Published in final edited form as:

Int J Drug Policy. 2016 July ; 33: 44–55. doi:10.1016/j.drugpo.2016.05.004.

Spatial Analysis of Drug Poisoning Deaths in the American West, particularly Utah

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Abstract

Background—Most states in the Western US have high rates of drug poisoning death (DPD), especially New Mexico, Nevada, Arizona and Utah (UT). This seems paradoxical in UT where illicit drug use, smoking and drinking rates are low. To investigate this, spatial analysis of county level DPD data and other relevant factors in the Western US and UT was undertaken.

Methods—Poisson kriging was used to smooth the DPD data, populate data gaps and improve the reliability of rates recorded in sparsely populated counties. Links between DPD and economic, environmental, health, lifestyle, and demographic factors were investigated at four scales using multiple linear regression. LDS church membership and altitude, factors not previously considered, were included. Spatial change in the strength and sign of relationships was investigated using geographically weighted regression and significant DPD clusters were identified using the Local Moran's I.

Results—Economic factors, like the sharp social gradient between rural and urban areas were important to DPD throughout the west. Higher DPD rates were also found in areas of higher elevation and the desert rural areas in the south. The unique characteristics of DPD in UT in terms of health and lifestyle factors, as well as the demographic structure of DPD in the most LDS populous states (UT, Idaho, Wyoming), suggest that high DPD in heavily LDS areas are predominantly prescription opioid related whereas in other Western states a larger proportion of DPD might come from illicit drugs.

Conclusions—Drug policies need to be adapted to the geographical differences in the dominant type of drug causing death. Educational materials need to be marketed to the demographic groups at greatest risk and take into account differences in population characteristics between and within States. Some suggestions about how such adaptations can be made are given and future research needs outlined.

Keywords

Drug poisoning deaths; American West; spatial analysis; Utah; LDS faith; altitude

Introduction

Drugs, illicit and non-, are the cause of drug poisoning deaths (DPD) whether intentional or unintentional. The number of DPD nationally has increased dramatically in the last 15–20 years (Manchikanti et al. 2012). Although DPD vary considerably between states the Western US (Figure 2a) has consistently displayed higher rates with only three of the eleven states having rates below the national average in 2008 and 2013 (www.healthindicators.gov). Also in 2010 four states in the Western US, New Mexico (NM), Nevada (NV), Arizona (AZ) and Utah (UT) were nationally ranked second, fourth, sixth and eighth respectively for DPD (TAH, 2013). The high ranking is a particular paradox for Utah.

A number of conditions particularly smoking related cancers, are far lower in UT than other states (Devesa et al., 1999; Goovaerts, 2009; Goovaerts and Gebreab, 2008 Merrill et al. 1999 and Tudor-Locke et al. 2007) which has been attributed to about 70% of the population being members of the Church of Jesus Christ of Latter-day Saints (LDS faith) (<http://www.theARDA.com>) that adhere to a health code prohibiting use of tobacco, alcohol, tea, coffee and illicit drugs (Merrill et al., 1999; Merrill and Lyon, 2005; Merrill and Folsom; 2005) and a mandate to obey the laws of the land (LDS Church, 2013). UT has the highest concentration of a single religion in the United States (Merrill, 2004); and consequently the lowest levels of smoking, alcohol consumption and illicit drug use in the USA (Merrill, 2004). Although concentrated in UT, much of the Western US was originally settled by the Mormon pioneers, so LDS membership is markedly higher in the Western US than the East, particularly in counties that border UT (Figure 1a).

To explain high rates of DPD in the American West and the apparent paradox of high rates in UT, we examined three broad groups of factors (economic, environmental, and health, lifestyle and demographic) affecting DPD using spatial methods. Although earlier studies have investigated DPD in the USA and individual states (Cheng et al. 2013; Edlund et al., 2007; Johnson et al. 2013; and Lanier et al. 2013; Potter et al. 2004) none of them used spatial methods. Another originality of the present study is the incorporation of two new putative factors: LDS membership and elevation. The former should help explaining the UT paradox while the latter was chosen because recent studies have linked high elevations with increased drug use (Fiedler et al. 2012; Kim et al., 2014), depression and suicide (Brenner et al., 2011; Kim et al., 2011), all of which influence DPD rates.

Literature Review

As DPD data include deaths from illicit and non-illicit sources, intentional and not, examining spatial variation in the factors that relate to DPD should point to spatial differences in drug source or intent. DPD has been hypothetically linked to a range of economic, environmental, health, lifestyle and demographic factors and these relationships will be reviewed following a description of relevant geographic characteristics of the Western US and UT.

Geographical Characteristics of the Western US and Utah

The Western US ranges in elevation from sea level along the Pacific coast to the high mountain peaks of the Rockies and Sierra Nevada yet elevation is predominantly high (Figure 1b). There are also large areas of arid land and desert in the south. Most of the facts about this region were gained from analysis of maps at www.census.gov unless otherwise stated. The highest population densities are found in the Pacific states (California (CA), Oregon (OR) and Washington (WA)) and in cities in valleys of the Mountain states (AZ, Colorado (CO), Idaho (ID), Montana (MT), NM, NV, UT and Wyoming (WY)) with large very sparsely populated areas elsewhere. Racially the region is predominantly white with Hispanics being the largest minority. Hispanic populations are mainly urban and located in the Pacific states and those that border Mexico with a decrease further north. Asian and Black populations are low throughout the region; the former is concentrated in large Pacific coast cities and the latter is greatest in southern CA, NV and AZ. The median age in the region is mostly low and the percentage of families and family size are high in CA and the south where the Catholic Hispanics are concentrated and in UT where the LDS population is highest.

