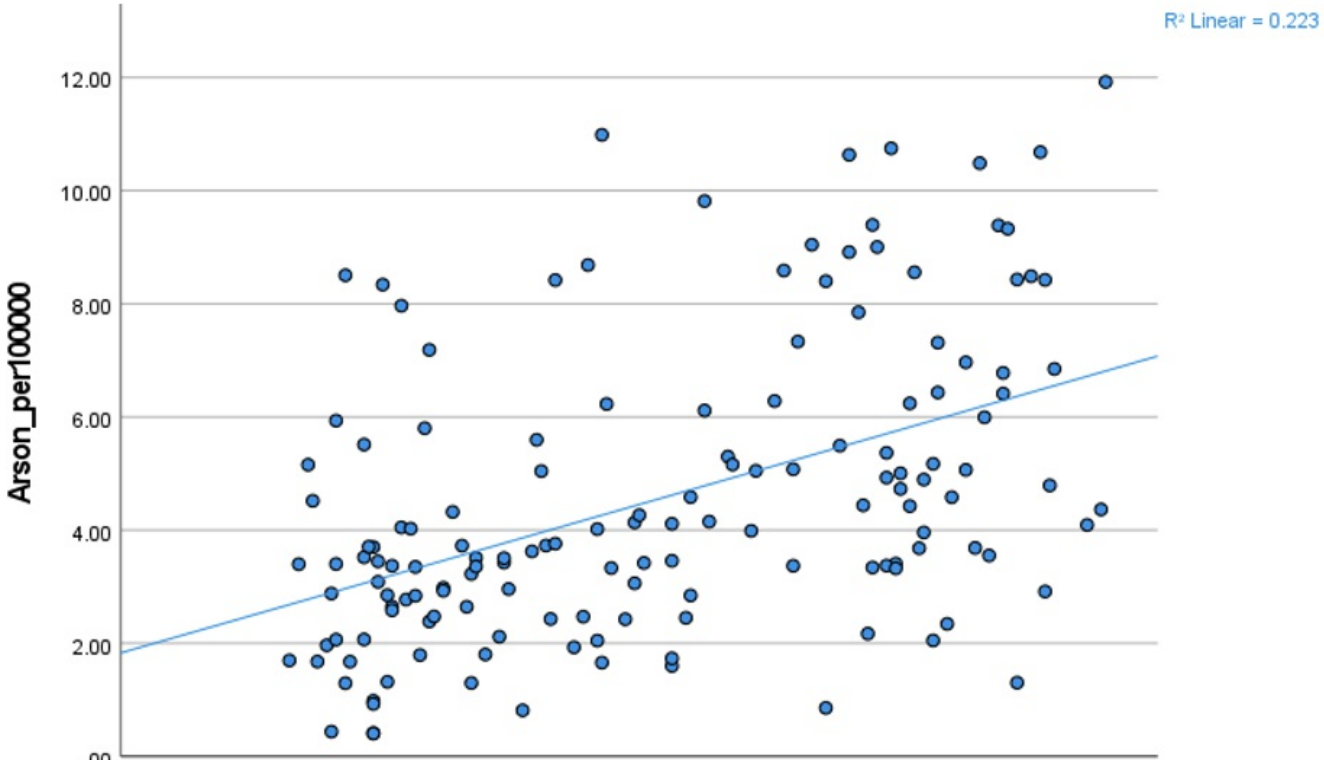


Figure 4. Scatter plot of AoP against mean monthly temperature

(i) A_nFam versus mean monthly temperature



(ii) *Ars* versus mean monthly temperature



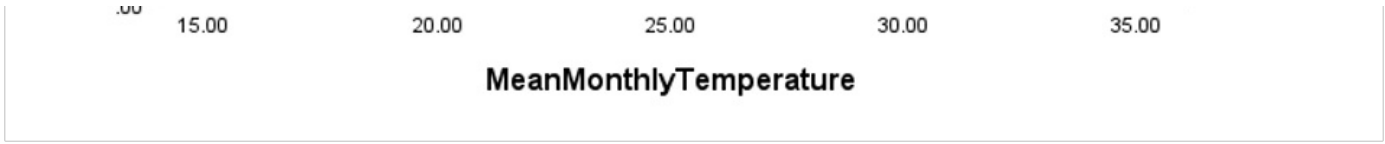


Figure 4(a). Scatter plots between *A_nFam* and *Ars*, and mean monthly temperature

Analysis of Midland: Vegetation Cover, Population and Crime Statistics

A report by the Department of Planning, Lands and Heritage (2021) shows Mesh Block Vegetation Cover and Tree Canopy for Midland in 2009 and 2016 *increased* from 7.98% to 10.39% of landmass. In addition, according to datasets of the ABS (2021), Midland's population of 6,335 (median=39) is spread over a landmass of 4.2km^2 (density=1,508 persons/km^2. Midland CBD has a population of approximately 1,142 people over a landmass of 2.05 km^2. The population of City of Swan municipality, in which Midland exists, is projected to rise by 85% by 2051. Number of dwellings required is predicted to increase sharply over the same period to keep in step with population growth.

Midland Crime Statistics

AoP statistics are 2,475 (2009), 4,598 (2016), 4,296 (2019), and 4,794 (2020). From these figures, 2009 to 2019 represents an 87% increase. ***AoPty*** statistics are 13,037 (2009), 14,368 (2016), 14,123 (2019), and 9,911 (2020) also rose on long-term trends but decreased significantly between 2019 and 2020. The reduction coincided with the first COVID lockdown in March to April 2020, and subsequent easing of restrictions ending in June 2020 presents an anomaly. Western Australian Police (2021) Crime Statistics Timeseries Data suggests overall OaP in Midland District increased. Historical sexual assault and Recent sexual assault increased 27.7% and 91.7% respectively also. Threatening Behaviour (Family) also rose by 30%. Similarly, AoPty decreased by 29.8% between 2019 and 2020 (Figure 5).

