# Water Scarcity, Conflict, and the Impact of Hydroelectric Dams in the Ganges-Brahmaputra-Meghna River Basin

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Introduction

Goals and Objectives

Data

Anticipated Methods and Procedures

Expected Results

Project Timeline

Conferences

References

# Introduction: Background

Freshwater is a finite resource, and its availability is being diminished by climate change, population growth, industrial pollution, and a loss of forested watersheds. Additionally, freshwater extractions have tripled over the last 50 years (United Nations, 2012).

Given the opposing forces of increased demand and a downward trend in availability, many experts believe water will be the source of future conflict. Conflict may arise from crop failure, extended drought, competition between industries, and/or mass-migrations.

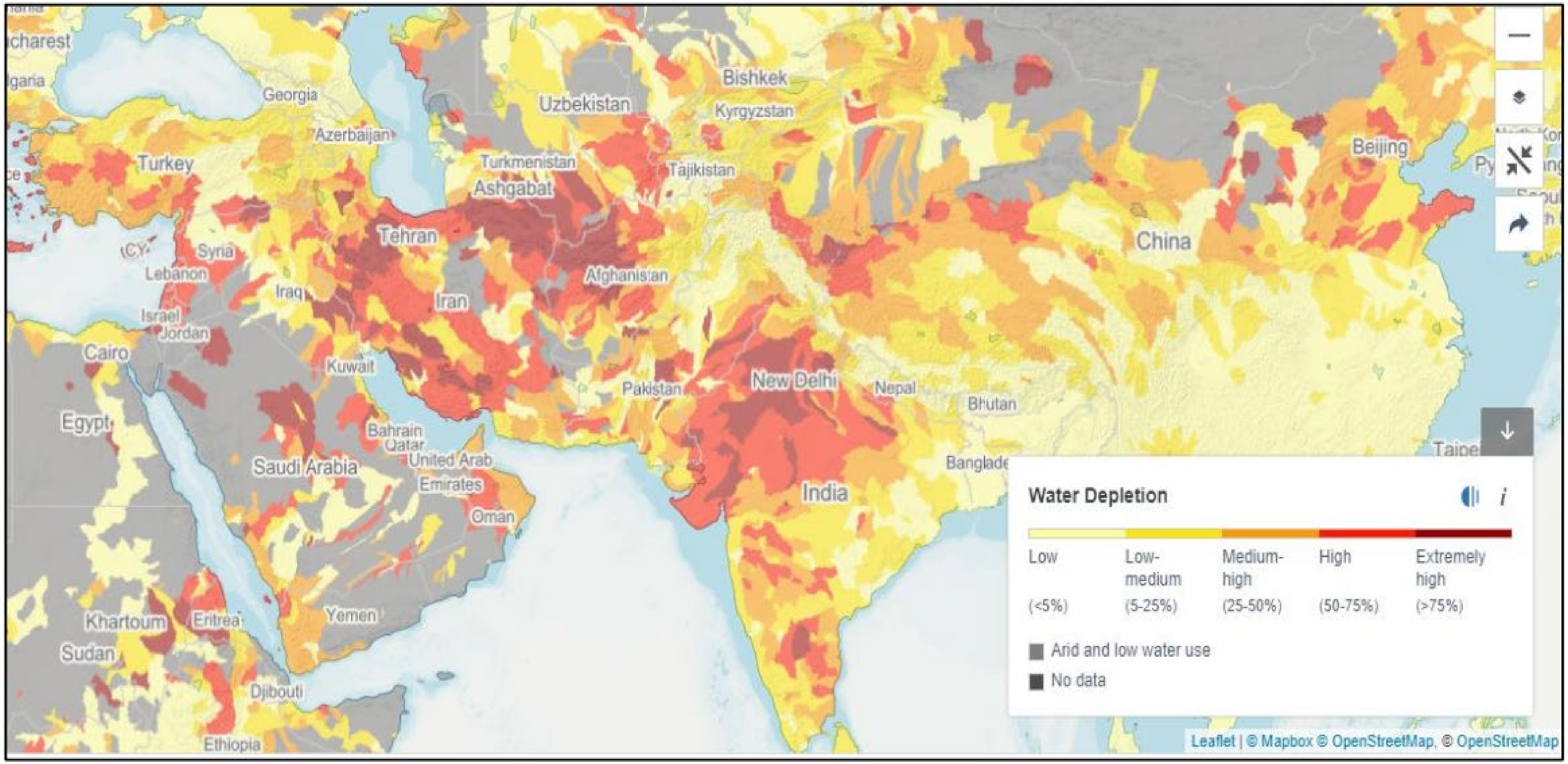
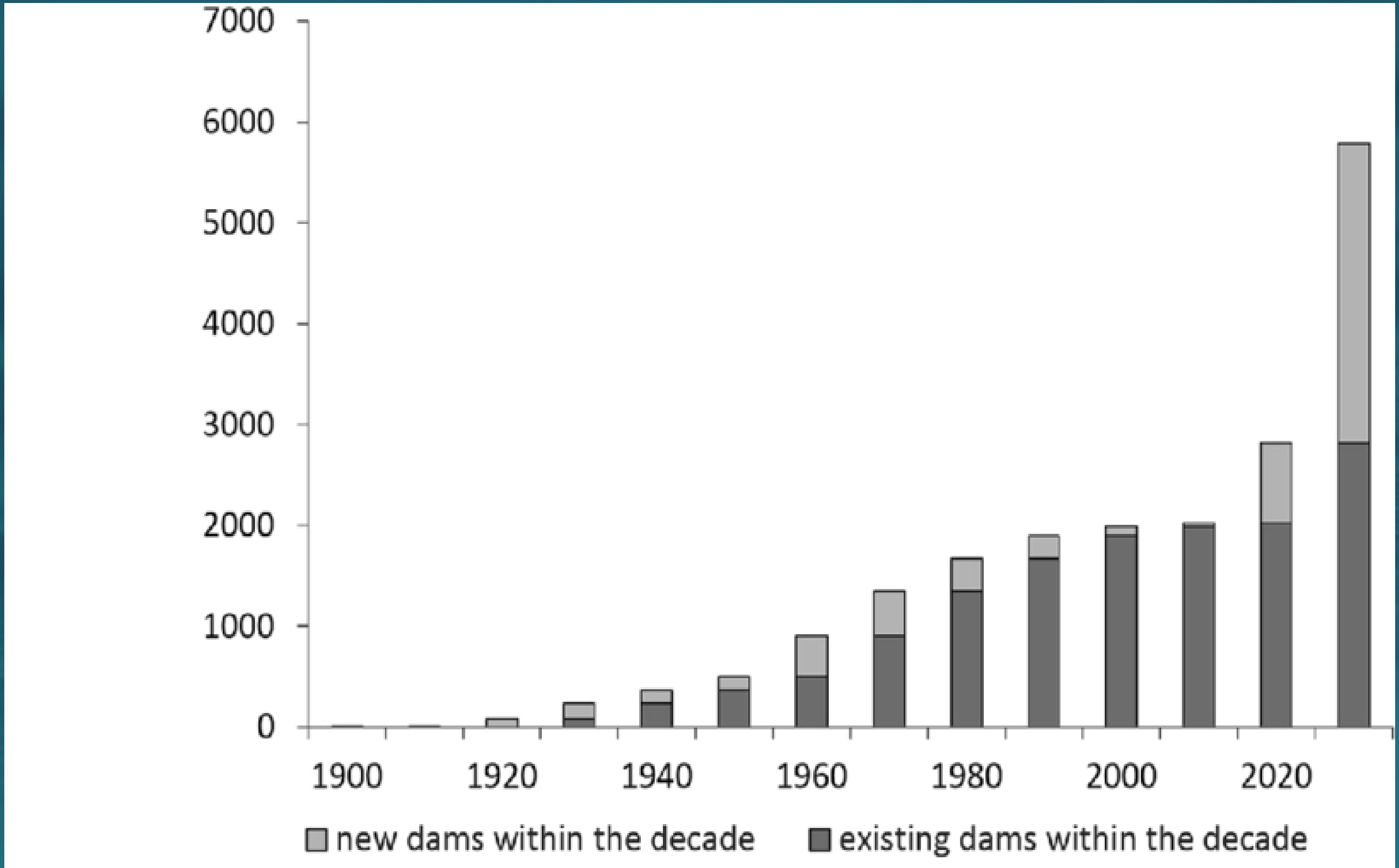



*Figure 2-Water Scarcity in the Middle East and Southwest Asia. Map by Carl Reed. Data obtained from World Resource Institute's Aqueduct Global Mapping Program.*

