A Tested Method for Assessing and Predicting Weather-Crime Associations

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Abstract

Few studies have focused on haze as a weather element and its correlation with crime. In this study, we examined haze as a weather variable to investigate its effects on criminal activity. We used both monthly crime data and weather records to build a regression model to predict crime cases considering three weather factors; temperature, humidity and haze. We applied this model in two different climate provinces in Saudi Arabia, namely, Riyadh and Makkah. Riyadh is a desert area and observes haze approximately 17 days per month on average, while Makkah is a coastal area observing haze an average of 4 days per month. We found a measurable relationship between each of these three variables and criminal activity. However, haze had the most effect on theft, drug and assault crimes in Riyadh compared to the other elements. Temperature and humidity have a significant relationship with crime in Makkah, while haze had no significant influence in that region.

Introduction

Scientific inquiries about weather-crime associations began in the mid-nineteenth century (Cohn, 1990; Lebeau, 2005). Sociologists, criminologists and geographers paid specific attention to weather-related causes behind crime during this time, as well as why crime was more common in some areas than in others. For example, in the United States, Dexter's study of 40,000 assault cases between 1891 and 1897 in New York City, found temperature to be the most significant factor associated with these cases (Joseph Cohen, 1941; Harries, 1980). Some researchers sought to understand the specific environmental effects on crime rates, such as the influence of climate, heat or surface temperature on human behaviour and crimes (Hu, Wu, Chen, Sun, & Li, 2017; Salleh, Mansor, Yusoff, & Nasir, 2012; Stevens, Beggs, Graham, & Chang, 2019). Such research has uncovered considerable evidence of a linear or curvilinear link between weather and criminal behaviour (Anderson, Anderson, Dorr, DeNeve, & Flanagan, 2000; Brunsdon, Corcoran, Higgs, & Ware, 2009; Bushman, Wang, & Anderson, 2005; Coccia, 2017; Cohn, 1990; Cohn & Rotton, 2000; Gangopadhyay & Nilakantan, 2017; Xu, Xiong, Abramson, Li, & Guo, 2020). There are also many researchers who have focused on how climate change and global warming relate to crime, establishing that there is in fact a relationship between these factors and crime (Kramer & Bradshaw, 2020; Kramer & Michalowski, 2012; Nurse, 2020).

The weather/crime association

Criminologists have reported that weather elements influence the nature and extent of crime committed, as individual personalities differ from place to place depending on the weather and climate (Kim, Ahn, & Lee, 2013). Anderson & Anderson (1984), (Miller, 2009) and Mares (2013a) believe this to be the reason that the southern portion of the United States has more crime than other regions in the country, as most of the population in that area lives within a high-temperature climate. High temperatures often lead to aggressive behaviour (Anderson & Anderson, 1984; Mares, 2013a) and have been found to be associated with social disorder and homicide in St. Louis (DeFronzo, 1984; Simister, 2002). Studies have found a strong positive relationship between temperature and violence in Dallas, Texas and New Zealand (Gamble & Hess, 2012; Horrocks & Menclova, 2011; Williams, Hill, & Spicer, 2015), theft and homicide in New Zealand (Wetherley, 2014), street robbery in the Strathclyde region of Scotland (Tompson & Bowers, 2015), and property crimes in India (Blakeslee & Fishman, 2015). Ranson (2014) in his study in the United States, discovered a strong positive association between temperature and homicide, rape and aggressive assault. Kieltyka, Kucybala, & Crandall (2016) tested how ecological factors such as the day of the week, the daily maximum temperature, and rain affected violence and firearm crimes in Chicago, and their findings indicated that temperature significantly affects these types of crimes.

Mares (2013), in St. Louis, Missouri, United States, discovered a significant relationship between most crime categories and climate change. In other studies on climate change and violence in the same city, Mares found that neighbourhoods with high social disadvantage have a high degree of violence as a result of anomalous temperature change (Mares, 2013b). Sorg & Taylor (2011) studied the effect of temperature on urban street robbery in Philadelphia, USA, and found that robbery increased when temperatures were higher. Michel et al. 2016) found the most important weather element associated with violent crime to be the maximum daily temperature in Baltimore, MD, USA. Brown & Esbensen, (2010) in USA, confirmed that most crimes are committed during the warmer seasons, such as July and August, and during the holiday season in December.

Elsewhere, Mishra (2015) found that temperature and humidity have a significant positive effect on criminal behaviour, particularly on homicide cases in Allahabad City, India (Mishra, 2015). Linning, Andresen, & Brantingham, (2016) investigated periodically fluctuating property crime patterns in Canada and found that cities with greater weather variations during the year also have increased property crimes during the summer months.

Some researchers have found that both heat and cold lead to a loss of self-control, while middle temperatures provide an optimal environment for self-control (Gailliot, 2014). Farrell & Pease (1994) found in their study in Merseyside, UK, that vehicle theft and burglary occur more often during cold seasons. Woodward (2008) found winter to be the high season for sheep theft in Wales, while spring was the low season. Kim et al. (2013) found in South Korea that most crimes happen when the weather is cloudy, the temperature is higher than 9°C and the humidity is above 50%. Among these variables, they found cloudy weather to have the highest effect on crime rates.

There are also studies that have researched the nexus between crime and air pollution, such as carbon cost or ozone levels, and these studies have found that these variables influence both social and crime policy (Kuo, 2021;Singh, 2021;Pease & Farrell, 2011; Rotton & Frey, 1985). Rotton & Frey (1985) for instance, suggested that air pollution may be a significant factor responsible for crime. However, there has been little research on the specific effects of atmospheric haze on criminal activity.

Social and crime theories can explain a great deal of the differences in criminal activities and the places they occur, and they can estimate or determine how much crime occurs. However, this leaves unanswered an important question about when crimes occur. Studying how climate patterns affect crime can help to answer this question, as well as predict when crimes occur during the year and whether this differs according to the type of crime, such as personal or property crimes. Most previous studies have used annual climate data to study the climate-crime association, although few studies suggest that analysing seasonality periods allows for a more accurate assessment such as (Mares, 2013a). Also, most of these studies have investigated the relationship between crime and the main weather elements (including temperature, humidity, wind speed and precipitation) and therefore, there is a need for studies focusing on haze and its direct effects on criminal behaviour.

Haze is an issue in most Middle Eastern countries, especially the Arabian Peninsula. Most of that area is desert which is exposed to sandstorms for much of the year (Al-Dousari, Doronzo, & Ahmed, 2017). More than 42 Tons of dust fall monthly on each square kilometre in the province of Riyadh (Meo et al., 2021; Modaihsh & Mahjou, 2013; Reinolsmann et al., 2021). It disrupts air traffic and road conditions where it limits the horizontal visibility over the country (SA General Authority of Meteorology and Environmental Protection, 2017). For this study, it was hypothesised that limited visibility caused by haze will increase opportunity for crime in these areas.

