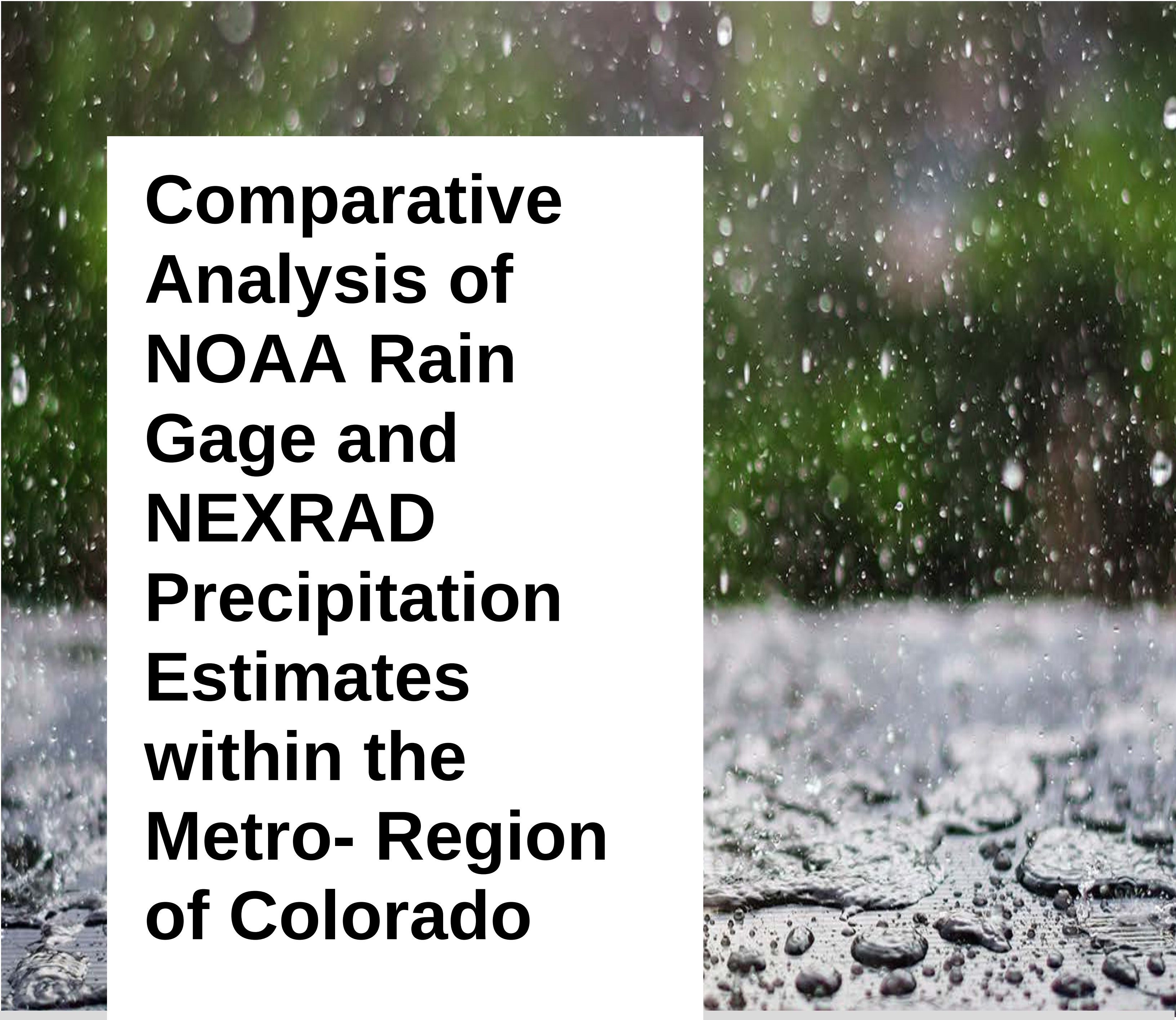

Comparative Analysis of NOAA Rain Gage and NEXRAD Precipitation Estimates within the Metro- Region of Colorado

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1. Introduction

1.1 Background

The knowledge and availability of precipitation data is critical in fully understanding hydrological processes, as this common climatological factor is used as an input in various models within hydrologic modeling. These models and capabilities can include flood prediction, yield estimation within agriculture, land management, stormwater management, and atmospheric simulation models. Traditionally, rainfall data is collected at meteorological stations, or rain gages, which are discrete point locations in space. In a well- designed rain gage network, point rainfall measured by gages presents a very reliable measurement of actual precipitation value at the corresponding location [1]. However, the precipitation values at the in-between areas have to approximated, therefore, the spatial variability of the rainfall may not be accurately represented by rain gage data alone. Two methods to obtain an estimate for the "in-between" areas include rain gage interpolation or the use of remote sensors, or ground- based radar, such as NEXRAD.