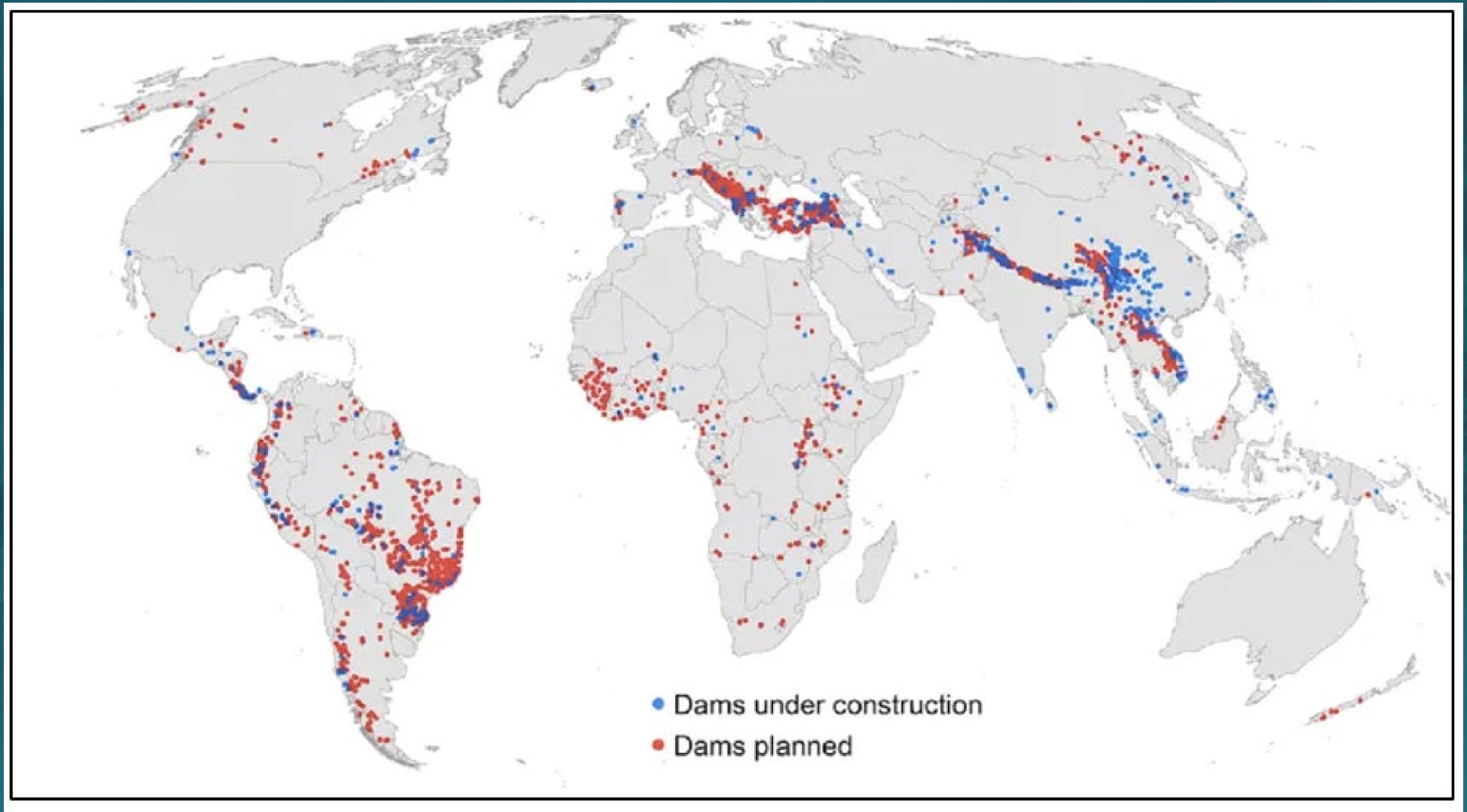
# Introduction: Large Water Transfer Projects

Large Water Transfer Projects (LWTPs) can reduce water availability downstream and disrupt natural sediment deposition.

Resources from LWTPs not always evenly allocated among industries and populations (i.e. rural vs urban, industrial vs. agricultural).




From Zarfl et al., 2014




From Zarfl et al., 2014

# Introduction: Study Area

GBM River Basin. Data from HydroSheds

"We assess that the effects of a changing climate and environmental degradation will create a mix of direct and indirect threats, including risks to the economy, heightened political volatility, human displacement, and new venues for geopolitical competition…The degradation and depletion of soil, water, and biodiversity resources almost certainly will threaten infrastructure, health, water, food, and security…and increase the potential for conflict over competition for scarce natural resources."

