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Urban Impacts on Extreme Rainfall: Evidence From a High-Resolution Radar Rainfall Product in the Dallas-Fort Worth Area

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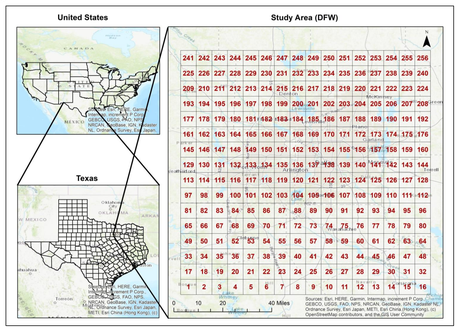
Introduction

- Severe flooding is caused by extreme rainfall.
- The 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, the 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 (Foss and Ko, 2019)
- 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 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 Northern Texas, the climate of the DFW area is humid subtropical.
- Average annual rainfall in DFW varies from 525 mm to 1200 mm.



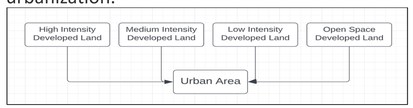
Research Questions

- Is the urban core the recipient of maximum rainfall?
- Has increase in urbanization(%) caused an increase in rainfall in the study area?
- Have the grids with the maximum % of developed land type received more rainfall than the grids with the lowest % of developed land type in each cluster?
- Has the downwind of the city received more rainfall under the prevailing wind regime?

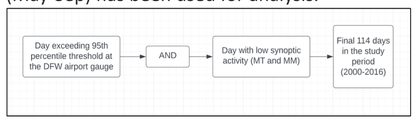
Methodology

Multi-Sensor Precipitation Estimate (MPE) with a spatial resolution of 4 km has been utilized to check the variation of extreme rainfall.

The 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 the 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 the K-Means Elbow method based on urbanization(%) in 2001 shown in Figure 1. These four clusters are: Urban Core (UC), Urban Periphery (UP), DFW-North (DFW-N) and DFW-South (DFW-S).
- Grids with highest and lowest urban classes (urban growth, urbanized, high, medium, low intensity and open space developed lands) were identified in each cluster to examine difference of maximum rainfall.

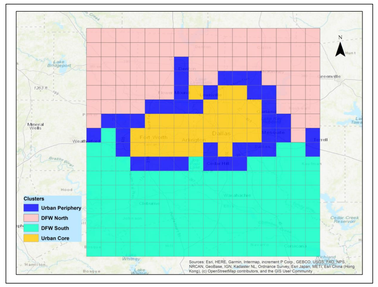


FIGURE 1 Division of 256 grids into four clusters

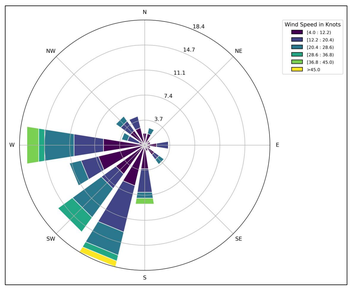


FIGURE 2 Wind rose plot for 114 days at 700hPa

Wind direction at 700 hPa was found for the 114 days using radiosonde data at Fort Worth station shown in Figure 2. South-West was the prevailing wind regime as 63 % of the extreme rainfall days were caused under SW winds.

Results

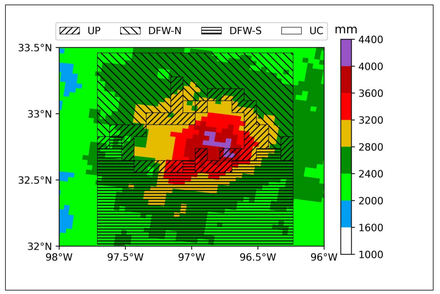


FIGURE 3 Spatial variation of total (daily) rainfall using MPE.

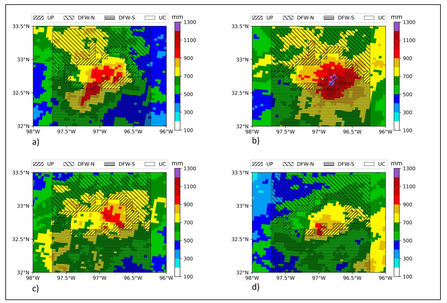


FIGURE 4 Spatial variation of total rainfall (6-hourly) using MPE a). 12AM- 6AM, b). 6AM- 12PM, c). 12PM- 6PM and d). 6PM- 12AM.

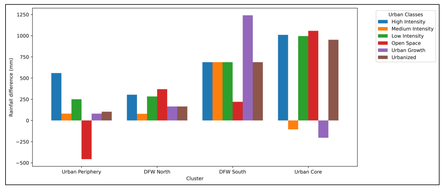


FIGURE 5 Difference of maximum rainfall for grids with different urban classes. A positive difference means that the grid with highest percentage of urban class received more rainfall than the lowest percentage of the particular urban class.

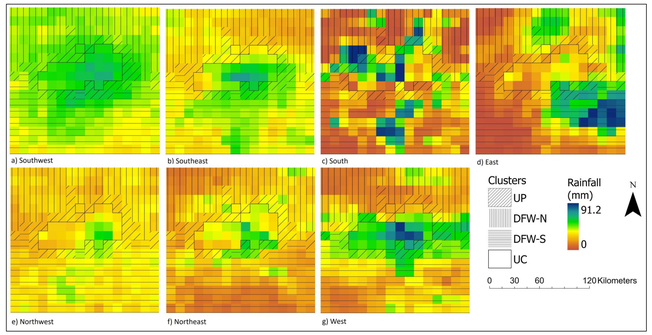


FIGURE 6 Spatial variation of total rainfall (6-hourly) using MPE a). 12AM- 6AM, b). 6AM- 12PM, c). 12PM- 6PM and d). 6PM- 12AM.

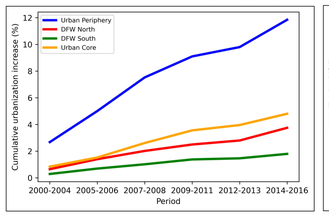


FIGURE 7 Cumulative urbanization (%) increase for all clusters.

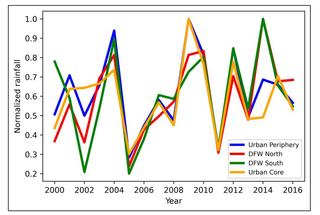


FIGURE 8 Normalized rainfall for all clusters

Conclusions

- Urban Core received maximum cumulative rainfall in the study period at daily and 6-hourly scale (Figure 3 and 4).
- Grid 138 with highest percentage of "High intensity developed land" received maximum rainfall.
- All clusters received highest average max rainfall from 6AM-12PM except DFW North which received highest average max rainfall from 12PM-6PM (Figure 4).
- In clusters, all grids (except 3 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 of these urban classes (Figure 5).
- Medium intensity developed land dominated in grids receiving highest total rainfall in each cluster.
- Under prevailing wind direction (SW winds), the downwind area (DFW-N) received 5% more rainfall than the upwind area. However, the UC cluster received highest rainfall (Figure 6).
- Maximum urbanization occurred before 2009 in all clusters (Figure 7), however, post 2009, all grids experienced an increase in average daily rainfall (Figure 8).

References

- Foss, Ann W., and Yekang Ko. "Barriers and opportunities for climate change education: The case of Dallas-Fort Worth in Texas." The Journal of Environmental Education 50.3 (2019): 145-159.
- Sheridan, S. C. (2002). The redevelopment of a weather-type classification scheme for North America. International Journal of Climatology: A Journal of the Royal Meteorological Society, 22(1), 51-68.