For this study, we used monthly data for both crime and climate, which provides a more accurate assessment than annual data. While most previous studies gave more consideration to the effects of temperature, humidity and precipitation on crime rates, this study focused primarily on haze, comparing its effects with two other important weather elements; temperature and humidity. We analysed this data to investigate the association between crime and weather factors, as well as to assess the association between each weather factor by each type of crime. Specifically, this study examined the interrelationship between temperature, humidity and particularly haze and six key criminal activities, namely, assault, alcohol, drug, theft, homicide and sexual assault crimes. It should be noted here that in Saudi Arabia, alcohol use is considered as a crime under Saudi law and Islamic law while it is not a crime in and of itself in most of the world. Also, drug use is recorded within drug crime along with drug smuggling. So, this study aimed to address important questions about how much haze influences crime compared with temperature and humidity, and which crime category is most affected. It also built a tested model to predict crime under weather conditions.

Methods

Study Area and Data

The study was conducted in the two largest provinces in Saudi Arabia: Riyadh and Makkah (Figure 1). The Riyadh province, considered a desert area, is located in the central part of the country and includes the capital city, Riyadh, the largest urban city in Saudi Arabia. The Makkah province is located in the western part of the country and is a coastal area. It is the second largest urban area after Riyadh and contains two main cities: Makkah and Jeddah. Makkah is considered a spiritual place for Muslims all over the world, while Jeddah is an important commercial port on the west coast (the Red Sea) (Algahtany & Kumar, 2016).

Data on monthly weather, minimum and maximum temperatures, humidity and haze were obtained from Saudi Arabia's General Authority of Meteorology and Environmental Protection (General Authority of Meteorology and Environmental Protection, 2016). Monthly criminal data, including data on assault, alcohol crimes, drug crimes, theft, homicide and sexual assault crimes, were collected from the Ministry of Justice in Saudi Arabia (Statistical Book, Ministry of Justice, 2013). These data were collected on a monthly basis spanning the seven years from 2004–2010. It should be noted that the crime data are based on criminal cases that have been tried and finalised judicially in the courts which provides a high level of accuracy (Algahtany, Kumar, & Barclay, 2019; Algahtany, Kumar, Barclay, & Khormi, 2018; Algahtany, Kumar, & Khormi, 2016; Algahtany, Kumar, & Khormi, 2014).

Study Design and Methods

This study used monthly criminal data, the average temperature for each month from January 2004 to December 2010, the monthly average relative humidity percentage and the amount of haze observed during the month. Multiple regression was used to test the weather-crime association.

Specifically, the multiple independent variables – temperature, humidity and haze – were measured against a single dependent variable, for each one of the six types of crimes; assault, alcohol crimes, drug crimes, theft, homicide and sexual assault crimes. We applied this study to two different cities: Riyadh and Makkah. We used the independent variables to predict the rate of crimes, and to do this, we used the following as our main multiple regression equation:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$,

where β_0 is the constant variable, which represents crime; β_1 is the slope coefficient for X_1 where X represents the independent variables, which are temperature, humidity or haze, numbered by 1, 2 and 3, respectively; and ε signifies errors or residuals.

To ensure that the correct model was chosen for this study, some common but important assumptions regarding the multiple regressions model were tested. Independence of error, linear relationship, homoscedasticity, multicollinearity, outliers and residuals (errors) were tested by the output of the residuals once a regression line was generated. A step process was employed to build the convenient regression model for the study, as shown in Figure 2. In order to clearly identify the effects of weather elements on the rate of each examined crime, this model was applied to each type of crime using the three independent variables; temperature, humidity and haze. The data met all the assumptions where we already had a continuous dependent variable, the crime, and three independent variables, including temperature, humidity and haze. The Durbin-Watson statistic confirmed the linear relationship between variables for each type of crime. multicollinearity and outliers or unusual points have been checked. We also checked leverage points and influential points where they were between 0.2 and 0.5. Cook's distance values have been checked for each case to measure the influence and recorded any values above 1 (Cook & Weisberg, 1982). Normal P-P Plot of Standardised Residual and Normal Q-Q Plot of Standardised Residual have been applied to check the normality. Finally, we built a prediction model based on our method, and based on our model results, the model can predict crime cases under the conditions of three weather factors (temperature, humidity and haze). This model was applied to assault crime as an example.

Results

The Durbin-Watson statistic used to measure the independence of errors (residuals), or the linear relationship between variables and each type of crime, ranged from 0–4. In all cases in the analysis, our measurements were between 0.536 and 2.331. The majority of values were approximately 2, which indicates that there was no correlation between residuals, and it can be accepted that there was independence of errors or residuals.

Table 1. Model summary

Dependent Variable	R		R Square		Adjusted R Square		Std. Error of the Estimate		Durbin-Watson	
	Riyadh	Makkah	Riyadh	Makkah	Riyadh	Makkah	Riyadh	Makkah	Riyadh	Makkah
Assault	0.405[a]	0.411[a]	0.164	0.169	0.133	0.138	13.321	16.645	2.054	1.068
Alcohol	0.378[a]	0.389[a]	0.143	0.151	0.111	0.120	8.578	8.874	2.331	1.867
Drug	0.425[a]	0.360[a]	0.181	0.129	0.150	0.097	99.725	167.711	2.147	0.536
Theft	0.557[a]	0.383[a]	0.310	0.147	0.284	0.115	16.797	27.004	2.139	1.099
Homicide	0.357[a]	0.262[a]	0.127	0.069	0.095	0.034	4.274	5.259	1.737	1.658
Sexual assault	0.361[a]	0.324[a]	0.130	0.105	0.097	0.071	18.678	23.796	2.208	0.698

a. Predictors: (Constant), Temperature, Humidity, Haze

Linearity testing was conducted by using partial regression plots between weather factors and each crime (Box & Cox, 1964), (Figures 3 and 4). For testing homoscedasticity, the spread of residuals are likely to be the same across the predicted values which means homoscedasticity has been met, as assessed by visual inspection of a plot of studentised residuals versus unstandardised predicted values (Figure 5).

The independent variables were highly correlated with each other (r = 0.9 and above) and there were no correlations larger than 0.7 in the correlations table. Second, the tolerance was greater than 0.1 and the VIF values less than 10. There were no collinearity problems in the dataset (Table 2).

Table 2. Tolerance and VIF

variables		Collinearity Statistics			
		Riyadh		Makkah	
		Tolerance	VIF	Tolerance	VIF
Assault	Temperature	0.291	3.440	0.456	2.194
	Humidity	0.307	3.259	0.460	2.173
	Haze	0.866	1.155	0.918	1.089
Alcohol					
	Temperature	0.291	3.440	0.456	2.194
	Humidity	0.307	3.259	0.460	2.173
	Haze	0.866	1.155	0.918	1.089
Drug					
	Temperature	0.291	3.440	0.456	2.194
	Humidity	0.307	3.259	0.460	2.173
	Haze	0.866	1.155	0.918	1.089
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	Haze	0.866	1.155	0.918	1.089
Homicide					
	Temperature	0.291	3.440	0.456	2.194
	Humidity	0.307	3.259	0.460	2.173
	Haze	0.866	1.155	0.918	1.089
Sexual assault					
	Temperature	0.291	3.440	0.456	2.194
	Humidity	0.307	3.259	0.460	2.173
	Haze	0.866	1.155	0.918	1.089

Histograms with a superimposed normal curve and a P-P Plot and Normal Q-Q Plot for the studentised residuals were used for checking unusual points and detecting outliers. The histograms in Figure 5 show that the standardised residuals were normally distributed in all cases. The P-P Plot in Figure 6 shows that the distribution was normally distributed and indicated that the residuals are close enough to normal to proceed with the analysis.