2021 Annual Threat Assessment of the Intelligence Community

# Goals and Objectives

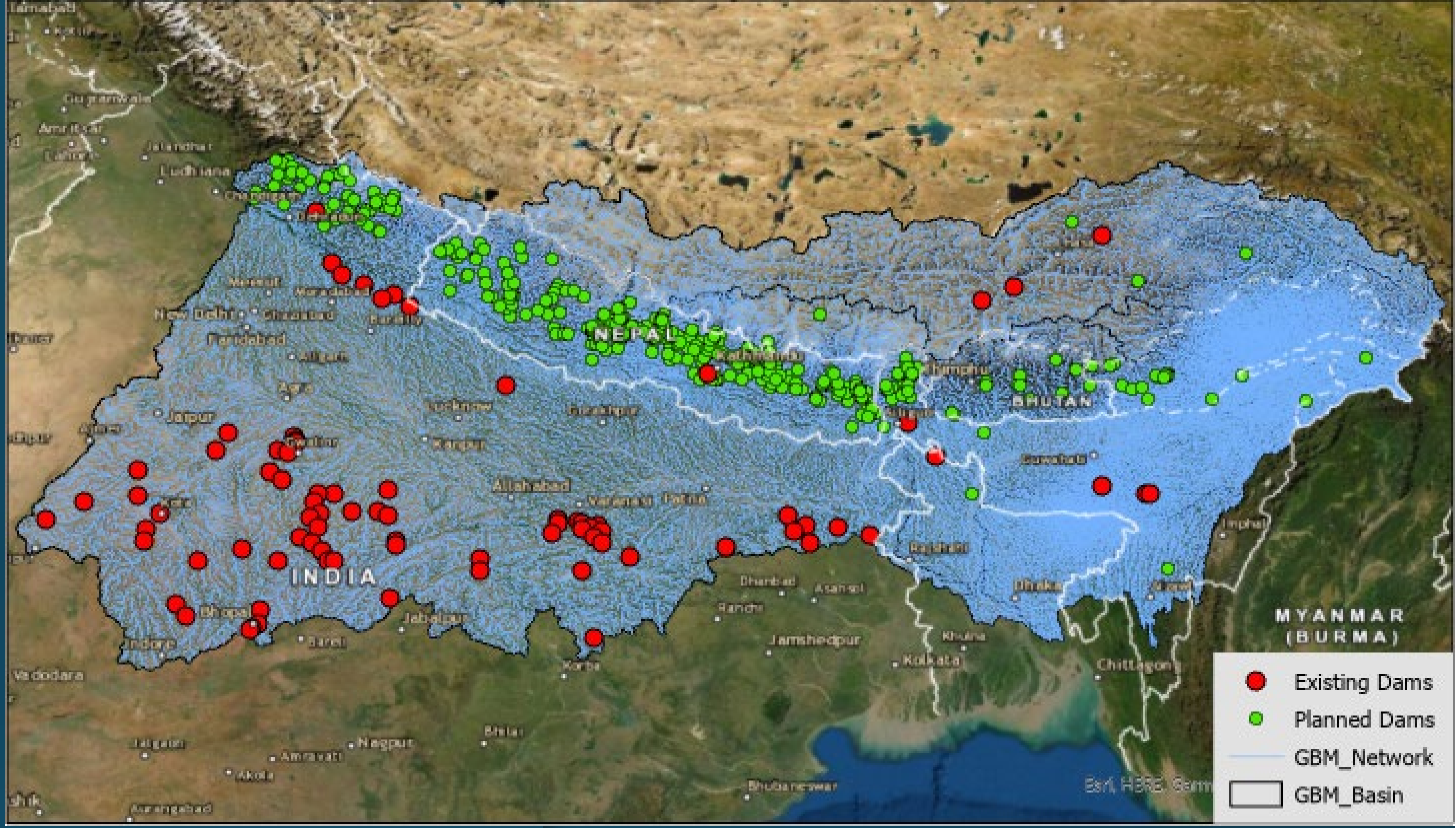
The objective of this project is to determine the relationship between water scarcity and conflict and examine the potential impacts of hydroelectric dams on the Ganges-Brahmaputra-Meghna River Basin.

# Data – GRanD

- The Global Dam and Reservoir Database (GranD) data is a comprehensive dataset that includes the georeferenced locations and attributes of 7,320 dams throughout the world.