Common rain gage interpolation methods include Theisen polygon, inverse-distance weighting, kriging, spline, and natural neighbor. The greatest error within rain gage interpolation is due to precipitation variability within short distances, as well as sparse or irregular gage networks [2]. Though the accuracy of interpolation methods has been found to be dependent on the location and the type of rainfall, the most commonly used interpolation method is the Theisen polygon method, due to its great simplicity compared to the other methods [3].

NEXRAD, or Next- Generation Radar, is a remote sensor that can also be used for precipitation estimation. Essentially, NEXRAD is a network of high resolution of S- band Doppler weather radars, and is operated by the National Weather Service [4]. NEXRAD detects precipitation and atmospheric movement by emitting short pulses of energy into the atmosphere. If these pulses strike an object, such as a raindrop or a snowflake, the radar waves are scattered in all directions, with a small part of the scattered energy directed back toward the radar [5]. This reflected signal is then received by the radar, and the strength of the returned radar wave, the time it took to travel, and the frequency shift of the pulse are analyzed through numerous algorithms and processed into precipitation data [6].

Though the application of NEXRAD has the ability to provide spatial distribution of precipitation data, the accuracy of this data has been continually researched and questioned for many years. For the most part, research has shown that there is a strong tendency for NEXRAD to greatly overestimate small rainfall and underestimate large rainfall amounts relative to a gage network, though providing fairly accurate spatial distribution of any storm event [7] [8]. Additionally, the accuracy of NEXRAD precipitation data has been found to decrease with increased distance from the NEXRAD station, with highest accuracy occurring within 100 km (62 miles) of the station [7]. The main causes of this result were concluded to be due to the dispersing of the radar beam and its height above the curved Earth's surface. Another strong correlation that has been found for

NEXRAD accuracy is that with increased altitude, there is decreased precipitation accuracy. The main reason for this result was concluded to be due to the orographic lift that occurs on windward slopes during increased precipitation events, effecting the reflectivity observations of the radar signal [7].

1.2 Objectives

A comparative analysis was performed for NOAA rain gage and NEXRAD daily precipitation estimates within the metro- region of Colorado for a storm on May 8, 2013. The main objectives of this analysis include:

- Compare storm rainfall totals for NEXRAD data at the individual rain gage locations.
- Compare area- average rainfall totals of rain gage interpolation methods and NEXRAD data.
- Compare the spatial distribution of NEXRAD to the distribution of rainfall through various rain gage interpolation methods.

1.3 Motivation

Inspiration for this research stemmed from a past of internship that covered a Clean Water Act and National Pollutant Discharge Elimination System (NPDES) enforcement case. Within this enforcement case, there was a need of rainfall analysis to prove that an industrial facility should have/was able to sample stormwater runoff. Unfortunately, the closest rain gage to the facility was 30 miles away, therefore NEXRAD data was suggested for further rainfall analysis.

2. Site Description

The metro- region of Colorado is located centrally within the state, focused around the city of Denver, as shown in Figure 1. The metro- region includes eight counties (Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, Jefferson, and Elbert County), covering approximately 6,385 miles. This region of Colorado is considered to have a semi- arid climate, with low humidity, moderate precipitation (10-15 inches annually), and over 3,100 hours of sunshine annually [8]. Additionally, the weather of Denver and the surrounding area is greatly influenced by the proximity of the Rocky Mountains to the west.