The results had linearity, as assessed by partial regressions plots and a plot of studentised residuals against the predicted values. Our data also had independence of residuals, as assessed by its Durbin-Watson statistic of 0.085, as well as homoscedasticity, as assessed by a visual inspection of a plot of studentised residuals versus unstandardised predicted values. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1. There were also no studentised deleted residuals greater than ±3 standard deviations, leverage values greater than 0.2 or Cook’s distance values above 1. The assumption of normality was met, as assessed using a P-P Plot.

Multiple correlation coefficients (R) measured the linear relationship between variables. In Table 1, drug and theft in Riyadh, along with assault in both Makkah and Riyadh, indicate a moderate association with 0.4 to 0.55. The other crimes are under 0.4. Therefore, the linear associations were still unclear. However, R is neither a unique nor common measure for assessing the fit of the model. Total variation explained (R2) coefficients measure the proportion of variance in the dependent variables, which when explained by the independent variables over and above the mean model, can be used to assess the overall model fit. All (R2) values in this model were less than 0.2, with the exception of theft in Riyadh, which was 0.31. This is considered a good measure for understanding these results (Draper & Smith, 2014).

Adjusted (R2) corrects the positive bias and provides the expected value. Our adjusted (R2) was less than 0.16 in all of the regressions, which indicates a low effect size according to Cohen's classification (Jacob Cohen, Cohen, West, & Aiken, 2013). For example, for assault crime in Riyadh, the coefficient for temperature was 0.739. The slope coefficient represents the change in the dependent variable (assault) for a one unit change in the independent variable (temperature, humidity and haze). As such, a one-degree increase in temperature is associated with an increase in assault of 0.739. There is an increase in assault because the slope coefficient is positive. It is important to note that this increase in assault for each extra degree in temperature applies when humidity and haze hold constant. It does not matter what those values are so long as they are kept constant. For other independent variables with the same crime in Riyadh, a one-degree increase in humidity is associated with a 0.164 increase in assault. An increase in the number of times that the haze phenomenon is observed is associated with an increase of 0.359 assault cases (Table 3).

Table 3. Regression coefficients and standard errors

variables	Riyadh			Makkah		
Assault	*B*	*SE4*	*ß*	*B*	*SE4*	*ß*
Intercept	5.784	13.739		-47.233	30.339	
Mean temperature	0.739	0.347	0.404*	2.275	0.649	0.529*
Humidity	0.164	0.197	0.154*	0.309	0.263	0.176*
Haze	0.359	0.197	0.2*	0.150	0.455	0.035*
Alcohol						
Intercept	21.774	8.847		28.110	16.175	
Mean temperature	0.298	0.224	0.256*	0.226	0.346	0.100*
Humidity	-0.048	0.127	-0.071*	-0.267	0.140	-0.288*
Haze	0.138	0.127	0.121*	-0.140	0.242	-0.062*
Drug						
Intercept	112.316	102.851		-552.124	305.692	
Mean temperature	1.103	2.599	0.080*	20.581	6.535	0.487*
Humidity	-0.566	1.474	-0.070*	3.491	2.655	0.202*
Haze	4.797	1.475	0.354*	5.535	4.582	0.131*
Theft						
Intercept	32.761	17.323		74.707	49.220	
Mean temperature	0.274	0.438	0.108*	1.080	1.052	0.157*
Humidity	-0.199	0.248	-0.134*	-0.713	0.427	-0.254*
Haze	1.078	0.248	0.433*	0.015	0.738	0.002*
Homicide						
Intercept	1.230	4.408		2.480	9.586	
Mean temperature	0.194	0.111	0.338*	0.298	.205	0.232*
Humidity	0.055	0.063	0.163*	0.003	.083	0.006*
Haze	0.121	0.063	0.215*	-0.104	.144	-0.082*
Sexual assault						
Intercept	15.717	19.263		-0.893	43.373	
Mean temperature	0.428	0.487	0.170*	1.553	0.927	0.262*
Humidity	0.005	0.276	0.004*	0.057	0.377	0.024*
Haze	0.652	0.276	0.264*	-0.912	0.650	-0.155*

Note. * $p< 0.05$; B = unstandardized regression coefficient; SE4 = Standard error of the coefficient; B = standardized coefficient

Regarding assault cases in Riyadh, the 95% confidence intervals (CI) of temperature were between 0.048 and 1.43, that is, we could be 95% confident that the true value of the slope coefficient was between these lower and upper bounds. The slope coefficient is statistically significant by interpreting the p-value, which was 0.036 where the p-value was less than 0.05 which confirmed a linear relationship between these two variables. Therefore, temperature and haze are statistically significant, while humidity is not, as the p-values were 0.036 for temperature, 0.072 for haze and above 0.05 for humidity. Thus, haze is the significant variable in this case (Table 4).