Although historically manufacturing dominated in the West, in 2013 the major industries in most states were health care and social assistance except NV and WY; and UT where accommodation and food services and retail and trade dominate, respectively (http://www.bls.gov/opub/ted/2014/ted_20140728.htm). Median household income is lowest in MT and NM and highest in CA, ID, UT, WA and WY while poverty levels are lowest in CO, UT and WY and highest in NM and AZ. Education levels are highest with large proportions of college degrees in CA, CO, MT, UT and WY and lowest in NV and NM. In the 2012 election, the Pacific states plus NV, CO and NM voted Democrat whereas AZ, ID, MT, UT and WY favored the Republican candidate.

Economic Factors

Economic variables like unemployment rate, median household income, poverty level and physician use delay due to cost are important to investigate when considering mortality rates because these can determine timely access to physical and mental health care which could reduce the risk of DPD. Access to physical and mental health care is an economic issue particularly in the USA where among those under 65, in 2012, 61% had private health insurance, 18% had Medicaid (government payment of medical expenses for low income citizens) and 17% were uninsured (CDC/NCHS, 2012). The proportion of uninsured people varies from 11–13% in the Northeast and Midwest compared to 18–20% in the South and West of the USA. Also in the Western region rates of uninsured people vary considerably with UT having the lowest rates (15.7%) and NV the highest (24.5) but in UT there is more variation between urban and rural areas with a range of 10–23% compared to 20–26% in NV (www.healthindicators.gov). In the USA those 65 and older (>65) or with certain disabilities are covered by the Federal health insurance program, Medicare. Uninsured individuals and those facing financial hardship might be more prone to delay visits to a doctor, saving old medications or self-medication with prescription drugs obtained illicitly because even those with private insurance pay a proportion of the bill for each doctor's visit and prescription (i.e. copay).

Other economic facts are that wealthier abusers are more likely to abuse prescription opioid (PO) obtained from a doctor while poorer PO abusers tend to obtain them from illicit sources (Cicero et al., 2012). Illicit drug use and DPD have been linked with economically depressed areas (Buchi et al., 1993; Johnson et al., 2013) like inner cities with few prospects for young people, high crime and delinquency rates and a ready street supply of illicit substances. In contrast, PO deaths have been linked to rural areas (Johnson et al., 2013; Leukefeld et al. 2005) suggesting that less infra-structure and greater distance to physical and mental health care facilities leads to higher DPD rates. Population density is used here as an indicator of urbanicity.

Environmental Factors

Recent studies found an association between high elevations and increased drug use (Fiedler et al. 2012; Kim et al., 2014), depression and suicide (Brenner et al., 2011; Kim et al., 2011). This is an important factor to investigate in the US Mountain West which lies in great part above 1,000 meters elevation (Figure 1b). Brenner et al. (2011) explain how lower oxygen levels at high elevations deplete serotonin increasing the risk of depression and suicide, while drug and alcohol use temporarily raises serotonin levels. Another putative factor for mental health and DPD is latitude which influences day length and can result in Seasonal Affective Disorder (Rosenthal et al. 1984).

Health, Lifestyle and Demographic Factors

According to several studies (Cheng et al. 2013; Johnson et al. 2013; Lanier et al. 2013; Edlund et al., 2007; Potter et al. 2004) those in drug treatment programs for illicit drug and PO addiction are more likely to smoke, have an alcohol problem and abuse other drugs. These facts suggest that DPD should be more common amongst those not practicing the LDS health code. Religiosity is important to DPD, particularly in UT as Merrill et al., (2001) found an inverse relationship between religious involvement and illicit drug-use. This phenomenon will be investigated using data on smoking and binge drinking rates, as well as LDS membership data as an indicator of religious involvement and adherence to LDS health code.

As DPD include self-inflicted, intentional deaths caused by drugs there are obvious links with suicide rates (Howard and Jenson, 1999; Donaldson et al. 2006) and years of life lost before age 75. Also mentally unhealthy days per month is used here to inform on mental health problems associated with DPD (Cheng et al., 2013; Cicero et al., 2008; Donaldson et al., 2006; Johnson et al., 2013; Webster et al., 2011). Depression is a mental health problem often linked with drug use and DPD so depression rates among Medicare beneficiaries (those >65 or disabled) were used as a covariate in the analysis.

Several studies linked DPD to physical health problems, suggesting that illicit drugs and POs are often used to treat physical pain (Berg et al., 2009; Cheng et al., 2013; Cicero et al., 2008; Lanier et al., 2013; Johnson et al., 2013; Sehgal et al., 2012, Wang et al. 2012). Legitimate prescriptions leading to addiction and then use of illicit drug sources is a pathway that may be more prevalent amongst those experiencing chronic pain (Rigg and Murphy, 2013).

Higher DPD rates among those that live alone (Johnson et al., 2013; Reddy et al., 2014) or without a family support structure (Johnson et al. 2013; Lanier et al. 2013) have been observed, suggesting that families can provide a support which results in less addiction or DPD. This is investigated here using average family size and percent family households.