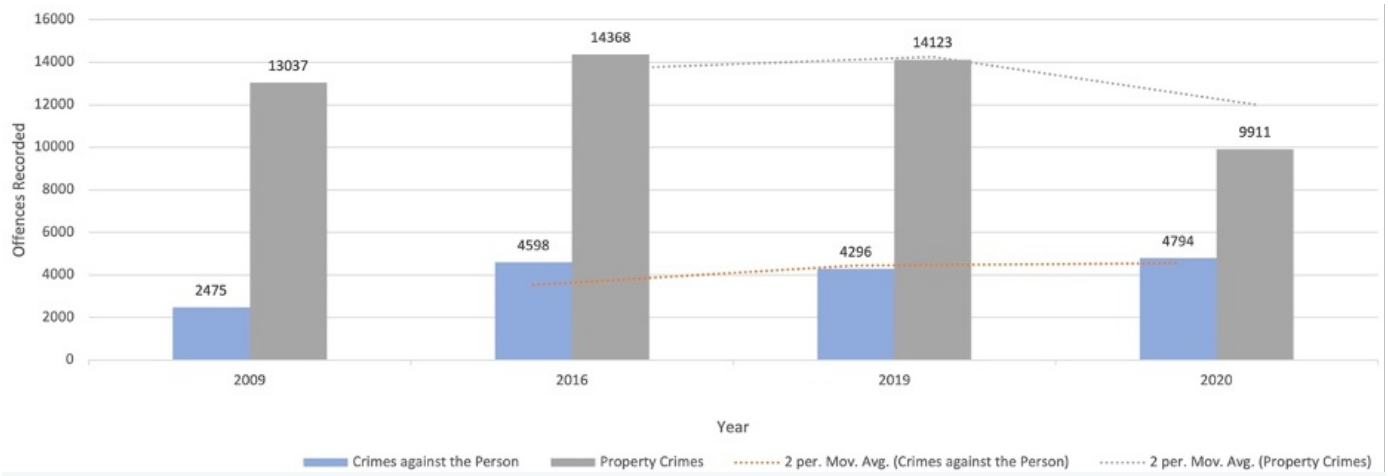


Figure 5. Midland's Crime Statistics (2009-2020). Adapted Western Australian Police (2021).

Statistics shows ±20% or higher between summer months of December to February, in comparison with the preceding 9-month average. Between 2007 and 2020, Western Australian Police (2021) figures suggest that this occurred on three

occasions for ***AoP*** (the average from March 2012 to November 2012 contrasted with December 2012 to February 2013 (+25%). Also, between March 2014 and November 2014, set against December 2014 to February 2015 (+21%), and averages across March 2018 and November 2018 compared with December 2018 to February 2019 (+22%).

This did not occur for *AoPty* but on one occasion, the average of March to November 2010 when compared with December 2010 to February 2011 (+19.6%). Across most other similar comparisons in this category, most increases are of less than 5%, and on three occasions had reduced between negative -0.5% to -10% (March 2009 to November 2009 compared with December 2009 to February 2010 (-10%)). It is also important to note that in Australia, December to February coincides with school holidays, which also coincides with increases in some crime categories.

Validation of Findings

Findings from this study support the notion of negative affect escape theory (Baron 1976). Baron posits a positive correlation exists between temperature and aggression but shifts upon discomfort as temperatures exceeded 30°C. The study highlights inconsistency in generalisability of studies that traverse from North to Southern hemisphere and compromised the nuances of fundamental socio-demographics across study groups. For greater clarity, in Australia, major school/other holidays occur during summer. This draws attention to a subsequent increase in alcohol consumption highlighted in this current research. Almost all local government areas in New South Wales had increased incidence of assault in summer. However, this declined as temperatures exceeded 30°C. Spatial variations informing relationship between temperature and rates of assault suggests that the findings should not be generalised even at a state level. Age and gender of both the offender and the victim were also included in the variables analysed in this study. Findings highlight that proactive policing may be impacted by high temperatures due to reduced interactions leading to arrest.

Stevens et al's., (2020) study aimed to determine if the crimes such as assault, theft and fraud are influenced by season and temperature within New South Wales, Australia through analysis of 11-year temporal and spatial temperature-crime dataset within the Australian context. Their analysis included a linear regression model that indicates that daily assault increased with rising temperature. The empirical findings in this study further show the crime-temperature relationship, set through an Australian context. They also highlight a significant number of variables and limitations worthy of further research. Stevens's study compared assault patterns with social media anger in response to variance in temperature in N.S.W., Australia. Assault data included domestic violence-related assault, non-domestic violence-related assault, and assault against police. Temperature exposure was estimated from Australian meteorological datasets, and social media data derived from "We Feel" a publicly available tool. The empirical nature of the study was limited by its comparison of different populations. Notwithstanding this, the study concludes that routine activity theory outlined by Rotton & Cohn (2003) applies. They found aggressive crimes increase in the presence of warmer weather, on weekends, and holidays which appears to promote assaults. The authors posit that increased time spent outdoor socialising with people might concurrently limit opportunities for online presence and vitriol. This study highlights further allied research that relates temperature with certain types of indoor and outdoor activities and resultant behaviour.

Wolf *et al* (2020) provide a systematic review and summation of existing literature on the health impacts of urban trees.

They analysed 201 studies relating to human health, environmental health, and urban forestry, informing future research, policy, and nature-based public health interventions. The study found trees may mitigate urban HIE through decrease in localised temperatures and reduce the incidence of various types of crime especially for young individuals in low-income urban areas. However, many variables still exist. As conclusion and recommendations, the study suggests exposure to urban trees provides health benefits and are an essential component of a health promoting environment. The evidence put forward in Wolf's study should not be overstated given the number of variables. Urban trees should be considered integral to urban planning and management for social public health. In addition, Wolf *et al*s study is not in the Australian context and thus does not relate directly to local situations in Australia.