Table 4. Correlation Coefficients

Variables	Riyadh						Makkah					
		95.0% Confidence Interval for B		Correlations				95.0% Confidence Interval for B		Correlations		
Assault	sig	Lower Bound	Upper Bound	Zero-order	Partial	Part	sig	Lower Bound	Upper Bound	Zero-order	Partial	Part
(Constant)	0.675	-21.56	33.124				0.123	-107.6	13.143			
Temperature	0.036	0.048	1.430	0.349	0.232	0.218	0.001	0.984	3.565	0.391	0.365	0.357
Humidity	0.407	-0.228	0.556	-0.24	0.1	0.085	0.245	-0.216	0.833	-0.2	0.130	0.119
Haze	0.072	-0.033	0.751	0.303	0.2	0.186	0.742	-0.755	1.055	-0.06	0.037	0.034
Alcohol												
(Constant)	0.016	4.168	39.380				0.086	-4.079	60.300			
Temperature	0.187	-0.147	0.742	0.359	0.147	0.138	0.516	-0.462	0.914	0.328	.073	.067
Humidity	0.705	-0.300	0.204	-0.32	-0.04	-0.04	0.061	-0.546	0.013	-0.38	-.208	-0.2
Haze	0.281	-0.115	0.390	0.235	0.121	0.112	0.564	-0.623	0.342	-0.16	-0.065	-0.06
Drug												
(Constant)	0.278	-92.36	317.1				0.075	-1160	56.222			
Temperature	0.672	-4.068	6.275	0.267	0.047	0.043	0.002	7.576	33.587	0.303	0.332	0.329
Humidity	0.702	-3.499	2.367	-0.24	-0.043	-0.04	0.192	-1.791	8.774	-0.12	0.145	0.137
Haze	0.002	1.861	7.733	0.403	0.342	0.329	0.231	-3.583	14.653	0.05	0.134	0.126
Theft												
(Constant)	0.062	-1.714	67.236				0.133	-23.24	172.66			
Temperature	0.533	-0.597	1.145	0.378	0.070	0.058	0.308	-1.014	3.174	0.342	.114	.106
Humidity	0.425	-0.693	0.295	-0.35	-0.089	-0.07	0.099	-1.563	0.138	-0.37	-0.183	-.17
Haze	0.000	0.584	1.572	0.512	0.436	0.403	0.984	-1.453	1.483	-0.11	0.002	0.002
Homicide												
(Constant)	0.781	-7.543	10.002				0.796	-16.6	21.558			
Temperature	0.085	-0.028	0.416	0.280	0.191	0.182	0.150	-0.110	0.706	0.250	.160	0.157
Humidity	0.389	-0.071	0.180	-0.18	0.096	0.090	0.971	-0.163	0.169	-0.18	0.004	0.004
Haze	0.059	-0.005	0.247	0.290	0.209	0.200	0.470	-0.390	0.182	-0.14	-0.081	-0.08
Sexual assault												
(Constant)	0.417	-22.62	54.053				0.984	-87.21	85.422			
Temperature	0.382	-0.541	1.396	0.264	0.098	0.092	0.098	-0.292	3.399	0.288	.184	0.177
Humidity	0.985	-0.544	0.555	-0.22	0.002	0.002	0.880	-0.693	0.806	-0.21	.017	0.016
Haze	0.021	0.102	1.202	0.326	0.255	0.246	0.164	-2.206	0.382	-0.22	-.155	-0.15

To test the model's statistical significance, we used ANOVA, as shown in Table 5, which explains the significance of the relationships in the model. It is a clear that p-values in all cases were less than 0.05, which indicates a statistically significant result, with the exception of homicide crimes in Makkah where the p-value was 0.125.

In the overall model, the addition of the independent variables in both cities was better than the mean model in predicting the dependent variable, and it is a statistically significant fit for the data rather than the mean model. Depending on the null hypothesis, we can deduce that the regressions coefficient (slope) overall in all tests is significantly different than zero. Temperature, humidity and haze predicted all types of crimes in both cities with statistical significance ($p > 0.05$), except for homicide in Makkah, while the p-value of homicide in Makkah exceeded 0.05 by 0.125 (Table 5).

Table 5. Statistical significance

ANOVA analysis				
Dependent Variables	Statistical significance			
	Riyadh	Sig.	Makkah	Sig.
Assault	$F(3, 80) = 5.239,\ p < 0.05$	0.002[b]	$F(3, 80) = 5.423,\ p < 0.05$	0.002[b]
Alcohol	$F(3, 80) = 4.441,\ p < 0.05$	0.006[b]	$F(3, 80) = 4.761,\ p < 0.05$	0.004[b]
Drug	$F(3, 80) = 5.886,\ p < 0.05$	0.001[b]	$F(3, 80) = 3.965,\ p < 0.05$	0.011[b]
Theft	$F(3, 80) =11.966,\ p < 0.05$	0.000[b]	$F(3, 80) = 4.594,\ p < 0.05$	0.005[b]
Homicide	$F(3, 80) = 3.893,\ p < 0.05$	0.012[b]	**$F(3, 80) = 1.971,\ p > 0.05$**	**0.125[b]**
Sexual assault	$F(3, 80) = 3.998,\ p < 0.05$	0.011[b]	$F(3, 80) = 3.121,\ p < 0.05$	0.031[b]
F. Indicates that we are comparing to an F-distribution (F-test).				
b. Predictors: (Constant), Haze, Humidity, Temperature				
3 in (3, 80): Indicates the degrees of freedom regression model.				
80 in (3, 80): Indicates the degrees of freedom residual or error.				
p : Indicates the probability of the F-values if the null hypothesis is true.				

Prediction model:

Using this prediction model, we can predict crime cases under the three weather conditions. Ideally, instead of using expensive procedures, we can use temperature, humidity and haze to predict assault crime in Riyadh using the following regressions equation:

Predicted assault = 5.784 – (0.739 x temperature) – (0.164 x humidity) – (0.359 x haze)

Based on this equation, we can predict the number of assault cases according to the mean temperature, mean percentage of humidity and the amount of haze observed in one month. If we assume that the mean temperature was 35°C in one month, the mean humidity in that month was 74% and haze was observed in that month 25 times, for example, the equation is calculated as follows:

Predicted assault = 5.784 + (0.739 x 35) + (0.164 x 74) + (0.359 x 25) = 52.76 cases

To build a prediction model using the LMATRIX method in SPSS Statistics Syntax Editor Software, we built the model to predict assault in Riyadh with these values for the variables' means:

DATASET ACTIVATE DataSet1.

UNIANOVA Assault WITH Temperature Humidity Haze

/METHOD=SSTYPE(3)

/INTERCEPT=INCLUDE

/CRITERIA=ALPHA(0.05)

/LMATRIX=ALL 1 35 74 25

/DESIGN= Temperature Humidity Haze.

Based on the model, we obtained the estimation result shown in Table 6. The mean number of assault cases is predicted to be approximately 52. The standard error of the prediction is 11.9, which provides the value of variability. The 95% CIs range from a lower bound of 28.984 assault cases to an upper bound of 76.563, and so we can be 95% confident that the true mean number of assaults during this month will be between 28 and 76 cases, with the mean equalling 52. This model can be applied to each crime category to predict the estimated crime cases under the different weather conditions.

Table 6. Prediction model result

Contrast Results (K Matrix)		
Contrast		Dependent Variable
		Assault
Contrast Estimate		52.773
Hypothesized Value		0
Difference (Estimate - Hypothesized)		52.773
Std. Error		11.954
Sig.		0.000
95% Confidence Interval for Difference	Lower Bound	28.984
	Upper Bound	76.563

Discussion

Multiple regressions proved to be a particularly useful method for understanding weather-crime associations in Saudi Arabia. Crimes can be predicted based on other variables, such as weather elements. However, before using multiple regressions, understanding that some of the different assumptions that this study's data had to be met was essential for obtaining a valid result. Based on this, the user can determine the model's overall fit and the contribution each of the variables made to the total variance. In this study, this method was critically tested to obtain as much accuracy as possible in analysing the correlations between crime and weather elements. We also circumvented some of the problems many studies face, such as inadequate sample sizes, poor control of extraneous variables, weak or inappropriate statistical techniques, and so on. To do this, we used accurate monthly totals of criminal activities and clear dependent and independent variables, and tested an appropriate technique.