Race is an important factor as illicit drug use is more prevalent among ethnic minorities (Buchi et al., 1993; Merrill et al., 2013) perhaps due to a propensity to live in more economically depressed inner city areas where illicit drug trade is rife. However, lower rates of PO abuse have been found in ethnic minority groups compared to the white population (Merrill et al. 2013).

While not considered in our regression analysis, figures on the age and gender structure in DPD by state are quoted and briefly discussed. Previous research has shown a greater tendency for young males to be involved with illicit drugs (Vitale and van de Mheen, 2006 and Zickler, 2000) while women are more likely to use POs. Since 1999, the national PO death rate among women has risen 400% compared to 265% in men (CDC, 2013). Faster increases in women have been linked to several factors such as greater likelihood of chronic pain, being prescribed higher doses for a longer time, developing dependence more quickly than men and being less likely to be diagnosed with an addiction problem (Svikis and Reid-Quinones, 2003).

Methods

Data Sources

Existing, publically available data at the national, state and county level were sought for this study. For the period 2006–2010, DPD data were downloaded from <http://www.healthindicators.gov>. Data is supplied annually by the Centers for Disease Control (CDC) from death certificates via the National Vital Statistics System-Mortality database. The “ICD-10 codes used cover accidental, intentional, and undetermined poisoning by and exposure to” a large range of illicit, prescription and over the counter drugs. DPD rate estimates based on fewer than 20 deaths are considered unreliable and are not provided. Table 1 summarizes information on other variables, such as dates of collection, their sources, and details on how various rates etc. were calculated. Rates were total (include both genders and all races) and age-adjusted as noted by the §’s in Table 1. An effort was made to obtain socio-economic and risk factor data for the same time period as DPD, but this was not always possible, so the years/year ranges closest in date to the DPD data and that were most complete were selected. This temporal mismatch might result in some bias, especially when the risk factors were measured for years after the date of the DPD. The analysis of county level data for DPD and each of the covariates also relies on the assumption that people died in their county of residence and did not relocate recently. This is obviously a limiting assumption.

Data on race and family structure were downloaded from <http://www.census.gov> and most other health and socio-economic indicators were obtained from <http://www.healthindicators.gov>. Many of these indicators are county-level estimates from the Behavioral Risk Factors Surveillance System (BRFSS) survey (Table 1). The BRFSS

“conducts state-based, random-digit—dialed telephone surveys of the non-institutionalized US civilian population aged 18 years collecting data on health conditions and health risk behaviors” (CDC, 2010). As these data are self-reported, there may be some bias due to underestimation of rates for activities that are illegal or culturally taboo such as illicit drug use or smoking in UT. Generally, data based on less than 50 responses are considered statistically unreliable and are removed. Several of the economic variables available from <http://www.healthindicators.gov> were estimated by the US census bureau through the Small Area Income and Poverty Estimates (SAIPE) program.

Data on LDS membership were obtained from the association of religious data archives (ARDA) which conducts surveys of US religious membership each decade. County level data on LDS membership from the 2000 survey were used in this study (Figure 1a). Membership numbers are based on members and their children in each congregation and are therefore associated with an individual’s county of worship rather than county of residence. The locational bias caused by differences between county of worship and residence are limited and tend to occur in the mid-west or east coast regions.

Over time the number of counties (3000+) changes slightly due to the creation of new counties. Discrepancies for data recorded during different time periods were addressed by removing new counties from the analysis. The bias (i.e. lower rates) caused by this action should, however, be minimal since just three changes occurred in the Western US and county boundaries did not change in UT.

Elevation data were obtained from the United States Geological Survey (USGS). Median elevation for each county in the USA was calculated from 30m Shuttle Radar Topography Mission (SRTM) elevation data of the USGS (<http://www.usgs.gov>) where each pixel represents a 30m × 30m block. There may be some bias related to whether the mean or median elevation for a county is used, but the patterns of mean and median elevation were very similar.

Statistical methods

Comparison tests—The rankings of DPD rates among counties with a high median elevation (>900m) were compared using Mann-Whitney U tests to determine if there were significant differences in DPD rates at high elevations. The 900 m threshold was based on Kim et al.’s (2011) finding of a significant increase in suicide at elevations 600–900 m due to depleted oxygen.

Poisson Kriging—For rare health outcomes (e.g. DPD), rates can appear very large or small in sparsely populated areas because they are based on a small population (small number problem). For example, one DPD recorded in a sparsely populated county can result in an unrealistically large rate. Also the DPD data downloaded from <http://www.healthindicators.gov> had many missing values for rural counties in the Western US (Figure 2b). Because health outcomes are often spatially correlated (Goovaerts and Gereab, 2008), missing or unreliable values can be estimated from data recorded in neighboring areas. Such estimation was conducted here using a technique known as Poisson kriging (PK) which computes missing DPD data and filters the noise attached to existing rates using a

weighted average of neighboring rates. The basic principle is to allocate smaller weights to less reliable rates based on small populations and rates recorded in more geographically distant counties. Kriging produces a smoother and more complete map that also reflects the broader patterns displayed in the state map; compare Figures 2a–c. For a description of this method with full details and equations, the interested reader is referred to Monestiez et al. (2006) and Goovaerts (2006).