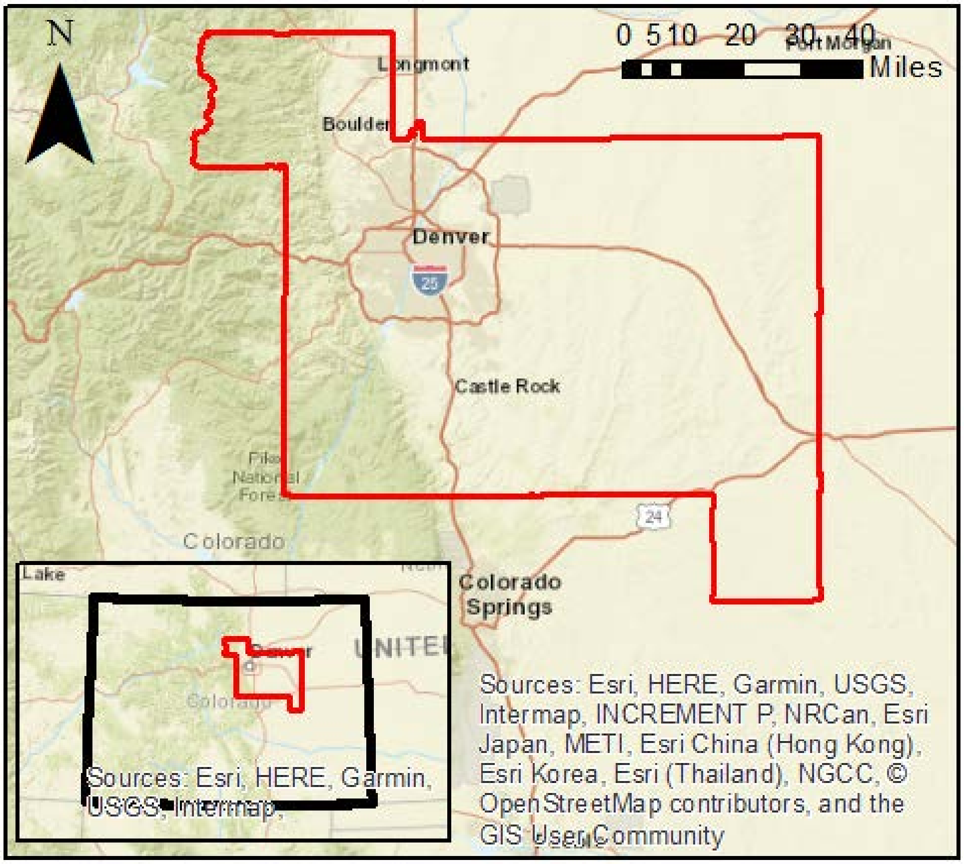

Figure 1: Map of the site investigated within this study, the metro- region of Colorado, as outlined in red.

3. Data Collection

3.1 Region Boundary

The state of Colorado boundary and each county boundary within the metro-region was obtained as a shapefile (Geographic coordinate system, no projection) from the Colorado Department of Public Health and Environment (CDPHE). The CDPHE is responsible for protecting and maintaining the health and environment of Colorado, and has a free online database, called CDPHE OpenData, that includes several shapefile boundaries [9].

3.2 Elevation

Elevation data for each of the respective counties within the metro- region of Colorado was obtained from the Geospatial Data Gateway as a 30-meter, 1- arc second resolution, DEM raster (NAD1983, UTM 13N Projection). The Geospatial Data Gateway is organized by the Natural Resources Conservation Service, Farm Service Agency, and Rural Development, and allows access to a map library of over 100 high resolution vector and raster layers [10].

3.3 Rain Gage Precipitation

Rain gage daily precipitation data was obtained from the National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center as a CSV (Comma- Separated Values) text file for the entire state of Colorado. NOAA's National Climate Data Center is responsible for reserving, monitoring, assessing, and providing public access to the Nation's treasure of climate and historical weather data and information [11].

3.4 NEXRAD Precipitation

NEXRAD precipitation data (Level III Data) was obtained from the National Oceanic Atmospheric Administration (NOAA) National Climate Data Center for NEXRAD Station KFTG (Denver Front- Range Airport). An additional software, NOAA's Weather and Climate Toolkit, was downloaded to view the obtained Level III NEXRAD data and to convert the data to an ESRI ASCII Grid (default cell size of 0.62 meters, geographic coordinate system, no projection). This toolkit is a free platform allowing the visualization and data export of weather and climate data, including radar, satellite, and model data [12]. All 24 one- hour precipitation datasets were converted to an ESRI ASCII Grid for the specific storm of May 8, 2013.

4. GIS Methodology

4.1 Map Projection

The coordinate system used within the GIS analysis was the North American Datum, 1983 (NAD83), and the Universal Transverse Mercator (UTM) 13N projection.

4.2 Region Boundary

The state and county shapefiles were imported into GIS, and each dataset layer was projected to the correct projection (NAD83, UTM 13N). Using the county boundaries and the 'Dissolve' tool, the outline of the metro- region was created.

4.3 Elevation

Each of the county elevation datasets were imported into GIS, and each raster layer was projected to the correct projection using the 'Project Raster', while setting the cell size to 100 meters. The cell size of 100 meters was chosen to simplify data and make processing faster. The 'Mosaic to New Raster' tool was used to merge each of the elevation rasters.

4.4 Rain Gage Precipitation

The NOAA rain gage precipitation data was downloaded as a CSV text file and imported into excel. All unnecessary data columns were deleted. With the excel file closed, the rain gage data table was imported into GIS using the longitude and latitude elements as inputs, and setting the input coordinate system to geographic. The data event was exported and projected to the respective projection. The gage data was then clipped to the metro- region boundary using the 'Clip (Analysis)' tool.

Figure 2 displays the result of this methodology, presenting the rain gage data for the May 8, 2013 storm event.

