Exploring the Role of Urbanization and Wind on the Distribution of Extreme Rainfall by Utilizing High Spatiotemporal Radar Rainfall Product: A Dallas Fort-Worth Case Study

Junaid Ahmad[1] and Jessica Eisma[1]

[1]Affiliation not available

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Abstract

Rapid urbanization has caused extensive land use changes, which may impact the local climatology and trigger extreme rainfall events. Wind, another important factor in rainfall, has been examined to determine its role in generating extreme rainfall in conjunction with land use changes. This study evaluates the variability of extreme rainfall in the Dallas Fort-Worth (DFW) area. The study area has been divided into 256 equal sized grids and grouped into 4 clusters. Spatial Synoptic Classification (SSC) technique has been adopted to select days with benign synoptic activity so that the role of large-scale weather patterns is reduced. Extreme rainfall days are defined as those exceeding the 95th percentile threshold of the daily rainfall observed at the DFW airport. After filtering data based on SSC and extreme rainfall criteria, 114 days are selected for the study period from 2000-2016. The Multi-Radar Multi-Sensor rainfall product has been used to examine the variability of extreme rainfall in grids and clusters. The variation in extreme rainfall for different land covers (e.g., high, medium, and low intensity developed land, and open space) has also been examined. The results reveal that the "Urban Core" cluster receives maximum rainfall across the study period. Also, the difference in cumulative maximum rainfall between highly urbanized grids and the lowest urbanized grid is highest in the "Urban Core" cluster. The grid with the highest percentage of "High intensity developed land" received the most rainfall. The wind regime associated with the most rainfall across the study period is from the South-West. Less urbanized grids located downwind of the highest urbanized grids received relatively more rainfall. Urbanization and the magnitude of extreme rainfall is proportional in most of the grids. The role of the Urban Heat Island will also be examined to determine its impact on extreme rainfall variability.

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Junaid Ahmad, Jessica Eisma

University of Texas at Arlington

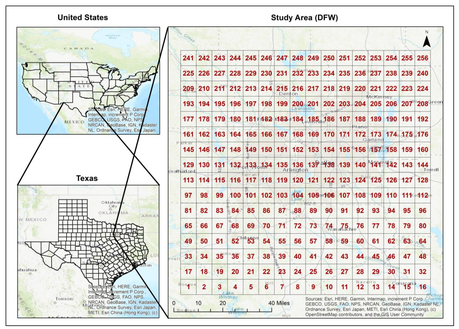
UNIVERSITY OF TEXAS ARLINGTON

Introduction

- Severe flooding is caused by extreme rainfall.
- Study investigates the impact of urbanization and wind on the variability of extreme rainfall in the Dallas Fort-Worth (DFW) area.
- DFW is the 4th largest metropolitan area in the USA with high urbanization growth.
- According to the US Census Bureau 2020, DFW area with a population of 7.6 million has increased by 1.2 million in the last decade displaying three times faster growth than the other metropolitan areas.
- The region is expected to reach 10.5 million by 2040 (NCTCOG, 2015)
- Potential place to investigate the urban effect on rainfall because of no immediate orographic or coastal effect.
- Study finds spatial and temporal variation of extreme rainfall in highly urbanized areas and also within classes of developed land (High, Medium, Low intensity and Open space).

Study Area

- Division of study area into 256 equal sized grids.
- The size of one grid is equal to 103 km^2 (10km X 10km approx.)
- Located in the Northern Texas, the climate of DFW area is humid subtropical.
- Average Annual rainfall in DFW varies from 525-1200 mm.



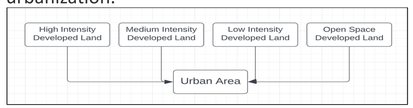
Research Questions

- Is urban core recipient of maximum rainfall?
- Which cluster received daily intense rainfall events overall?
- Which developed land use has received maximum rainfall overall in each cluster?
- Has the grids with maximum % of developed land type received more rainfall than the grids with lowest % of developed land type in each cluster?
- What is the prevailing wind regime? Has downwind of the city received more rainfall under prevailing wind regime?

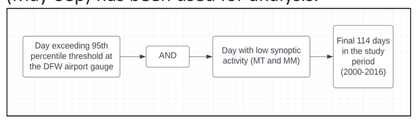
Methodology

Multi Radar Multi Sensor (MRMS) having spatial resolution of 1-km has been utilized to check the variation of extreme rainfall.

National Land Cover Database has been used for land cover data to estimate urbanization.

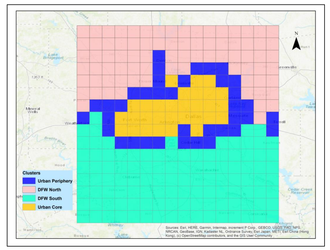


To minimize the influence of large-scale weather, days with low synoptic activity have been selected at Dallas station using Spatial Synoptic Classification method(Sheridan, 2002). Summer season (May-Sep) has been used for analysis.



Days exceeding 95th percentile at the DFW airport were selected to identify extreme rainfall days.

After filtering based on Spatial Synoptic Classification and extreme rainfall threshold, the analysis included 114 days for the study period (2000-2016). The grids were divided into four clusters using K-Means Elbow method based on urbanization(%) in 2001.