Local Moran's I (LMI)—The local Moran's I (Anselin, 1995) is a statistic that compares each county-level DPD rate with the average rate recorded in neighboring counties to test for the presence of significant positive (spatial clusters) or negative (spatial outliers) spatial autocorrelation. Determining whether the local autocorrelation is significantly different from zero requires knowledge of the distribution of LMI values under the null hypothesis of spatial randomness. Monte Carlo simulation is used to repeatedly (999 times) randomly shuffle all the DPD rates and the distribution of simulated LMI values is then compared with the sample value computed from the data to calculate the p -value of the test. Where $p > 0.05$ the spatial correlation is not-significantly (NS) different from zero. Conversely, $p \leq 0.05$ indicates that the corresponding county is either: (i) a significant spatial outlier (HL: high value surrounded by low values (pink) and LH: low value surrounded by high values (pale blue)) or (ii) part of a cluster (HH: high value surrounded by high values (red), and LL: low value surrounded by low values (blue)) (see Figure 3a for an example). The Simes correction was used to correct p -values for multiple testing because significance testing of the LMI for each county increases the number of tests and therefore the risk of false positives. For full details of the LMI method including equations the interested reader is directed to Goovaerts and Jacquez (2005).

The LMI was used to identify significant clusters of particularly high or low DPD rates (univariate LMI) and for investigating potential factors that influence them (bivariate). The bivariate LMI statistic is a variant of the univariate form that identifies counties that are members of significant clusters ($p \leq 0.05$) for two different variables simultaneously (Figure 3b–g). The first and second letters of the HH, LL, LH and HL designations refer to the types of clusters and size of the values of the first and second variables, respectively. So in Figure 3d, pink, HL areas, indicate significant clusters of high rates of DPD that are also part of significant clusters of low smoking rates.

Multiple Linear Regression (MLR)—MLR was conducted with DPD as the dependent variable. A best subset approach was employed where every possible model is computed and the model with the lowest Akaike Information Criterion (AIC) is selected. The variables to include in regression were determined by correlation analysis to select only those that are strongly correlated with the dependent variable to avoid multi-collinearity and over-parameterization. The effect of scale on MLR was explored by analyzing the following datasets: county data for the continental USA, counties in the Western US and counties in UT only.

Geographically Weighted Regression (GWR)—Geographically Weighted Regression (GWR) (Fotheringham et al. 2002) is a moving-window approach to regression that uses a small subset of data to determine regression model coefficients for the central

county in the window. Conducting GWR across the study area shows how correlation coefficients between variables change spatially; for example certain factors are strongly correlated with DPD in some places but not others or the sign of the correlation may change. Here the neighborhood size was set to the 25 closest counties and equal weight was given to each county in the window.

Comparison tests were performed in GenStat (Payne, 2006) while all other analyses (Poisson Kriging, LMI, MLR and GWR) were performed using BioMedware's SpaceStat Software (Jacquez et al. 2014).

Results

Economic Factors

The MLR results for DPD are summarized in Table 2. Although the R-squared values are slightly smaller after smoothing by Poisson kriging, these results are based on a much larger dataset (i.e. no missing values) and more reliable rates after filtering of noise caused by the small number problem. Therefore, exact parameter estimates and *p*-values are only reported for Poisson kriging. Positive parameters for median household income and population density combined with negative ones for poverty indicate that DPD is more prevalent in wealthier, urban areas with low poverty rates. This was true for all geographies where these variables were included in the model apart from western counties where population density had a negative contribution (Table 2) suggesting that at this scale more DPD occur in rural areas with less access to physical and mental health care. Although the above results suggest that DPD are mostly related to wealthier areas, regression parameters were positive for unemployment and physician use delayed owing to cost. This brings to light an important issue in the USA: most people with private health insurance gain this through their employment and many people do delay the use of a physician owing to cost whether they have medical insurance or not.

The opposite contribution of economic variables in the regression model highlights the complex situation with private health insurance in the US and the existence of 2 sources of DPD: (i) from illicit drugs which tend to occur in poverty stricken inner city areas, and (ii) PO deaths which tend to occur in wealthier areas or rural areas in the west. The cluster analysis (LMI) illustrates how these patterns vary spatially. Figure 3a shows that there are HH clusters of DPD in northern CA, NV and most of NM and Figure 3g shows that in NM and southern CO these clusters are associated with similar clusters of poverty. In UT and south-western WY, however, there are significant clusters of high DPD where there are clusters of low poverty rates (Figure 3g). These counties are in the most populous areas of UT and the fossil fuel belt which has a large sub-population of non-LDS, single male, migrant workers. Results for median household income and physician use delayed due to cost (not shown) showed very similar patterns to poverty (Figure 3g) with clusters of high rates being associated with high median household income and low amounts of physician use delayed due to cost in UT and WY and the reverse pattern in NM and CO.

The cluster analysis for DPD and population density (Figure 3f) shows a pattern with latitude: clusters of low DPD with low population density (LL) occur in northern states such

as MT, WY and ID whereas clusters of high DPD with low population density (HL) are observed in the south of the region in NV, UT and NM. This suggests that the effect of rurality depends on environmental factors such as the aridity of the region. NV, UT and NM all have large rural areas that are barren desert whereas MT, WY and ID are less arid. This factor should perhaps be investigated in future studies. The cluster map for suicide (not shown) indicated that these same rural counties in NV, UT and NM had high suicide rates as did counties in MT and ID but in the north these were not associated with high DPD. This suggests that those living in the desert rural areas in the south are more prone to intentional suicide using drugs.