There remain some important questions that require more detailed answers. Can we expect when crime will occur? During what time of year does crime increase, and what types of crime? During what time of the year will people or properties be at the greatest risk for crime, and why? These questions are important for researchers, practitioners and society in general. Seeking answers to these questions can provide insight into the time of criminal activity according to the depicted crime rates, in addition to offering some possible reasons for this in terms of weather factors and season of the year. It can help further investigations into the associated climate patterns and factors responsible for increased crime at a particular time of year. Being able to expect the occurrence and types of crime can also allow for more intense observations by increasing surveillance and support at the right time and place, which will be an important preventative measure for reducing future crime. We sought to obtain as much information as possible to answer these important questions, and assist future researchers find such answers.

Most of the literature on the effects of weather on crime has focused on the main weather elements, such as temperature. These previous studies found a strong positive correlation between temperature and criminal behaviour, such as violence (Gamble & Hess, 2012; Horrocks & Menclova, 2011; Williams et al., 2015), theft and homicide (Wetherley, 2014), and property crimes (Blakeslee & Fishman, 2015). However, we argued that there could be other weather elements that have a more significant influence on crime or particular types of crime than temperature, humidity or rainfall, such as haze.

The findings revealed that in the Riyadh province, haze was the most significant weather factor associated with occurrences of theft, drug, sexual assault crimes and homicide, while high temperature was the most influential factor behind alcohol and assault. In adding haze as a weather variable, we found it as the most significant factor in most of Riyadh's crime. In Makkah, temperature and humidity were the first and second most influential factors for all six categories of crime. Temperature was the most significant factor in assault, drug, homicide and sexual assault crimes. Humidity was the most significant factor in alcohol and theft crimes. It is worth noting that the haze correlation in Riyadh was more significant because it is a desert area and therefore has a high range of haze. Makkah is different; there was no effective influence of haze in Makkah, which lacks enough haze to be an effective variable on crime rates. It is a coastal area with a high range of humidity and rainfall, much more so than Riyadh, and as Rotton and Frey (1985) reported that humidity with rainfall removes pollution from the air this means that these traits lower Riyadh's haze content.

The results indicated that crime can be attributed to weather conditions that predispose people to commit certain crimes. This is a logical finding. People are usually outdoors in warm seasons, which increases the chances of both personal and property crimes. Assault and violence are frequent during these times of year, as people spend more time outside of their homes. At the same time, this also makes their homes suitable targets for theft and burglary. By contrast, people primarily remain at home during cold weather and snowy seasons, which reduces the opportunities for both of these types of crimes (Cohn, 1990; Ding & Zhai, 2021; Ranson, 2014). Thus, there are less suitable targets for burglars in these seasons, and there are fewer people outside, reducing the opportunity for personal crimes.

Our results support the findings of several previous studies that have found that humidity has a significant positive effect on crime {Kim, 2013 #11}, notably homicide cases {Mishra, 2015 #27}. There are few studies on the effects of haze on crime, apart from those that slightly indicate such effects of air pollution, such as Pease & Farrell (2011) and Rotton & Frey, (1985) who suggested that air pollution could influence crime and might be somewhat responsible for it. While Riyadh is located in the middle of Saudi Arabia, haze is experienced more than 17 days per month. In this study, haze was an essential factor in our analysis and had measurable effects on homicide, drug, theft and sexual assault crimes.

Although there were no available detailed data such as whether more crime occurs during the day or night, or on work days or the weekend, this information could allow for a better understanding of the correlations between weather elements and criminal issues. However, this study's prediction model was able to answer the study's questions, as it provided important signals for crime expectation during a particular time of year or during instances of particular weather conditions. During haze, visibility of drivers is reduced to a few meters which limits police surveillance and creates opportunity for crimes such as property crime, drug dealing, homicide and kidnapping or sexual assault. As such, future research is encouraged to examine these matters. What this study does do is make an interesting and useful contribution to the literature by intensively studying the effects of haze on crime. It would be interesting to see if these results can be replicated in other cities worldwide.

Conclusion

The findings suggest that cities that experience greater amounts of haze encounter significant increases in homicide, drug, theft and sexual assault crimes, and that different weather events affect the type of crime experienced. More detailed information providing weekly, daily and hourly data would provide a better understanding of these relationships between weather elements and crime events. Unfortunately, such data was not available for use in this research in Saudi Arabia. However, advocating for disaggregate analysis is expected to be a topic of significant interest in the future in some cities which is usually subject to sandstorms, such as Riyadh, or haze, such as the Hejaz region.

While these findings characterised two parts of Saudi Arabia, these criminal activities are common to other areas throughout the country and around the world. The model generated can be used to assist both researchers and security agencies in predicting and even preventing crimes before they occur. In particular, being able to expect the time when crimes will occur can also allow for more intense observation through increased surveillance and support during the right time and in the right place, which is another important preventative key for reducing future crimes. By providing insights into climate-crime associations and by adding more weather variables to research – in this case, atmospheric haze – this study helps to provide answers to these important questions and provides future studies with a foundation as they strive further to answer these questions.

Declarations

All data which have been used in this study are available data and published on the website of Ministry of Justice, Saudi Arabia. So, there is no need for ethics approval or consent to participate. All authors are consent for publication. There are no competing interests, no funding. Mofza Algahtany who has written the manuscript; Elaine Barclay who reviewed the manuscript and added changes and references and Lalit Kumar had the final review.