Wu et al., (2019) sought to determine if spatial access and distribution of urban parks in metropolitan Beijing and related to residential satisfaction, and how different socio-spatial factors influenced their perceived satisfaction in this relationship. The study's regression analysis suggested that the likelihood of satisfaction decreased as crime rate rises, as did the interaction between access to parks and local crime rates. The distance to parks suggested a statistically significant association with perceived satisfaction "towards the greenness domain" such that immediacy of park access results in higher satisfaction. Variables considered in the analysis included four categories: residential satisfaction, spatial access of urban greenness, neighbourhood characteristics, and household demographic characteristics. Demographic characteristics included: age, gender, education, income, and family size. However, the study sample is significantly more homogenous than Australian context. Urban park-related variables in the study considered distance to and size of park. Although this study does not directly align with the parameters of this research, it highlights the existence of other critical environmental considerations that influences behaviour beyond the scope of other studies.

Baryshnikova, Davidson and Wesselbaum (2021) assessed weather–crime relationship at an hourly level rather than daily. At an hourly rate precipitation was found to be a more significant variable on crime than temperature, and thus should not be disregarded. The research also studied relationship between four other weather variables (temperature, humidity, precipitation, wind speed) and crime. Crimes included in the study are a select group of violent crimes and property crimes and city-level data, collected over 2014–2017 from Chicago, Indianapolis, Los Angeles, and New York, the largest cities in the USA by population. Findings suggest that relationship between weather and crime differ significantly and is non-linear when observed at a daily versus hourly intervals, and their subsequent impact on results and conclusion are relevant. The study, though not in the Australian context, further supports the notion that other variables are significant and must be considered.

Discussion

This study espouses the complexity and variables involved in linking heat and HIEs to crime and violent behaviour. Only one study, Stevens et al., (2020), has examined how seasons and temperature affected crime rates in Australia. Assault, theft, and fraud are amongst the variables examined. They are directly related to this research. In contrast, other studies had focused on heat related to social media behaviour and health. Moreover, this research highlights a paucity of existing studies beyond the United States and European contexts. Therefore, studies are unlikely to be generalisable to other

socio-economic circumstances, cultural, and ethnic circumstances beyond the context studied. The study suggests that much of the literature reviewed has significant limitations or does not consider criminality holistically or as part of a complex ecosystem of society, social norms, and morphology of landscape over time.

In Perth, tree canopy area increased by 4% between 2009 and 2016. Tree canopy coverage and suburban maturity have been widely researched (Lowry et al., 2012; Luck et al., 2009; Mockrin et al., 2019). Troy et al. (2007) found that residence age and tree coverage are positively correlated (around 45 years). Mockrin et al. (2019) found different relationships between dwelling age and urban tree canopy. These relationships were non-linear and negative when comparing United State locations. Lowry et al. (2012) added that community and housing age influenced the relationship between urban tree cover and socioeconomic factors of vegetation cover. Luck et al. (2009) found that housing density increases vegetation over time, showing that communities ‘green up’ after development.

Global studies also neglect "blue" infrastructure like coastal areas and vast bodies of water. Thermal mass and direction are also a vital omission. Most capital cities in Australia are located around the coast, which is colder and wetter than interior places. As air travels from high to low pressure zones, cooler ocean air pushes toward warmer air onshore, generating a sea breeze. This cools coastal areas but not interior areas. Blue infrastructure was rarely included in heat-crime research, nonetheless a key variable in HIE. Urban development's influence on cooling channels may have substantial implications for understanding sea breezes in cities.

Research typically correlates environment, vegetation, social, and demographic information. Law enforcement efforts and initiatives are usually overlooked e.g., police "actions" that target certain forms of crime in specific locations. Guerette and Bowers (2009) found this may lower crime in targeted regions while increasing crime in non-targeted areas. Normative literature, e.g., Clarke and Weisburd (1994) has reported on crime implications of displacement and diffusion. Moreover, transit nodes are and their surrounding environments that the extant literature suggest are interconnected are largely not considered as variables in the heat-crime literature as it is in the urban-crime literature.

Moreover, studies do not typically attribute drug use as a variable in the populations studied. For example, the impact of heat on drug affected persons and crime. Surveys relating to illicit drug use by people aged 14 and over in Australia considered age, geographic area, level of socioeconomic advantage and disadvantage, and a person’s education (Australian Government [Australian Institute of Health and Welfare], 2020). In 2019, 43% people in Australia were reported to have used an illicit drug at some point in their lifetime, whilst 16.4% had used one in the last 12 months. For example, the use of cannabis, cocaine, ecstasy, inhalants, hallucinogens, and ketamine all increased from 2016 to 2019, and so was non-medical use of pharmaceuticals, painkillers, opioids, and codeine. Future studies may draw to conclusions on such increases and their relevance to variables of crime, urban tree canopy, heat and HIE.

Crime statistics need to be considered proportionately and examined per 100,000. This is to examine the correlation between crime rate and population growth, dwelling growth, and growth in economic activities. In addition, offenders' statistics may include alleged offences that are later retracted or unsubstantiated, which are not redacted from databases and risk biasing results. In Australia, lesser incidents such as disturbances, disorderly behaviour, damage, and other events may be reported to municipal rangers instead of police. Such occurrences are not included in police crime

statistics, and offences of a sexual nature, and domestic violence are more likely to affect women, children, and disadvantaged socioeconomic groups, regardless of vegetation density. Such crimes may be underreported due of apathy toward authority and sensitivity of the crime type.

Service and coverage may vary per municipality. The percentage of house ownership and rental might also impact findings; however, they are not uniformly examined among studies. Crime may also change with population density. Radial, suburban, and gridded patterns that create mono-functional zones or segregated precincts may catalyse crimes. High-rise residential with mixed-use, single residences, pedestrianised precincts and public realm, vehicular-dependent cities, rate of movement, and scale also affect sustainable densification and placemaking (Jonescu et al., 2018).

Prima fasciae, the Midland case study does not suggest a positive correlation between temperature, crime statistics, green canopy cover (which rose over time) with population density. Thus, longitudinal studies might draw to different conclusions across the literature reviewed. Accordingly, future studies could consider recidivism rates [small fraction of the population overrepresented in crime statistics], in conjunction with population density. Heat, HIE, and canopy cover may not affect recidivism rates, which may have grown independently of population expansion and density.