Wind direction at 700 hPa was found for the 114 days using radiosonde data at Fort Worth station. Concentration Factor , CF (Phillips & McGregor, 2001, Hand & Shepherd, 2009) was estimated to find wettest location under prevailing wind regime.

$$CF = 100\left(\frac{Rf}{NRd} - \frac{Nf}{N}\right)$$

Rf is the maximum total rainfall on all days, Nf is the number of days with a given flow direction, Rd is the mean daily max rainfall, N is the total number of days.

If the CF is positive (negative), then the rainfall percentage is greater (lower) than the percentage frequency of occurrence of that particular flow group. Positive(highest) concentration factor means wettest place.

CF for grids and clusters were calculated.

Z-score were calculated for maximum daily rainfall event for grids with highest urbanization growth rate, highest urbanization (%), highest high intensity developed land, highest medium intensity developed land, highest low intensity developed land and highest open space developed land.

Results

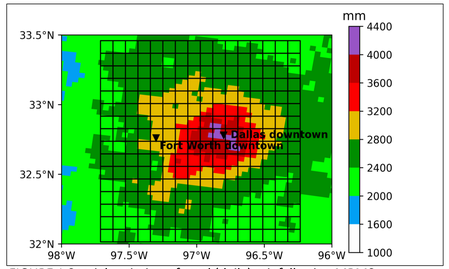


FIGURE 1 Spatial variation of total (daily) rainfall using MRMS.

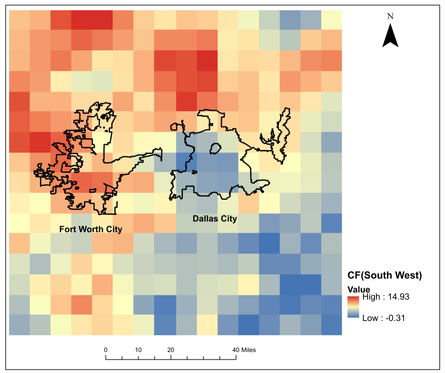


FIGURE 2 Distribution of Concentration Factors under prevailing wind regime.

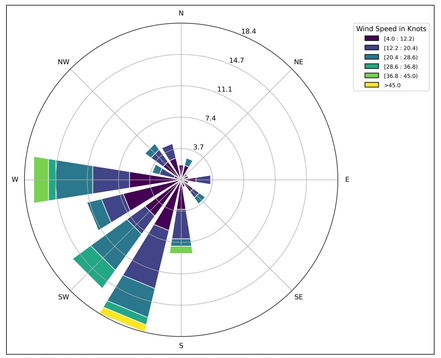


FIGURE 3 Wind rose plot for 114 days at 700hPa.

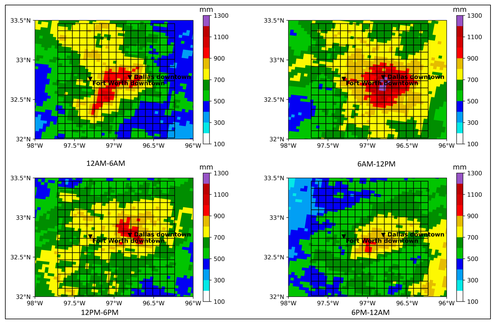


FIGURE 4 Spatial variation of total rainfall (6-hourly) using MRMS.

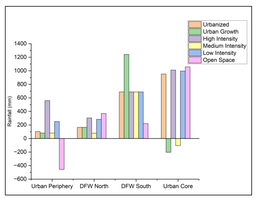


FIGURE 5 Difference of cumulative maximum rainfall between highest and lowest grid category in all clusters.

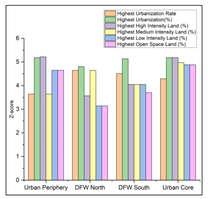


FIGURE 6 Z-score for highest maximum rainfall event in grids of each cluster with highest categories.

Conclusions

1. Urban Core received maximum cumulative rainfall in the study period.
- Grid 138 with highest percentage of "High intensity developed land" was the recipient of maximum rainfall.
- Max urbanization (%) increase of 36.8% was observed in Grid 203. It also has highest CF among all grids with highest growth of urbanization(%) under prevailing wind regime.
- DFW North located downwind of Dallas and Fort Worth cities has highest CF under prevailing wind regime.
- All clusters received highest average max rainfall from 6AM-12PM except DFW North which received highest average max rainfall from 12PM-6PM.
- Grids with maximum categories in Urban Cluster received daily intense rainfall as highest z-scores were found in majority of categories.
- In all clusters, majority of grids with highest percentage of urban growth, urbanization, high intensity, medium intensity, low intensity and open space received more cumulative max rainfall as compared with grids having lowest percentages.
- Medium intensity developed land was dominant among grids receiving highest total rainfall in each cluster.

References

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- Hand, L. M., & Shepherd, J. M. (2009). An investigation of warm-season spatial rainfall variability in Oklahoma City: Possible linkages to urbanization and prevailing wind. Journal of Applied Meteorology and Climatology, 48(2), 251-269
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