Finally, GWR (maps not shown) showed how population density and unemployment were negatively and positively related, respectively to DPD in poor rural south western UT but the sign of these relationships reversed toward the wealthier urban north and east of the state. This suggests that physical and financial access to health care and social determinants of health such as income, education and personal health practices may be important within UT (Novilla et al. 2011). This was confirmed by a strong negative correlation ($r = -0.835$, $p = 0.02$) between DPD and health rankings based on the social determinants of health and the strong contrast between two counties in UT. Carbon County, an economically deprived mining area, had the highest DPD rate in the state while the lowest was recorded for Cache County. Although both counties have similar median household incomes, Carbon County has 20–30% less LDS population, twice the rate of teen pregnancies, unemployment and single-parent families, four times the smoking rate and three times fewer college graduates than Cache County (Novilla et al. 2011). This result illustrates the sharp social gradient that exists within UT and the importance of social determinants of health to DPD in remote rural areas.

Environmental Factors

The map of state-level DPD (Figure 2b) is remarkably similar to patterns of elevation in the USA (Figure 1b) with high rates in Western and Appalachian mountain states. Also the only states in the west to have DPD rates lower than national ones (CA, OR and WA) contain the lowest elevations in the West. Mann-Whitney U tests confirmed that DPD rates were significantly greater at high elevations (>900 m) for all counties nationally, for western counties ($p < 0.001$) and all states ($p = 0.019$). The fact that elevation had only a significant contribution in MLR at the national level (Table 2) suggests the lack of a strict linear relationship between elevation and DPD, but that DPD do increase only once a certain threshold has been passed where the atmosphere becomes markedly thinner. The bivariate LMI map for DPD and median elevation (Figure 3c) indicates the presence of significant clusters only in low elevation Pacific coast areas and in the highest elevation areas of UT, WY, CO and NM. Counties at both elevations belong to clusters of low and high DPD rates indicating that other socio-economic factors are probably more important in determining DPD rates within the western region. Nevertheless clusters of low DPD at the highest elevations were found to be associated with high rates of binge and excessive drinking rates (maps not shown). This suggests that particularly at high elevations drugs and alcohol may act as a substitute for one another in temporarily increasing serotonin levels.

Health, Lifestyle and Demographic Factors

For MLR analysis (Table 2) The LDS rate was included in the final models at all scales but was only significant for the Western counties and nationally for the raw data. In the former case the parameter was positive whereas it was negative nationally and for UT suggesting that nationally and within UT the more LDS in a county, the lower the DPD rate. This suggests that the apparent paradox of high DPD in UT as a whole, given the LDS health code, are associated with areas where the LDS population is smaller. Indeed there was a moderate negative relationship between DPD and LDS population for all UT counties ($r = -0.66$, $p = 0.075$). The GWR map for DPD and LDS population showed the largest and unexpected (given the LDS health code) positive correlations (Figure 4a) for counties where the median elevation ranges from 2000 to 4000 m (Figure 1b). In contrast, correlations between DPD and LDS rate were negative in western UT where elevations are lower (Figure 4a). This suggests that elevation may be an important factor in high DPD in UT despite the LDS health code. The bi-variate LMI map for DPD and LDS (Figure 3b) shows counties that are part of HH clusters of DPD and LDS rates within UT and eastern NV. This positive association, as observed in MLR at some scales and in GWR for the highest elevations, interestingly stops suddenly at the UT/ID border even though there are several counties in southern ID that have low DPD rates but high (>60%, Figure 1a) LDS population levels (Pale blue, LH clusters in Figure 3b). This again suggests that the unexpected positive association between DPD and LDS may be coincidental and have more to do with health care and drug policies which change at state borders.

MLR results (Table 2) for binge drinking and smoking differ from existing literature which suggests a positive association between DPD and these two covariates. Correlations with DPD are mostly negative when these covariates are included in regression models, but they are not significant at all scales. This result suggests that smoking and drinking may act as a substitute for drug use and vice versa. The negative contribution and significance of binge drinking within UT suggests adherence to LDS health code by the majority and perhaps points to PO which are not against the LDS health code or the law as the main source of high DPD or as previous individual level studies have shown, that those dying from drug poisoning do not live the health code (Cheng et al. 2013; Johnson et al. 2013; and Lanier et al. 2013). Cluster analysis illustrates the negative association between DPD and smoking in UT (Figure 3d) with a HL cluster for most of UT. The map for binge drinking (not shown) was very similar but also had HL clusters in MT, ID and CO. HH clusters of DPD and smoking in NV and NM confirm the positive associations discussed in the literature. The local relationship between DPD and binge drinking, as analyzed by GWR, was negative in the highest elevation counties and turned positive in western UT (Figure 4b). This agrees with the earlier finding that at the highest elevations DPD was high where binge drinking was low and vice versa. For mentally unhealthy days (map not shown) the correlation with DPD was strongly positive in the highest elevation counties and declined according to an east/west gradient within UT to become negative. These results suggest that mental health is particularly important to DPD at the highest elevation and that binge drinking may act as a substitute for drug use in such areas. This agrees with the findings of Brenner et al. (2011) who identified a decrease in mental health status at altitude for those with already low

serotonin levels as these levels can be reduced further in the hypoxic conditions at high elevation.