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Figures

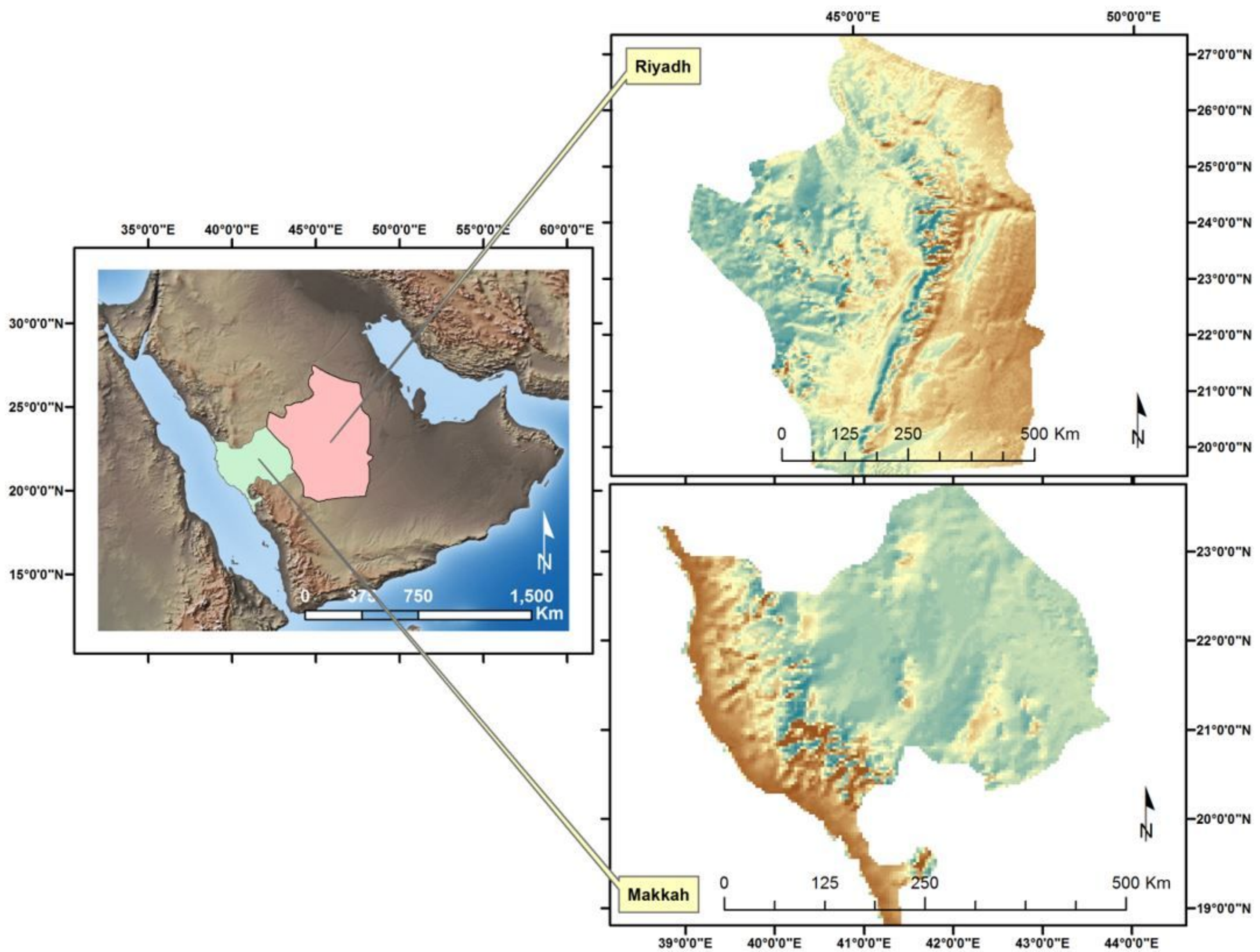

Figure 1

Selected study areas

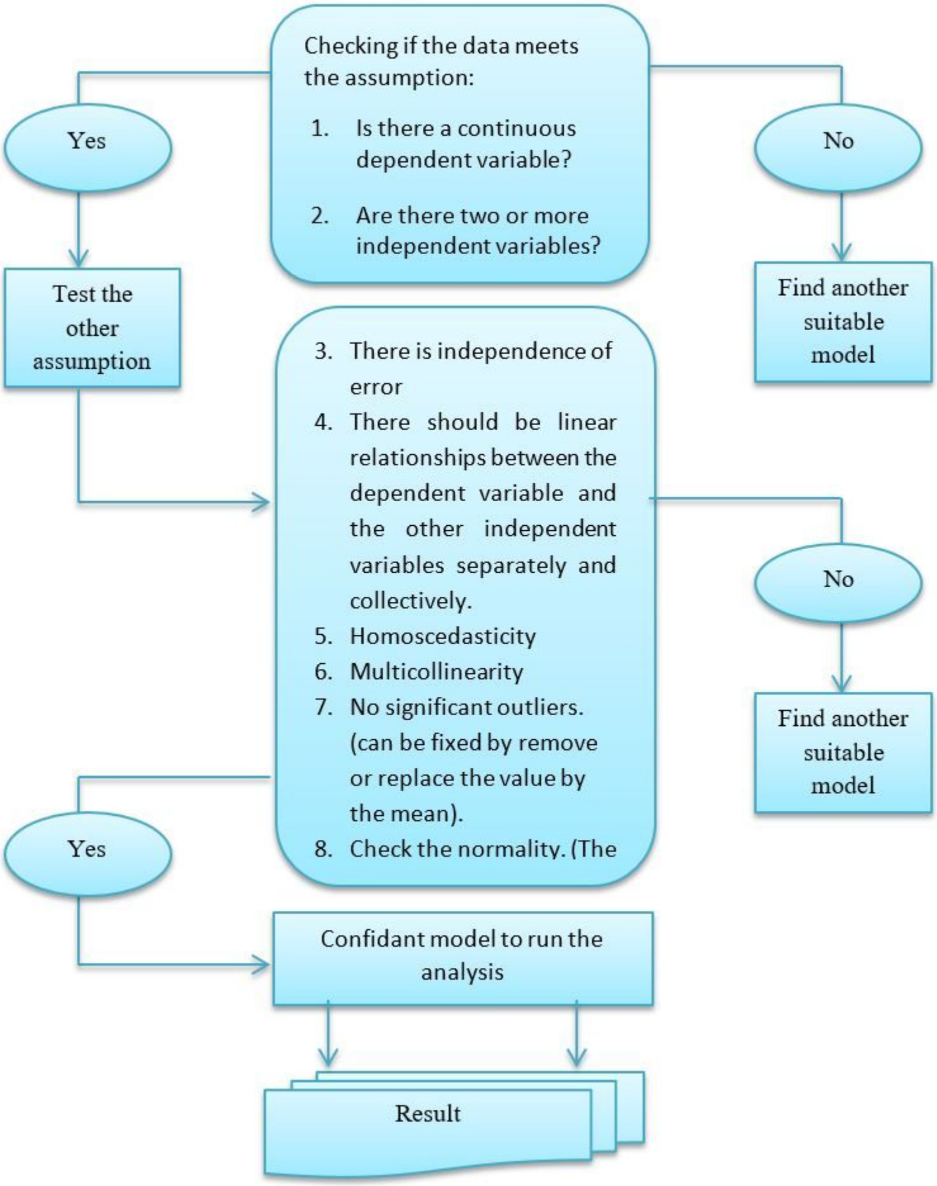