Conclusion

Although existing studied have drawn correlations between temperature and crime rates there are many such a correlation could occur in the absence of longitudinal studies. The current study draws to various anomalies worth of further investigation such as recidivism, urban composition of the areas being studied, and variables that exist beyond temperature, population, and crime. Further considerations should be cognisant of economic downturns, recession, unemployment, and inflationary pressures that may cause cost of living pressures (and other critical events) that may lead to an increase in certain categories of crime. Apathy in reporting with perceived non-action by authority may impact crime reporting and thus not be reflective of the occurrence of crimes in the statistics. Findings from this study highlight the significance of variability in location-based climate change outcomes.

The study emphasise that; the heat-sink properties of thermal mass which can lead to exacerbated UHIEs; orientation, which can influence passive cooling; and blue grids which, in conjunction with orientation and breezes can be utilised to alleviate heat, are often ignored in normative literature, in the design and development characteristics of cities researched. Urban morphology mediates immediate micro-climate heat islands with dramatically different temperatures from surrounding local belts.

Human behaviour and criminality, and their interactions with social systems are multifaceted. They often make urban design decisions difficult. The challenge is exacerbated by changes in macro- and micro-climates. Urbanisation and de-greening, leading to urban heat islands (UHI), are important also. Extant literature is in its infancy and mostly based on Northern Hemisphere case studies. Yet if hypotheses concerning symbiotic links between urban environment, local atmospheric climate, and human criminal inclinations are correct, built environment specialists must collaborate on

evidence-based study to grasp the intricacy, dimensions, and possible determinants of emerging crime and behavioural norms. This is intended to lessen urbanisation's consequences.

This study's analysis of growth, crime, demographic, and temperature analysis of Midland, in Perth Western Australia assessed the validity of existing theories that associate criminality and patterns of criminal behaviour. Local crime, temperature, and vegetation cover data were analysed. Validity was done thorough an evaluation of field literature.

The findings do not support a significant positive correlation between green canopy cover with temperature, long-term crime, and population density. However, the population for Midland was expected to grow substantially by 2051. The study acknowledges that while the commonly tested variables applied by most other studies did not have a statistically significant impact on crime in the case study area, there are other variables that may influence crime discussed throughout the paper.

Such prediction of potential impact of local heat and canopy cover on urban criminal behaviour could benefit the long-term aspirations of designers and policymakers in the (re) shaping of city infrastructure through development policy largely set prior to the eminence of climate change and heat islands. Development policy, for example could consider, alignment, orientation, above and below-ground infrastructure, materiality, blue grid optimisation, vegetation, and greening policies for active cooling. Further research in the area of police resource planning and resource implementation could benefit from understanding the likely correlations between long-term heat projections and an anticipated increase in crime.

Funding

The author (s) received no financial support for the research, authorship, and/or publication of this article.

Declaration of conflict of interest

The authors declare no commercial or financial relationships as a potential conflict of interest.

Footnotes

[1] For category definitions see: Western Australian Police. 2021. "Archived Crime Statistics Reports."

References

- .id Community Pty Ltd. 2021. "East Metropolitan Region: Estimated Resident Population (ERP)." Profile.id.com.au.id Community Pty Ltd. November 30, 2021. https://profile.id.com.au/wapl/population-estimate?WebID=700
- Aguiar, Axton. 2012. "Urban Heat Islands: Differentiating between the Benefits and Drawbacks of Using Native or Exotic Vegetation in Mitigating Climate." Thesis, University of Wollongong. https://ro.uow.edu.au/theses/3751/

- Amati, Marco, Bryan Boruff, Peter Caccetta, Drew Devereux, Joe Kaspar, Kath Phelan, and Alex Saunders. 2017. "Where Should All the Trees Go? Investigating the Impact of Tree Canopy Cover on Socio-Economic Status and Wellbeing in LGA's." Horticulture Innovation Australia Ltd. https://202020vision.com.au/media/162691/wsattg_combined-lr.pdf
- Anderson, Craig A., and Dona C. Anderson. 1984. "Ambient Temperature and Violent Crime: Tests of the Linear and Curvilinear Hypotheses." *Journal of Personality and Social Psychology* 46 (1): 91–97. https://doi.org/10.1037/0022-3514.46.1.91
- Anderson, Craig A., Brad J. Bushman, and Ralph W. Groom. 1997. "Hot Years and Serious and Deadly Assault: Empirical Tests of the Heat Hypothesis." *Journal of Personality and Social Psychology* 73 (6): 1213–23. https://doi.org/10.1037/0022-3514.73.6.1213
- Australian Bureau of Statistics (ABS). 2022. "2021 Midland, Census All Persons QuickStats | Australian Bureau of Statistics." Www.abs.gov.au. June 29, 2022. https://www.abs.gov.au/census/find-census-data/quickstats/2021/SAL50947
- Australian Bureau of Statistics [ABS]. 2018. "3218.0 - Regional Population Growth, Australia, 2018-19." Abs.gov.au. c=AU; o=Commonwealth of Australia; ou=Australian Bureau of Statistics. 2018. https://www.abs.gov.au/AUSSTATS/abs@.nsf/Explanatory%20Notes/3218.0
- Australian Government (Australian Institute of Health and Welfare). 2020. "National Drug Strategy Household Survey 2019: In Brief. Drug Statistics Series No. 33. PHE 271." *AIHW*. Canberra, ACT: Australian Institute of Health and Welfare 2020. https://www.aihw.gov.au/getmedia/b0cbb555-ebec-4bc1-8ca1-0d6b567e321f/aihw-phe-271-NDSHS-2019-in-brief.pdf.aspx?inline=true
- Baron, Robert A. 1972. "Aggression as a Function of Ambient Temperature and Prior Anger Arousal."*Journal of Personality and Social Psychology* 21 (2): 183–89. https://doi.org/10.1037/h0032892
- Baron, Robert A., and Paul A. Bell. 1976. "Aggression and Heat: The Influence of Ambient Temperature, Negative Affect, and a Cooling Drink on Physical Aggression." *Journal of Personality and Social Psychology* 33 (3): 245–55. https://doi.org/10.1037/0022-3514.33.3.245
- Baryshnikova, Nadezhda, Shannon Davidson, and Dennis Wesselbaum. 2021. "Do You Feel the Heat around the Corner? The Effect of Weather on Crime." *Empirical Economics*, September, 1–21. https://doi.org/10.1007/s00181-021-02130-3
- Benson, Michael L. 2013. *Crime and the Life Course: An Introduction*. New York: Routledge.
- Bloxham, Paul, Daisy McGregor, Ewan Rankin, and Economic Analysis Department. 2010. "Housing Turnover and First-Home Buyers." Sydney, N.S.W: Reserve Bank of Australia. https://www.rba.gov.au/publications/bulletin/2010/jun/pdf/bu-0610-1.pdf
- Boyanowsky, Ehor. 2020. *Crime and Criminality: Social, Psychological, and Neurobiological Explanations*. Toronto: University of Toronto Press.
- Branas, Charles C., Rose A. Cheney, John M. MacDonald, Vicky W. Tam, Tara D. Jackson, and Thomas R. Ten Have. 2011. "A Difference-In-Differences Analysis of Health, Safety, and Greening Vacant Urban Space." *American Journal of Epidemiology* 174 (11): 1296–1306. https://doi.org/10.1093/aje/kwr273