Other health and lifestyle variables that were most consistently included in regression models (Table 2) and were significant at each scale were the number of mentally unhealthy days, suicide and years of potential life lost before age 75. The latter was significant at all scales and always had positive coefficients which makes sense as DPD tends to occur at younger ages than chronic conditions causing death in the elderly. Number of mentally unhealthy days, depression Medicare beneficiaries and suicide all showed positive coefficients with DPD as one might expect given the links between mental health, suicide and DPD rates. However, different results were found for UT counties: depression Medicare beneficiaries, and mentally unhealthy days were not significant and the contribution of suicide was significant, albeit negative. Because DPD includes both intentional and accidental poisonings, this suggests that within UT there may have been more accidental rather than intentional DPD. Potential reasons include: more accidental DPD in children given the large family size in UT (www.census.gov) and those who do not drink or smoke being less 'drug savvy' especially in relation to prescription medications. Indeed, according to Porucznik et al. (2011) among Utahns who were using PO not prescribed to them 85.2% said it was given to them by a friend or relative without charge whereas nationally this rate was only 56.5%. The idea of less PO awareness in UT is also backed up by other studies. McNeely et al. (2014) reported that 96% of people were able to identify illicit drugs but that previous illicit drug users behave more cautiously in relation to PO and are significantly less likely to misunderstand what PO misuse is (McNeely et al. 2014) and those who have used alcohol, illicit drugs or smoked are more likely to store and dispose of PO safely (Reddy et al. 2014).

The positive contribution both nationally and within UT of physically unhealthy days (Table 2) suggests that a significant proportion of the DPD are from PO prescribed for physical pain and ailments. Indeed, McCabe et al. (2007) and UDH (2012) report that the major uses of PO in UT, even among abusers, are for physical health problems and pain relief. The cluster map for physically unhealthy days (Figure 3e), shows that several counties in NV and NM belong to HH clusters with DPD (Figure 3e) suggesting that PO deaths prescribed for pain may also be a source of DPD in these counties. However, these counties were also part of HH clusters for suicide rates suggesting more deaths were intentional in these counties.

In MLR analysis (Table 2) percent of family households had negative parameter estimates and was significant at all scales apart from within UT, which agrees with previous studies that those without a family support system are more likely to experience DPD. The lack of significance in UT might be explained by the large percentage of families throughout the state and individual level data, as used by Lanier et al (2013), is a better indication of the family structure of those that die. The percent white population was significant at the national scale with a positive parameter indicating greater DPD among the white population which seems to agree with suggestions in the literature that PO overdose is predominantly a white problem and becoming a bigger proportion of DPDs throughout the US.

Although not examined explicitly in MLR, LMI or GWR analysis, age and gender are important demographic variables to examine in DPD. National figures for 2005–2011 (not shown) showed that males have larger DPD rates than women for all age groups, in particular 18–24 year olds. This reflects the greater tendency for young males to be involved with illicit drugs (Vitale and van de Mheen, 2006 and Zickler, 2000). Within the Western US, only CA, CO and OR followed this national pattern. AZ, NM, NV and WA followed the national pattern for all but those aged 65+ and for Wyoming the 55–64 age group. In these states women had slightly higher DPD rates in these oldest age groups. For ID, UT and WY DPD rates were larger for males in the 18–44 age groups, but for the 45+ the DPD rates were greater for women and these differences tended to be greatest for the 45–54 age group and in ID and UT. This pattern was also found for four Utah counties where there was sufficient data for a demographic breakdown of DPD. This demographic breakdown suggests that a higher proportion of DPD are from PO in ID, UT and WY than nationally given that the recent increase in PO deaths is far greater for women than men (CDC, 2013). Legitimate prescription represents the most frequent first exposure to PO for women (Cicero et al., 2008), which might explain why DPD are higher in UT women than men, and suggests that PO may act more as a ‘gateway drug’ for women. In a UT study of PO deaths, 91.8% had a legitimate prescription (markedly higher than the 79–85% observed nationally by Cicero et al., 2008). Also figures for total PO deaths within UT (not shown) showed a marked decrease following the introduction of the Prescription Pain Medication Program (PPMP) in 2007.

Discussion and Future Research

The spatial analyses here have demonstrated how the impact of putative factors on DPD varies with scale and location. It has brought to light the different relationship of several factors to DPD in different areas of the Western US, particularly in UT relative to NV and NM.

Economic Factors

Analysis demonstrated the importance of economic factors on DPD in the American West, in particular the impact of private health insurance which is often provided by employers and healthcare provision/access influenced by political policies which change at state borders. Economic policies to address the social gradient within the desert west and UT, in particular, targeted at counties like Carbon that have an extreme problem, may help reduce some of differences in DPD between counties. A comparative analysis of policies that differ between states and the physical accessibility of healthcare, mental healthcare and drug treatment facilities in the rural desert west is needed.