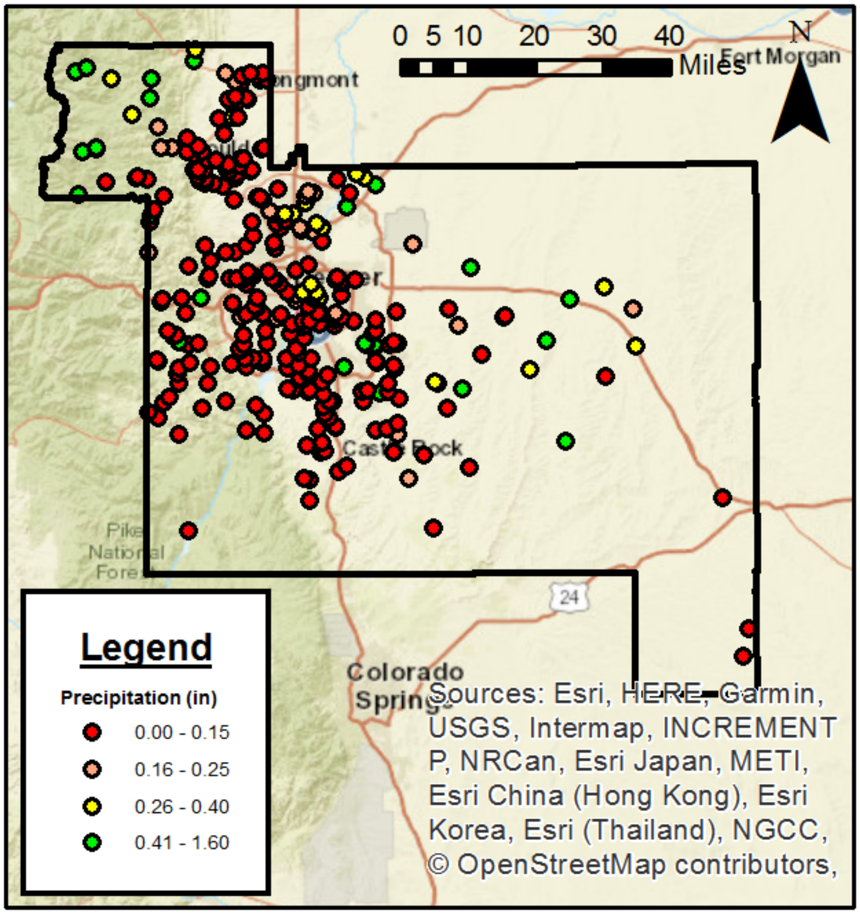

Figure 2: Rain gage precipitation estimates for the May 8, 2013 storm event.

4.5 NEXRAD Precipitation

Each of the 24 NEXRAD one-hour precipitation datasets were imported into GIS and projected to the respective projection using the 'Batch, Project Raster' tool; the raster cell size was set to 100 meters. The 'Cell Statistics' tool was used to sum each of these raster layers together, while making sure to ignore no data values. Figure 3 displays the result of this methodology, presenting the NEXRAD precipitation data for the May 8, 2013 storm event, as well as the location of the NEXRAD station.