- Brantingham, Patricia, and Paul Brantingham. 1995. “Criminality of Place.” *European Journal on Criminal Policy and Research* 3 (3): 5–26. https://doi.org/10.1007/bf02242925
- Bureau of Meteorology. 2022. “Weather Station Directory.” Bom.gov.au. Commonwealth of Australia. 2022. http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=36&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=009021
- Caccetta, Peter, Simon Collings, Andrew Devereux, Kassell Hingee, Don McFarlane, Anthony Traylen, Xiaoliang Wu, and Zheng-Shu Zhou. 2015. “Monitoring Land Surface and Cover in Urban and Peri-Urban Environments Using Digital Aerial Photography.” *International Journal of Digital Earth* 9 (5): 457–75. https://doi.org/10.1080/17538947.2015.1046510
- ———. 2018. “Mesh Block Vegetation Cover and Tree Canopy for Perth and Peel - 2018.” Melbourne, VIC: Clean Air and Urban Landscapes Hub (CAUL). https://data.aurin.org.au/dataset/caul-mesh-block-2011-caul-tree-canopy-wa-2018-na
- Cerchiai, Luca, Lorena Jannelli, and Fausto Longo. 2004. *Greek Cities of Magna Graecia and Sicily.* Translated by J Paul. Los Angelis: Getty Publications.
- Chakraborty, Tirthankar, Angel Hsu, Diego Manya, and Glenn Sheriff. 2019. “Disproportionately Higher Exposure to Urban Heat in Lower-Income Neighborhoods: A Multi-City Perspective.” *Environmental Research Letters* 14 (10): 105003. https://doi.org/10.1088/1748-9326/ab3b99
- City of Swan. 2022. “History of Midland.” Wa.gov.au. 2022.https://www.swan.wa.gov.au/Your-City/History-heritage/History-of-Midland
- Clarke, Ronald V., and David L. Weisburd. 1994. “Diffusion of Crime Control Benefits: Observations on the Reverse of Displacement.” Edited by Ronald V. Clarke. *Crime Prevention Studies* 2: 165–83.
- Cohn, Ellen G, and James Rotton. 2003. “Even Criminals Take a Holiday: Instrumental and Expressive Crimes on Major and Minor Holidays.” *Journal of Criminal Justice* 31 (4): 351–60. https://doi.org/10.1016/s0047-2352(03)00029-1
- Cousin, Elissa, and Emmanuelle Taugourdeau. 2016. “Cost Minimizing Water Main Quality Index: A Static Cost Minimization Approach.” *Water Resources and Economics* 15 (July): 28–42. https://doi.org/10.1016/j.wre.2016.06.001
- Cozens, Paul. 2011. “Urban Planning and Environmental Criminology: Towards a New Perspective for Safer Cities.” *Planning Practice and Research* 26 (4): 481–508. https://doi.org/10.1080/02697459.2011.582357
- Cozens, Paul, and Warren Christensen. 2011. “Environmental Criminology and the Potential for Reducing Opportunities for Bushfire Arson.” *Crime Prevention and Community Safety* 13 (2): 119–33. https://doi.org/10.1057/cpcs.2010.24
- Cozens, Paul, and Shane Grieve. 2009. “Designing Crime Precipitators in Northbridge after Dark: Urban Governance in Slumber.” In *Proceedings of the Annual State of Australian Cities (SOAC) Conference: City Growth, Sustainability, Vitality and Vulnerability*. Perth: University of Western Australia. http://soac.fbe.unsw.edu.au/2009/PDF/Cozens%20Paul_Greive%20Shane.pdf
- Curran, Daniel J. 1998. “Economic Reform, the Floating Population, and Crime.”*Journal of Contemporary Criminal Justice* 14 (3): 262–80. https://doi.org/10.1177/1043986298014003004
- Davies, Toby, and Shane D. Johnson. 2014. “Examining the Relationship between Road Structure and Burglary Risk

via Quantitative Network Analysis." *Journal of Quantitative Criminology* 31 (3): 481–507. https://doi.org/10.1007/s10940-014-9235-4