As an indication of how drug related policies vary in the West, strategies that different states have in place to combat PO problems can be examined. While all states have a Prescription Drug Monitoring Program (PDMP), use by prescribers is only mandatory in CO, NV and NM. Between 2008 and 2013 the only Western state to experience a marked decrease in DPD was NM while AZ experienced the greatest increase. In 2013, NM had 10 out of 10 policies in place to curb prescription pain medication problems while AZ only had 4 (TAH,

2013). The number of policies in place in each state was significantly higher ($p=0.01$) in states that voted Democrat in the 2012 general election (CA, CO, NV, NM, OR, WA) and the only states in the region to experience a decrease in DPD between 2008 and 2013 (WA, OR and NM) had scores of 8–10 and had the Naloxene protocol in place (TAH, 2013). The expanded availability and use of Naloxene, a rescue drug seems key in helping reduce DPD but also seems to be a political issue that is hindering reduction of DPD in some states.

Environmental Factors

Nationally higher elevation states tend to display higher DPD rates, yet other analysis showed that at the highest elevations (2000–4000 m) there were either high DPD or high binge drinking levels, the former in highly LDS areas and the latter in non-LDS areas. This suggests a particular potential PO problem in the highest elevation counties with large LDS population. Other environmental variables of potential interest include the degree of aridity due to differences observed between the desert south and moister northerly states. Based on these results there is a need for increased funding for drug education, addiction treatment facilities, clinical studies and mental healthcare provision in the highest elevation and rural desert counties.

Health, Lifestyle and Demographic factors

The positive association between DPD and LDS rate in the west, the distinct behavior of UT for smoking and percent of family households, and gender differences in the three most LDS populous states (Figure 1a), all point to greater proportions of PO deaths making up DPD in these states and UT in particular. While previous individual level studies within UT indicated significantly higher DPD rates among those not practicing the LDS health code (Cheng et al. 2013; Edlund et al., 2007; Johnson et al. 2013; Lanier et al. 2013 and Potter et al. 2004), the significance of physically unhealthy days suggests that PO may act more as a gateway drug in UT particularly for women and this largely drug naive population. Specific studies are needed to examine the factors leading to DPD or pathways to addiction in those of the LDS faith. Also within heavily LDS areas PO education should show that religious people are not immune to such problems and be targeted at those aged 45+, particularly women. Although not a particularly high-risk group the higher rates of DPD in women than men in the 65+ age group in all but 3 western states suggests greater research and education is needed for the elderly about DPD. In reviewing literature on substance abuse among those >50, Rosen et al. (2013) found that only 1% of articles in the top ten gerontology and substance abuse journals addressed substance abuse in the >50s. This is a research gap that needs addressing.

Conclusions

Spatial analysis of DPD in the Western US highlighted the importance of economic factors, like the social gradient presented by the rural/urban divide in the west and particularly in UT. Environmental factors are clearly linked with this divide; the highest elevation and desert areas tend to be sparsely populated and were also identified as particularly high risk areas for DPD. The unique characteristics of DPD in UT in terms of health and lifestyle factors such as smoking, drinking, family size and LDS membership as well as the

demographic structure of DPD in most LDS populous states (UT, ID, WY), suggest that high DPD in UT and other heavily LDS areas are predominantly the result of a PO problem unlike the other states of the Western US where a larger proportion of deaths might come from illicit drugs. The two different drug problems call for distinct strategies to combat them given the different economic, lifestyle and demographic situations of those they tend to affect.

We identified specific research needs into DPD deaths in the Western US and the state of UT. There is also a need for health care and drug monitoring policies that recognize the geographic diversity of the states within the American West. Given these differences more detailed spatial studies should be conducted where there are other unusual populations and large populations living at high altitudes so that policies can be adapted locally.

Acknowledgments

Dr. Goovaerts' work was funded by grant R21 ES021570 from the National Cancer Institute. The views stated in this publication are those of the authors and do not necessarily represent the official views of the NCI.

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Figure 1.
USA County Maps of (a) percentage of LDS population, (b) Median Elevation

Figure 2.

Maps of rates of drug poisoning deaths recorded by state for 2008 (a) and by county for 2006–2010: (b) raw rates and (c) rates estimated by Poisson kriging.

Figure 3.
Results of univariate (a) and bivariate (b–g) local Moran’s I analysis for drug poisoning deaths (DPD) and related variables.

Figure 4.
Results of geographically weighted regression (GWR): local correlations between drug poisoning death (DPD) rates estimated by Poisson kriging and related variables