Figure 2

Study Design

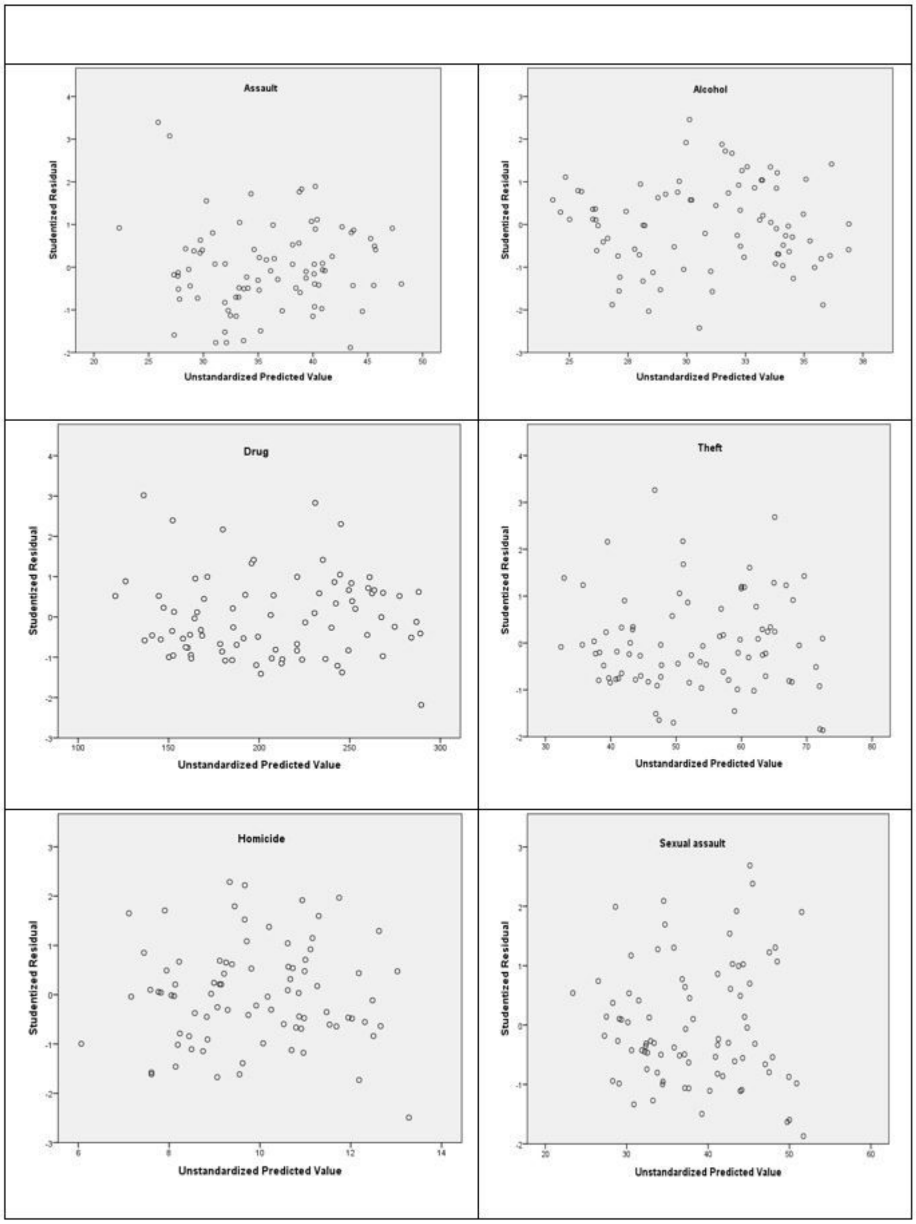

Figure 3

Riyadh linearity

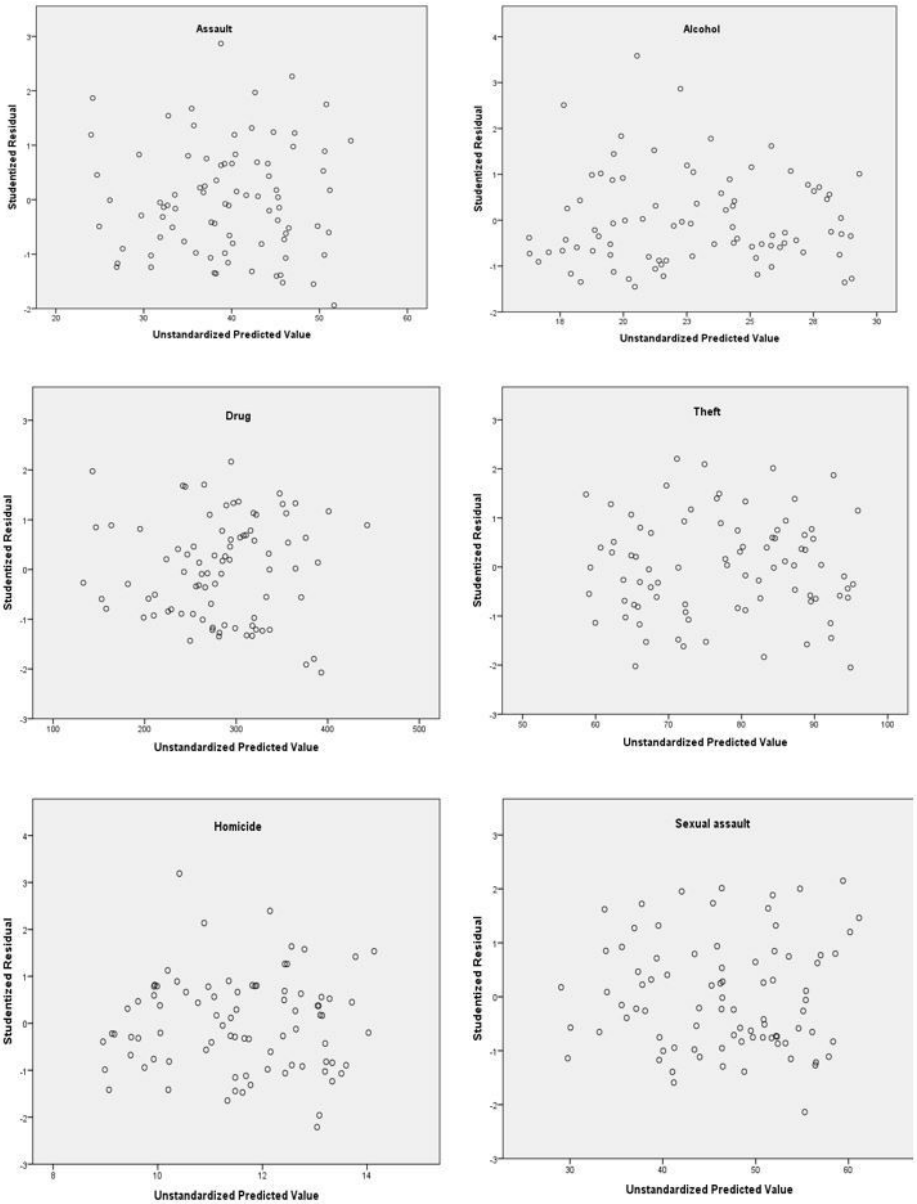

Figure 4

Makkah linearity