- Donovan, Geoffrey H., and Jeffrey P. Prestemon. 2010. "The Effect of Trees on Crime in Portland, Oregon." *Environment and Behavior* 44 (1): 3–30. https://doi.org/10.1177/0013916510383238
- Eck, John, and David L. Weisburd. 2015. "Crime Places in Crime Theory." Papers.ssrn.com. Rochester, NY. July 12, 2015. https://ssrn.com/abstract=2629856
- Fafchamps, Marcel, and Christine Moser. 2003. "Crime, Isolation, and Law Enforcement."*Journal of African Economies* 12 (4): 625–71.
- Felson, Marcus. 2003. "The Process of Co-Offending."*Crime Prevention Studies* 17: 149–68.
- Fleischman, Anat, Nomi Werbeloff, Rinat Yoffe, Michael Davidson, and Mark Weiser. 2014. "Schizophrenia and Violent Crime: A Population-Based Study." *Psychological Medicine* 44 (14): 3051–57. https://doi.org/10.1017/s0033291714000695
- Gaubatz, Kathlyn Taylor. 1995. *Crime in the Public Mind*. Ann Arbor: University of Michigan Press.
- Gehl, Jan. 2011. *Life between Buildings: Using Public Space*. Washington, DC: Island Press.
- Grann, Martin, and Seena Fazel. 2004. "Substance Misuse and Violent Crime: Swedish Population Study."*British Medical Journal* 328 (7450): 1233–34. https://doi.org/10.1136/bmj.328.7450.1233
- Grove, J. M., A. R. Troy, J. P. M. O'Neil-Dunne, W. R. Burch, M. L. Cadenasso, and S. T. A. Pickett. 2006. "Characterization of Households and Its Implications for the Vegetation of Urban Ecosystems." *Ecosystems* 9 (4): 578–97. https://doi.org/10.1007/s10021-006-0116-z
- Guerette, Rob T., and Kate J. Bowers. 2009. "Assessing the Extent of Crime Displacement and Diffusion of Benefits: A Review of Situational Crime Prevention Evaluations." *Criminology* 47 (4): 1331–68. https://doi.org/10.1111/j.1745-9125.2009.00177.x
- Harp, Ryan D, and Kristopher B Karnauskas. 2020. "Global Warming to Increase Violent Crime in the United States." *Environmental Research Letters* 15 (3): 034039. https://doi.org/10.1088/1748-9326/ab6b37
- Helmke, Juliet. 2022. "Could a Tree Planting Mandate in New Builds Combat Rising Suburban Heat?" March 22, 2022. https://www.smartpropertyinvestment.com.au/research/23646-could-a-tree-planting-mandate-in-new-builds-combat-rising-suburban-heat
- Henning, Sabine. 2017. "Overview of Global Trends in International Migration and Urbanization." https://www.un.org/en/development/desa/population/events/pdf/expert/27/presentations/I/presentation-Henning-final.pdf
- Hipp, John R., Young-An Kim, and Kevin Kane. 2018. "The Effect of the Physical Environment on Crime Rates: Capturing Housing Age and Housing Type at Varying Spatial Scales." *Crime & Delinquency* 65 (11): 1570–95. https://doi.org/10.1177/0011128718779569
- Holland, Marjorie M, Paul G Risser, and Robert J Naiman. 1991. *Ecotones: The Role of Landscape Boundaries in the Management and Restoration of Changing Environments*. Boston: Springer Us.
- Homely. 2022. "Midland, WA 6056 - Suburb Profile & Local Reviews." Homely. May 15, 2022. https://www.homely.com.au/midland-swan-perth-greater-western-australia

- Jacobs, Jane. 1961. *Death and Life of Great American Cities.* New York: Random House.
- Jonescu, Emil E. 2013. “Strategic and Tactical Architecture: An Intellectual Instrument of Law Enforcement.” In *Reframing Punishment: Silencing, Dehuminisation and the Way Forward*, edited by Selina Doran and Laura Bouttell, 261–76, Part III. Oxford, UK: Inter-Disciplinary Press (Print) ISBN 978-1-84888-210-2.
- Jonescu, Emil E, Jonathon Peake, and Khoa Do. 2020. “Feasibility Analysis into Deathscape Infrastructure: A Case Study Supporting Bereavement Spaces for Perth.” *The International Journal of Design in Society*14 (3): 1–17. https://doi.org/10.18848/2325-1328/cgp/v14i03/1-17
- Jonescu, Emil E, Monty Sutrisna, Khoa Do, and Titus Mercea. 2018. “Interaction between Urban Densities, Surveillance and Infrastructure: Re-Purposing CCTV to Support Social and Physical Densification, and Trends That Propagate Sustainable Urban Spaces.” In *42nd AUBEA: Australasian Universities Building Education Association Conference, Curtin University, Singapore*. Vol. 3 Sustainability. Perth, Western Australia: Curtin University.
- Kelly, Morgan. 2000. “Inequality and Crime.” *The Review of Economics and Statistics*82 (4): 530–39. http://www.jstor.org/stable/2646649
- Kent, Martin, Wendy J. Gill, Ruth E. Weaver, and Richard P. Armitage. 1997. “Landscape and Plant Community Boundaries in Biogeography.” *Progress in Physical Geography: Earth and Environment*21 (3): 315–53. https://doi.org/10.1177/030913339702100301
- Kitchenham, Barbara. 2004. “Procedures for Performing Systematic Reviews.” Department of Computer Science, Keele University and National ICT, Australia Ltd.
- Kuo, Frances E., and William C. Sullivan. 2001. “Environment and Crime in the Inner City.”*Environment and Behavior* 33 (3): 343–67. https://doi.org/10.1177/0013916501333002
- Loukaitou-Sideris, Anastasia, Robert Liggett, and Hiroyuki Iseki. 2002. “The Geography of Transit Crime: Documentation and Evaluation of Crime Incidence on and around the Green Line Stations in Los Angeles.” *RePEc: Research Papers in Economics* 22 (2): 135–51. https://doi.org/10.1177/0739456X022384
- Lowry, John H., Matthew E. Baker, and R. Douglas Ramsey. 2011. “Determinants of Urban Tree Canopy in Residential Neighborhoods: Household Characteristics, Urban Form, and the Geophysical Landscape.” *Urban Ecosystems* 15 (1): 247–66. https://doi.org/10.1007/s11252-011-0185-4
- Luck, Gary W., Lisa T. Smallbone, and Rachel O’Brien. 2009. “Socio-Economics and Vegetation Change in Urban Ecosystems: Patterns in Space and Time.” *Ecosystems* 12 (4): 604–20. https://doi.org/10.1007/s10021-009-9244-6
- Madensen, Tamara D., and John E. Eck. 2012.*Crime Places and Place Management*. Edited by Francis T. Cullen and Pamela Wilcox. *Oxford Handbooks Online*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199747238.013.0029
- Mares, Dennis M., and Kenneth W. Moffett. 2015. “Climate Change and Interpersonal Violence: A ‘Global’ Estimate and Regional Inequities.” *Climatic Change* 135 (2): 297–310. https://doi.org/10.1007/s10584-015-1566-0
- ———. 2019. “Climate Change and Crime Revisited: An Exploration of Monthly Temperature Anomalies and UCR Crime Data.” *Environment and Behavior* 51 (5): 502–29. https://doi.org/10.1177/0013916518781197
- Mednick, S. A., and J. Volavka. 1980. “Biology and Crime.”*Crime and Justice* 2: 85–158.
- Mehta, Divya, and Elisabeth B. Binder. 2012. “Gene × Environment Vulnerability Factors for PTSD: The HPA-Axis.”