Table 1

Covariates used for regression: period of recording, sources and descriptions

Variable	Years	Source	Description
Economic variables			
Median Household Income (\$)	2010	www.healthindicators.gov	Estimated by Census Bureau based on data for the SAIPE program
Physician use delayed due to cost (%) [§]	2004–2010	www.healthindicators.gov	Estimates based on BRFSS survey question about physician use being delayed due to cost in the past year.
Population density (per square mile)	2010	www.healthindicators.gov	Number of persons divided by total land area
Poverty rate (%) [§]	2007	www.healthindicators.gov	Estimated by Census Bureau based on data for the SAIPE program
Unemployment 16+ (%)	2008	www.healthindicators.gov	LAUS data come from the CPS, the official measure of the labor force for the nation
Environmental variables			
Median Elevation (m)	2000	www.usgs.gov	30m SRTM elevation data from USGS used to calculate the median elevation by county
Health, Lifestyle and demographic variables			
Average family size	2000	www.census.gov	Families have at least 2 members related by birth, marriage or adoption
Binge drinking (%) [§]	2005–2011	www.healthindicators.gov	Adults 18+ drinking ≥5 drinks (men) or >4 drinks (women) at one time. Estimates based on BRFSS survey question
Depression Medicare beneficiaries (%)	2008	www.healthindicators.gov	% of Medicare beneficiaries (Adults 65+ and disabled) with depression
Family households (%)	2000	www.census.gov	Family households have at least two people related by birth, marriage, or adoption living in same house
LDS rate (per 1000)	2000	www.theARDA.com	Adherents associated with congregations (baptized members plus their children)
Mentally unhealthy days (per month) [§]	2005–2009	www.healthindicators.gov	For adults 18+. Estimates based on BRFSS survey
Physically unhealthy days (per month) [§]	2005–2009	www.healthindicators.gov	For adults 18+. Estimates based on BRFSS survey question
Race (% Black, Hispanic, Asian etc.)	2000	www.census.gov	Percentages of people by race, Black, Hispanic, Asian etc.
Smoking (%) [§]	2003–2009	www.healthindicators.gov	Estimates based on BRFSS survey
Suicide deaths (per 100,000) [§]	2005–2011	www.healthindicators.gov	Deaths from an act inflicted on oneself with intent to kill - intent determined by coroner [*] .
Years of potential life lost before 75 [§]	2006–2008	www.healthindicators.gov	Sum of life-years lost among persons dying before age 75 divided by persons under age 75
Mortality Data			
Drug Poisoning deaths (per 100,000) [§]	2006–2010	www.healthindicators.gov	Age-adjusted rates of accidental, intentional, and of undetermined poisoning by and exposure to various drugs illicit and non-illicit

[§]Rates are total (both genders, all races) and age-adjusted^{*} Estimates based on fewer than 20 deaths are considered unreliable and removed

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Behavioral Risk Factors Surveillance System (BRFSS) survey, estimates based on fewer than 50 cases are unreliable and removed.

Small Area Income and Poverty Estimates (SAIPE) program

Shuttle Radar Topography Mission (SRTM)

YPLL puts more emphasis on causes of death that are more common at earlier ages, because persons dying at younger ages will have more years subtracted from age 75. Therefore it may underestimate the importance of chronic and other conditions occurring later in life. – Health indicators

Local Area Unemployment Statistics (LAUS)

Current Population Survey (CPS)

Shuttle Radar Topography Mission (SRTM)

United States Geological Survey (USGS)

National Center for Health Statistics (NCHS)

Table 2

Best Subset Multiple Linear Regression Models fitted to Poisson Kriged (PK) and raw Drug Poisoning Deaths Rate in three different geographies: All US counties, western counties, and Utah counties

Independent variable – Drug Poisoning Death Rate (PK)		All Counties (PK) R ² =0.489		Western Counties (PK) R ² =0.517		Utah Counties (PK) R ² =0.907	
Independent variable – Drug Poisoning Death Rate (raw)		All Counties (raw) R ² =0.541		Western Counties (raw) R ² =0.563		Utah Counties (raw) Insufficient data	
Term		Parameter estimate	p-value	Parameter estimate	p-value	Parameter estimate	p-value
Intercept		-1.4341	0.6562**	14.2501	0.0059	31.384	0.0172
<i>Economic variables</i>							
Median household Income (\$)		0.0001	0.0007**	---	---	---	---
Physician use delayed due to cost		0.1989	0*	---	---	---	---
Population density		0.0001	0.0785	-0.0001	0.0115	0.0022	0.0139
Poverty (%)		-0.0750	0.0671	-0.2467	0.0011*	---	---
Unemployment 16+ (%)		33.9602	0*	29.1759	0.0730	412.5122	0.0050
<i>Environmental variables</i>							
Elevation median		0.0020	0*	0.0007	0.0773	---	---
<i>Health and lifestyle variables</i>							
Binge drinking		-9.3447	0.0011	-13.5953	0.0652	-50.2225	0.0221
Depression Medicare beneficiaries		40.7192	0**	51.1445	0*	---	---
Mentally unhealthy days		1.0702	0*	1.4731	0.0014	---	---
Physically unhealthy days		0.9714	0*	---	---	0.9761	0.1573
Smoking (%)		-0.0726	0.0221*	0.1195	0.0886	-0.2209	0.1925
Suicide		0.1434	0**	0.0963	0.1080	-0.5206	0.0303
<i>Socio-demographic variables</i>							
Average Family Size		-3.7485	0	---	---	---	---
Families (%)		---	---	-0.3269	0.0*	-0.32804	0.0811
Hispanic (%)		---	---	0.1319	0.0	---	---
LDS rate		-0.2360	0.4860*	0.0074	0.0002	-0.0092	0.1001
White (%)		0.0303	0.0039*	0.0361	0.1608	---	---

Independent variable – Drug Poisoning Death Rate (PK)				Western Counties (PK) R ² =0.517		Utah Counties (PK) R ² =0.907	
Independent variable – Drug Poisoning Death Rate (raw)				Western Counties (raw) R ² =0.541		Utah Counties (raw) Insufficient data	
Term	Parameter estimate	p-value	Parameter estimate	p-value	Parameter estimate	p-value	p-value
Years of potential life lost before 75	0.0007	0 ^{**}	0.0008	0.0005 ^{**}	0.0020	0.0013	

Significance at the 0.05 level indicated in bold,

* p-value <0.05 for raw drug poisoning data,

** p-value = 0 for raw drug poisoning data.

The dashed line indicates variables that were not selected in the model.