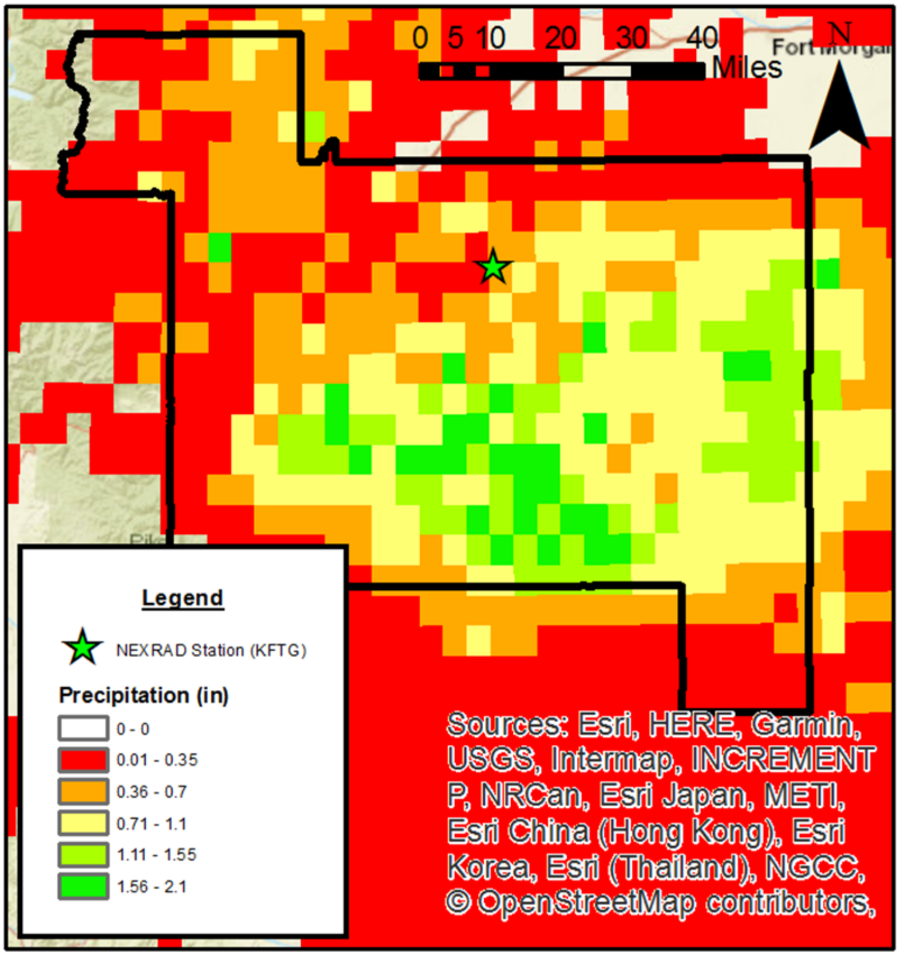

Figure 3: NEXRAD precipitation estimates for the May 8, 2013 storm event.

4.6 Analysis of NEXRAD Data at Rain Gage Locations

The 'Extract Values to Points' tool was used to find the NEXRAD precipitation estimate at each individual rain gage location. Within the attribute table of this new layer, a field was added to calculate percent error (Equation 1), assuming rain gage estimates as the theoretical value.

$$\%\ \boldsymbol{Error} = |\boldsymbol{NEXRAD} - \boldsymbol{Gage}| \,/\, \boldsymbol{Gage} * \mathbf{100} \qquad \textbf{Equation 1}$$

Additionally, the 'Point Distance' tool was used to calculate the distance of each rain gage from the NEXRAD station and zonal statistics was used to calculate an area- average rainfall, as both of these are used in further analysis.

4.7 Rain Gage Interpolation Methods

When performing the various rain gage interpolations, the rain gage data for all of Colorado was used in analysis, versus just the clipped rain gages within the metro-region. To obtain the various interpolation data, the 'Create Thiessen Polygon' and 'Feature to Raster' tools were used to produce a Thiessen polygon interpolated raster, and then the various methods of spline, inverse- distance weighted, natural neighbor, and kriging were produced from the respective Interpolation tools within Spatial Analyst. Table 1 summarizes each of the interpolation methods performed and the respective inputs. Additionally, zonal statistics was performed on each of the interpolation methods that were chosen to be used in further analysis to calculate an area- average rainfall.

Table 1: Summary of rain gage interpolation methods.

Interpolation Method	**Type**	**Other Parameters**	**Cell Size (m)**	**Used in further analysis?**
Thiessen Polygon	N/A	N/A	100 (using ‘Feature to Raster’)	Yes
Spline	Regularized	Default	100	No (negative values)
Spline	Tension	Default	100	No (negative values)
Natural Neighbor	N/A	N/A	100	Yes
Inverse Distance Weighted	Variable Radius	Power: 2	100	Yes
Inverse Distance Weighted	Fixed Radius	Power: 2 Radius: Default	100	No (not a smooth raster)
Kriging	Ordinary, Spherical, Variable Radius	Default	100	Yes
Kriging	Ordinary, Gaussian, Variable Radius	Default	100	Yes

5. Results and Analysis

5.1 Comparative Analysis of NEXRAD and Rain Gage Precipitation Estimates

As stated in Section 4.6, NEXRAD precipitation data was calculated at each individual rain gage location and the percent error between the two precipitation estimates were compared. Figure 4 displays the percent error between NEXRAD data at each rain gage location within the metro- region. As observed within Figure 4, there is large discrepancy between the two precipitation estimates, concluding that NEXRAD data has the ability to greatly overestimate rainfall data. According to literature, NEXRAD data does have the tendency to overestimate rainfall data, especially for smaller storms, though not necessarily to the extent found within this particular study [7]. A potential reason for this great inaccuracy of the NEXRAD data is the type of data that was chosen for analysis. NEXRAD provides eleven various precipitation products, all using various algorithms and processing methods. One- hour precipitation data was chosen for this study, while there are other data types such as storm total precipitation, digital precipitation array, and dual-polarization one- hour precipitation (just to name a few). If a higher processed data type would have been used, it is possible that more accurate results would have been obtained.