Neuropharmacology 62 (2): 654–62. https://doi.org/10.1016/j.neuropharm.2011.03.009

- Mockrin, Miranda H., Dexter H. Locke, Susan I. Stewart, Roger B. Hammer, and Volker C. Radeloff. 2019. "Forests, Houses, or Both? Relationships between Land Cover, Housing Characteristics, and Resident Socioeconomic Status across Ecoregions." *Journal of Environmental Management* 234 (March): 464–75. https://doi.org/10.1016/j.jenvman.2018.12.001
- Moosa, Ahdha, Khoa Do, and Emil E Jonescu. 2020. "Design Response to Rising Sea Levels in the Maldives: A Study into Aquatic Architecture." *Frontiers of Architectural Research* 9 (3): 623–40. https://doi.org/10.1016/j.foar.2020.04.002
- Moreira, Gustavo, and Vania Ceccato. 2021. "Testing Theft Transmission in and around São Paulo Metro Stations, Brazil." *Journal of Transport Geography* 94 (June): 103116. https://doi.org/10.1016/j.jtrangeo.2021.103116
- Muggah, Robert. 2021. "Climate Change and Crime in Cities." *Igarapé Institute*, 2021. https://igarape.org.br/wp-content/uploads/2021/07/Climate-change-and-crime-in-cities.pdf
- Newman, Oscar. 1977. *Defensible Space: People and Design in the Violent City*. London: Architectural Press.
- Newton, Andrew D, Henry Partridge, and Andy Gill. 2014. "Above and Below: Measuring Crime Risk in and around Underground Mass Transit Systems." *Crime Science* 3 (1): 1–14. https://doi.org/10.1186/2193-7680-3-1
- Nieuwenhuijsen, Mark J. 2020. "Green Infrastructure and Health: Annual Review of Public Health." *Annual Review of Public Health* 42 (1): 317–28. https://doi.org/10.1146/annurev-publhealth-090419-102511
- O'Connor, Colin. 2020. "Humid Heat Already Exceeding Human Tolerance in Some Regions | American Association for the Advancement of Science." Www.aaas.org. American Association for the Advancement of Science. 2020. https://www.aaas.org/news/humid-heat-already-exceeding-human-tolerance-some-regions
- Oc, Taner, and Steven Tiesdell. 1999. "The Fortress, the Panoptic, the Regulatory and the Animated: Planning and Urban Design Approaches to Safer City Centres." *Landscape Research* 24 (3): 265–86. https://doi.org/10.1080/01426399908706563
- Owens, E J. 1991. *The City in the Greek and Roman World*. New York: Routledge.
- Pai, Madhukar, Michael McCulloch, Jennifer D Gorman, Nitika Pai, Wayne Enanoria, Gail Kennedy, Prathap Tharyan, and John M Colford Jr. 2004. "Systematic Reviews and Meta-Analyses: An Illustrated, Step-By-Step Guide." *The National Medical Journal of India* 17 (2): 86–95.
- Panas, Antonis, and John P. Pantouvakis. 2010. "Evaluating Research Methodology in Construction Productivity Studies." *The Built & Human Environment Review* 3 (1).
- Perez, Lilian G., Terry L. Conway, Adrian Bauman, Jacqueline Kerr, John P. Elder, Elva M. Arredondo, and James F. Sallis. 2018. "Sociodemographic Moderators of Environment–Physical Activity Associations: Results from the International Prevalence Study." *Journal of Physical Activity and Health* 15 (1): 22–29. https://doi.org/10.1123/jpah.2017-0163
- Rad, Hadi Rezaei, and Narges Afzali. 2021. "Measuring Effects of Building Orientation and Vegetation on Thermal Comfort by ENVI-Met (Case Study: Maslak Area, Istanbul)." *A/Z ITU Journal of Faculty of Architecture* 18 (1): 127–37. https://doi.org/10.5505/itujfa.2020.89106
- Rafter, Nicole. 2016. *Criminal Brain, Second Edition: Understanding Biological Theories of Crime*. New York: NYU Press.