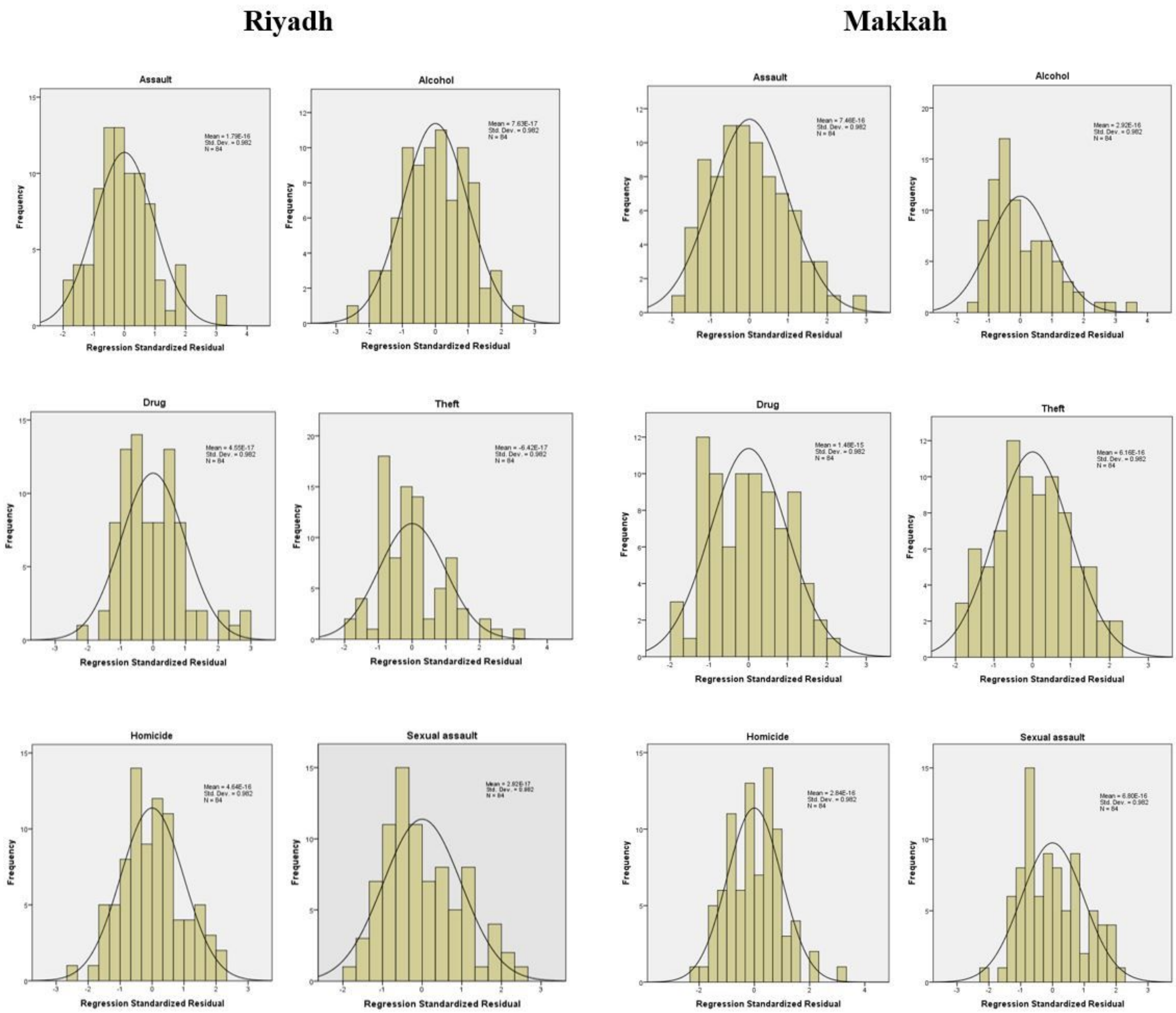

Figure 5

histogram with superimposed normal curve

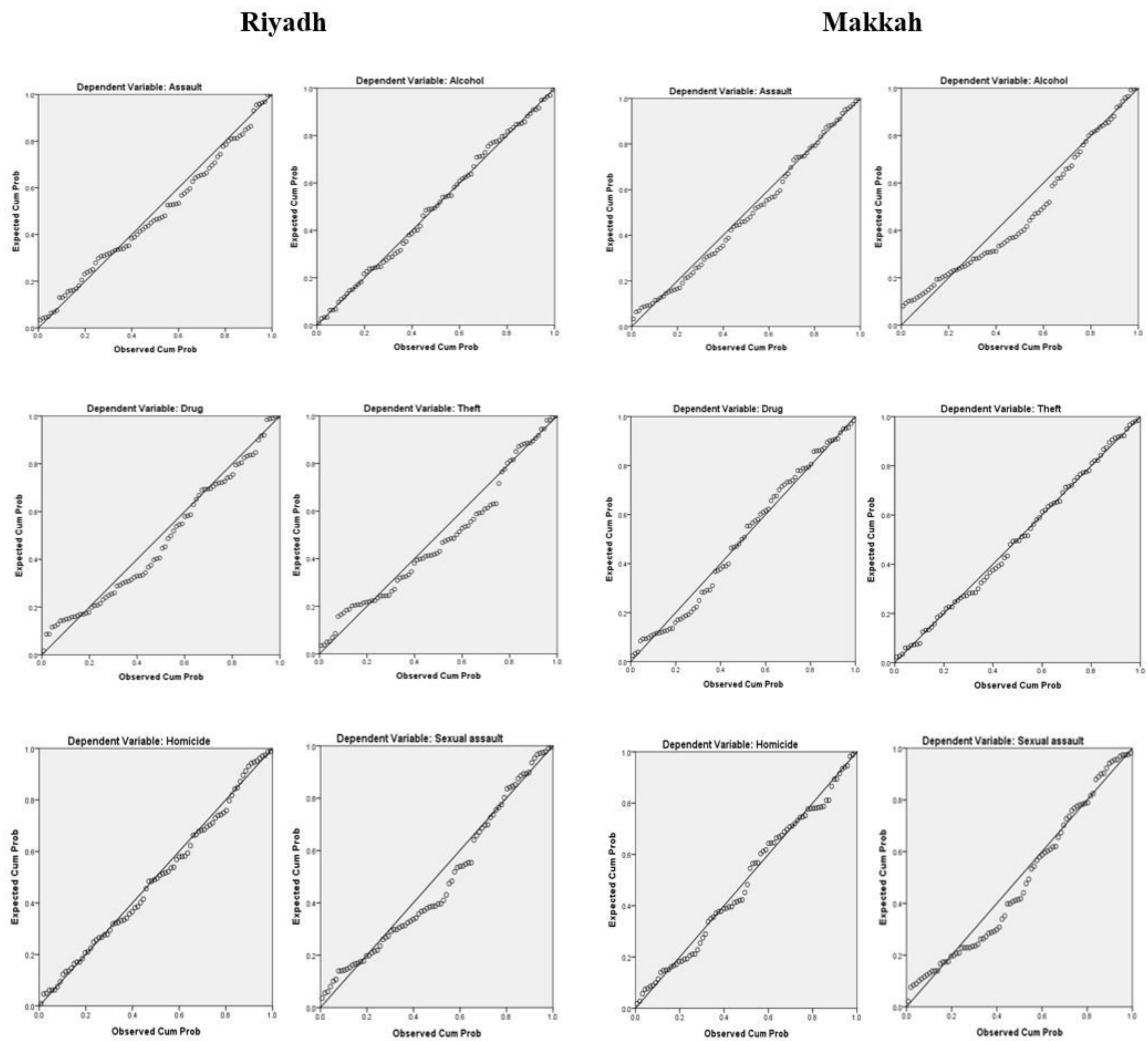

Figure 6

Normal P-P Plot of Regression Standardized Residual