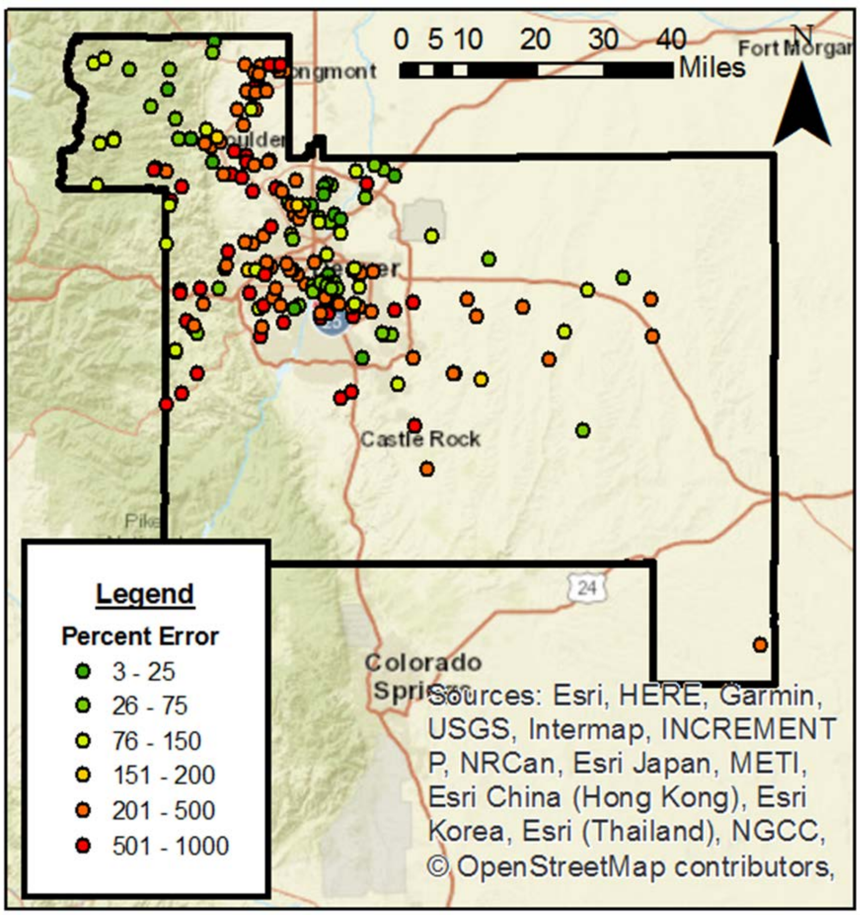

Figure 4: Percent error between NEXRAD and rain gage precipitation estimates at each rain gage location for the May 8, 2013 storm event.

Further analysis was performed to analyze the potential of any correlations between NEXRAD accuracy and rain gage elevation, as well as NEXRAD accuracy and the rain gage distance from the NEXRAD station. Both of these parameters, distance and elevation, have showed to have a strong correlation within literature [7]. Figure 5 presents the correlation of rain gage distance from the station and NEXRAD accuracy (represented as percent error). As observed within this figure, this study found no correlation. While NEXRAD radar can reach up to approximately 150 miles in each direction, the farthest gage within the metro-region is just over 70 miles away; therefore, if a larger study site that covered up to 150 miles around the station was chosen, potentially a stronger correlation would have showed. Figure 6 presents the correlation of rain gage elevation and NEXRAD accuracy. As observed within this figure as well, this study found no correlation for elevation and NEXRAD accuracy. This result could simply be due to the fact that the NEXRAD accuracy is so low, correlations could not be made.

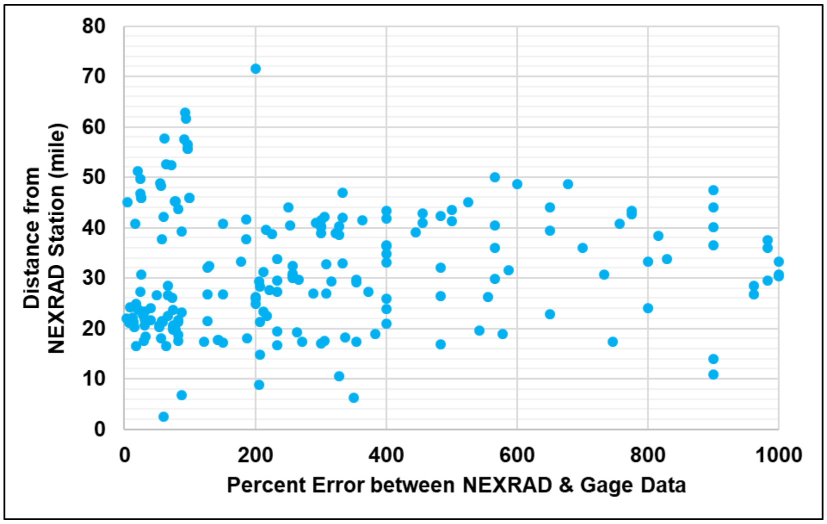

Figure 5: Gage distance from NEXRAD station vs. NEXRAD accuracy.