- Ranson, Matthew. 2012. “M-RCBG Associate Working Paper Series | No. 8 Crime, Weather, and Climate Change.” https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/files/ranson_2012-8.FINAL.pdf
- Raymond, Colin, Tom Matthews, and Radley M. Horton. 2020. “The Emergence of Heat and Humidity Too Severe for Human Tolerance.” *Science Advances* 6 (19). https://doi.org/10.1126/sciadv.aaw1838
- Rotton, James, and Ellen G. Cohn. 2003. “Global Warming and U.S. Crime Rates.” *Environment and Behavior* 35 (6): 802–25. https://doi.org/10.1177/0013916503255565
- ———. 2004. “Outdoor Temperature, Climate Control, and Criminal Assault.” *Environment and Behavior* 36 (2): 276–306. https://doi.org/10.1177/0013916503259515
- Saunders, Alex, John Duncan, Joe Hurley, Marco Amati, Peter Caccetta, Joanne Chia, and Bryan Boruff. 2020. “Leaf My Neighbourhood Alone! Predicting the Influence of Densification on Residential Tree Canopy Cover in Perth.” *Landscape and Urban Planning* 199 (July): 103804. https://doi.org/10.1016/j.landurbplan.2020.103804
- Sherwood, Steven C., and Matthew Huber. 2010. “An Adaptability Limit to Climate Change due to Heat Stress.” Edited by Kerry A. Emanuel. *Proceedings of the National Academy of Sciences* 107 (21): 9552–55. https://doi.org/10.1073/pnas.0913352107
- Silva, Patrik, and Lin Li. 2020. “Urban Crime Occurrences in Association with Built Environment Characteristics: An African Case with Implications for Urban Design.” *Sustainability* 12 (7): 3056. https://doi.org/10.3390/su12073056
- Sohn, Dong-Wook. 2016. “Residential Crimes and Neighbourhood Built Environment: Assessing the Effectiveness of Crime Prevention through Environmental Design (CPTED).” *Cities* 52 (March): 86–93. https://doi.org/10.1016/j.cities.2015.11.023
- Stevens, Heather R., Paul J. Beggs, Petra L. Graham, and Hsing-Chung Chang. 2019. “Hot and Bothered? Associations between Temperature and Crime in Australia.” *International Journal of Biometeorology* 63 (6): 747–62. https://doi.org/10.1007/s00484-019-01689-y
- Stevens, Heather R., Petra L. Graham, Paul J. Beggs, and Ivan C. Hanigan. 2020. “In Cold Weather We Bark, but in Hot Weather We Bite: Patterns in Social Media Anger, Aggressive Behavior, and Temperature.” *Environment and Behavior* 53 (7): 787–805. https://doi.org/10.1177/0013916520937455
- Su, Nanxi, Wenjing Li, and Waishan Qiu. 2023. “Measuring the Associations between Eye-Level Urban Design Quality and On-Street Crime Density around New York Subway Entrances.” *Habitat International* 131 (January): 102728. https://doi.org/10.1016/j.habitatint.2022.102728
- Swyngedouw, Erik. 2014. “The Violence of Sustainable Urbanity.” *Harvard Design Magazine* 37: 24–29.
- Troy, Austin, J. Morgan Grove, and Jarlath O’Neil-Dunne. 2012. “The Relationship between Tree Canopy and Crime Rates across an Urban–Rural Gradient in the Greater Baltimore Region.” *Landscape and Urban Planning* 106 (3): 262–70. https://doi.org/10.1016/j.landurbplan.2012.03.010
- Twinam, Tate. 2017. “Danger Zone: Land Use and the Geography of Neighborhood Crime.” *Journal of Urban Economics* 100 (July): 104–19. https://doi.org/10.1016/j.jue.2017.05.006
- United Nations. 2018. “68% of the World Population Projected to Live in Urban Areas by 2050, Says UN | UN DESA | United Nations Department of Economic and Social Affairs.” *United Nations Department of Economic and Social Affairs*, May 16, 2018. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-

prospects.html

- ———. 2019. “World Population Prospects: The 2019 Revision.” Department of Economic and Social Affairs Population Dynamics. United Nations, Department of Economic and Social Affairs, Population Division. 2019. https://population.un.org/wpp/
- Watts, Reginald E. 1931. “The Influence of Population Density on Crime.”*Journal of the American Statistical Association* 26 (173): 11–20. https://doi.org/10.1080/01621459.1931.10503145
- Weisburd, David, Laura A. Wyckoff, Justin Ready, John E. Eck, Joshua C. Hinkle, and Frank Gajewski. 2006. “Does Crime Just Move around the Corner? A Controlled Study of Spatial Displacement and Diffusion of Crime Control Benefits.” *Criminology* 44 (3): 549–92. https://doi.org/10.1111/j.1745-9125.2006.00057.x
- Weisburd, David, Laura Wyckoff, Justin Ready, John Eck, Josh Hinkle, and Frank Gajewski. 2005. “The Author (S) Shown below Used Federal Funds Provided by the U.S. Department of Justice and Prepared the Following Final Report: Document Title: Does Crime Just Move around the Corner? A Study of Displacement and Diffusion in Jersey City, NJ.” https://www.ojp.gov/pdffiles1/nij/grants/211679.pdf
- Western Australian Police. 2021. “Archived Crime Statistics Reports.” Western Australia Police. WA Police Force. November 29, 2021. https://www.police.wa.gov.au/crime/~/link.aspx?_id=FFCE49444D4B4124A409647EC48EFD88&_z=z
- Western Australian Police Force. 2021. “Your Local Police: Interactive Maps.” Western Australia Police Force. Western Australia Police Force. 2021. https://www.police.wa.gov.au/Contact-Us/Police
- Wilson, James Q., and Richard J. Herrnstein. 2010. “Crime and Human Nature.” In*Encyclopedia of Criminological Theory*, edited by Francis T Cullen and Pamela Wilcox. Thousand Oaks, Calif.: Sage Publications.
- Wolf, Kathleen L., Sharon T. Lam, Jennifer K. McKeen, Gregory R.A. Richardson, Matilda van den Bosch, and Adrina C. Bardekjian. 2020. “Urban Trees and Human Health: A Scoping Review.” *International Journal of Environmental Research and Public Health* 17 (12): 4371. https://doi.org/10.3390/ijerph17124371
- World Population Review. 2021. “2021 World Population by Country.” Worldpopulationreview.com. 2021. https://worldpopulationreview.com/
- Wright-Wendel, Heather E. 2011. “An Examination of the Impacts of Urbanization on Green Space Access and Water Resources: A Developed and Developing World Perspective.” Dissertation, University of South Florida.
- Wu, Wenjie, Mark (Xin) Wang, Ning Zhu, Weiyang Zhang, and Hua Sun. 2019. “Residential Satisfaction about Urban Greenness: Heterogeneous Effects across Social and Spatial Gradients.” *Urban Forestry & Urban Greening* 38 (February): 133–44. https://doi.org/10.1016/j.ufug.2018.11.011
- Yu, Danlin, and Chuanglin Fang. 2022. “How Neighborhood Characteristics Influence Neighborhood Crimes: A Bayesian Hierarchical Spatial Analysis.” *International Journal of Environmental Research and Public Health*19 (18): 11416. https://doi.org/10.3390/ijerph191811416