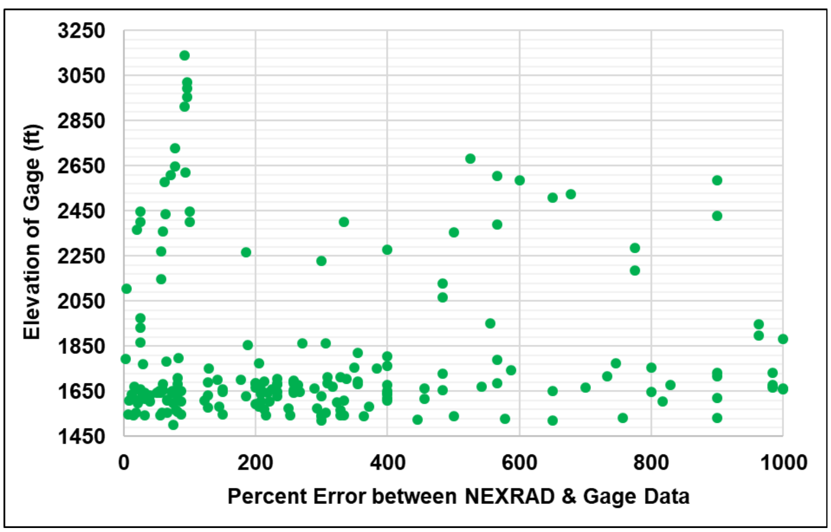

Figure 6: Gage elevation vs. NEXRAD accuracy.

5.2 Rain Gage Interpolation Analysis: Area- Average Rainfall Totals

As stated in Section 4.6 and Section 4.7, area- average rainfall totals were calculated for the NEXRAD data and the various interpolation methods, as shown in Table 2. Due to the great overestimation of the NEXRAD data, it is difficult to compare the area- average rainfall totals of NEXRAD to the interpolation methods Though when observing the interpolated area- average rainfall totals, each of the methods are found to be fairly similar to each other (ranging from 0.19- 0.22 inches). Thiessen polygon, which according to literature is the most commonly used interpolation method, resulted in the highest area- average rainfall total [7].

Table 2: Summary of area- average rainfall totals for NEXRAD and interpolation methods.

	NEXRAD	Thiessen Polygon	Natural Neighbor	Inverse Distance Weighted (Variable)	Kriging (Ordinary, Gaussian, Variable)	Kriging (Ordinary, Spherical, Variable)
Area- Average Rainfall (in.)	0.69	0.22	0.21	0.20	0.19	0.19

5.3 Rain Gage Interpolation Analysis: Spatial Distribution

Though NEXRAD precipitation data can greatly overestimate rainfall data, according to literature, it is still proven to have fairly accurate spatial distribution of precipitation [8]. Figure 7 presents the map of NEXRAD precipitation data compared to each of the interpolation methods. Visually, each interpolation method was compared to the spatial distribution of the NEXRAD data. When observing Figure 7, it looks as if the natural neighbor and Thiessen polygon methods match the high rainfall points of the NEXRAD precipitation distribution the best (shown in green). It is interesting to note here, that although the Thiessen polygon method is a much simpler method than the others, it is still found to show very similar high rainfall points compared to the NEXRAD data. Overall, though both natural neighbor and Thiessen polygon methods match the high rainfall points of the NEXRAD data, the Thiessen polygon method shows a great amount of zero precipitation values, resulting in natural neighbor most likely best matching the spatial distribution of the NEXRAD data, though there is still quite of bit of discrepancy between these spatial distributions. This discrepancy is most likely due to the fact that NEXRAD shows its greatest rainfall within the east and southeast regions of the metro- region, yet when looking at Figure 2, these areas have the lowest density of rain gage networks within the region. Rain gage interpolation accuracy will greatly decrease with decreased rain gage network density.

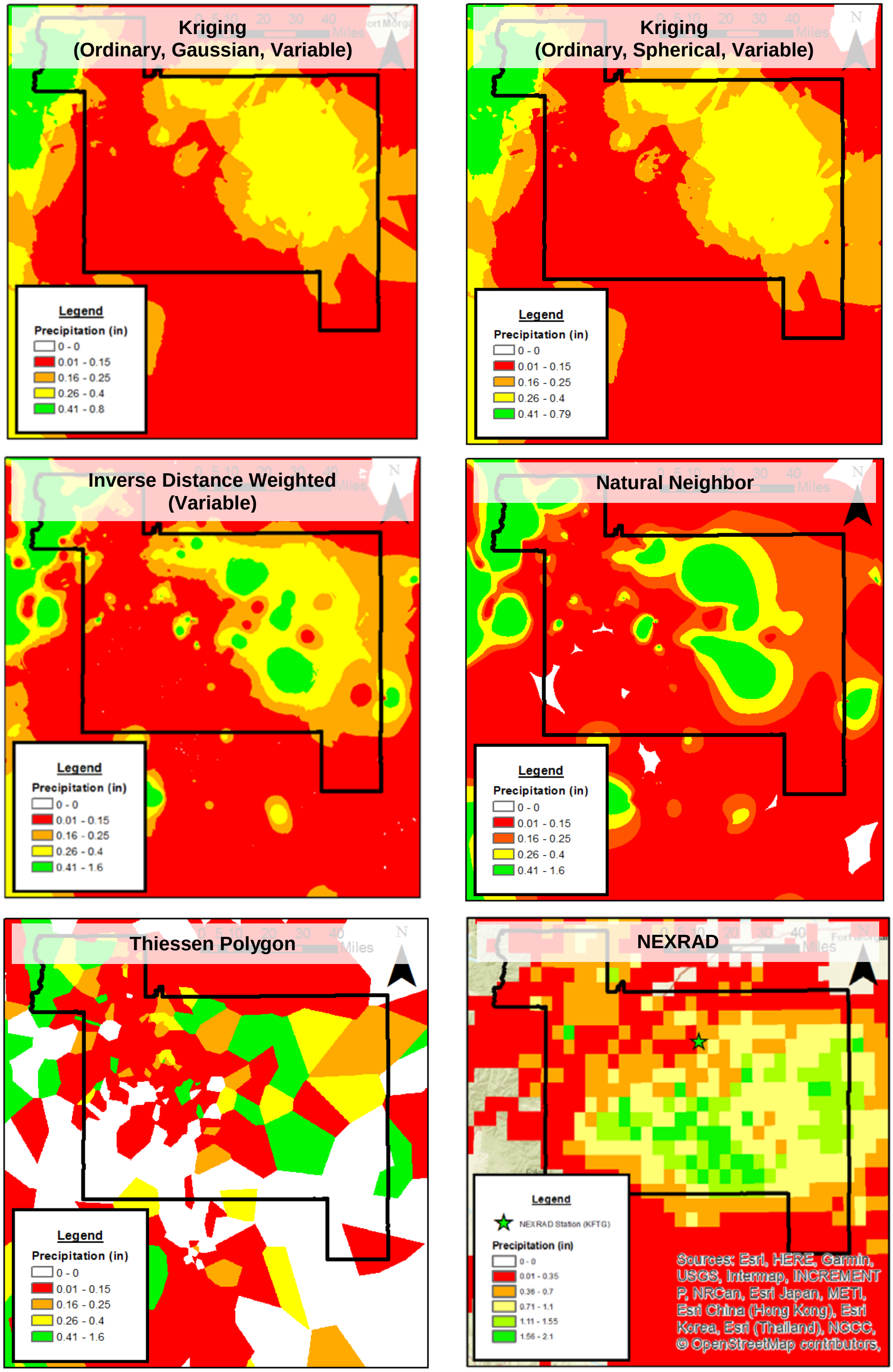

Figure 7: Precipitation estimates of NEXRAD data and various interpolation methods.

6. Conclusion

The knowledge and availability of precipitation data is critical in fully understanding hydrological processes, as precipitation is a commonly required input in various models within hydrologic modeling. Though, rain gage precipitation estimates have been found to be the most accurate rainfall measurement, when an area of interest is in the "in- between" areas of a rain gage network, methods such as rain gage interpolation and radar measurements may be used to estimate rainfall, though each of these methods can come with an amount of uncertainty. Within this study, NEXRAD precipitation data was found to greatly overestimate rainfall at each rain gage location. A potential cause for this great inaccuracy could be due to the type of NEXRAD data used within this analysis; one- hour precipitation totals were used, which have a lower level of processing and different algorithm compared to other available NEXRAD precipitation products. Additionally, when comparing the spatial distribution of NEXRAD data to those of various rain gage interpolation methods, the natural neighbor method showed to best represent the spatial distribution of the NEXRAD data. In conclusion, though this study may not have received the most "predicted" results, it has been a successful proof of methodology and has shown that ArcGIS can be used for extensive rainfall analysis. Recommendations for future work include comparing various NEXRAD precipitation products, a larger site area, and storm events of difference sizes.

7. References

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