- In addition to completed dams, GRanD contains the latitude and longitude of planned dams, dams currently under construction, and reservoirs associated with dams.

- There are currently 83 completed dams and 414 planned dams in the GBM Basin.



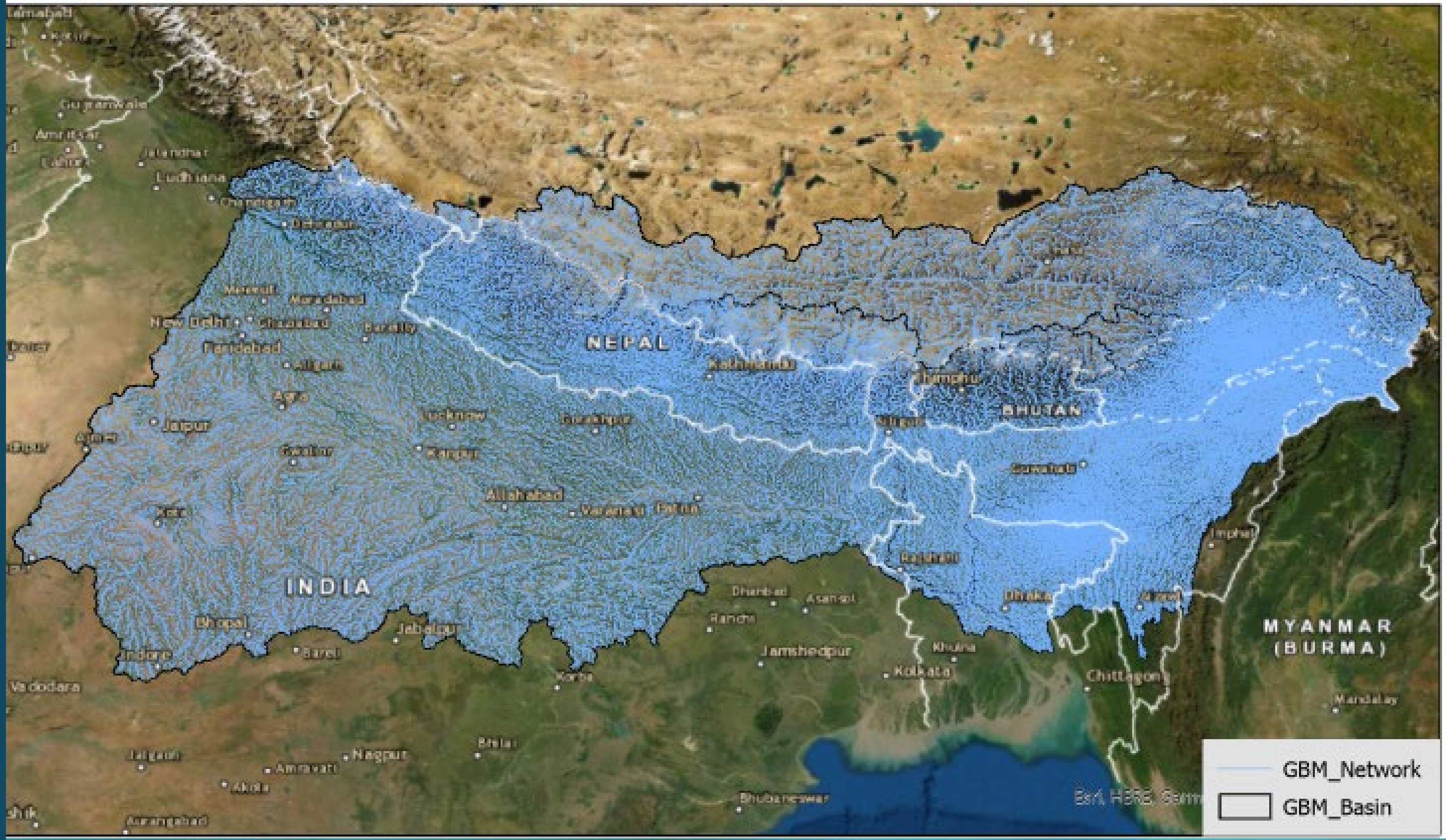
# Data - HydroSheds

- HydroSheds data was developed by the USGS and is the source for river, basin, and DEM data sets.

- Provides vector and raster layers for stream networks, watershed boundaries, lakes, and accumulation data.

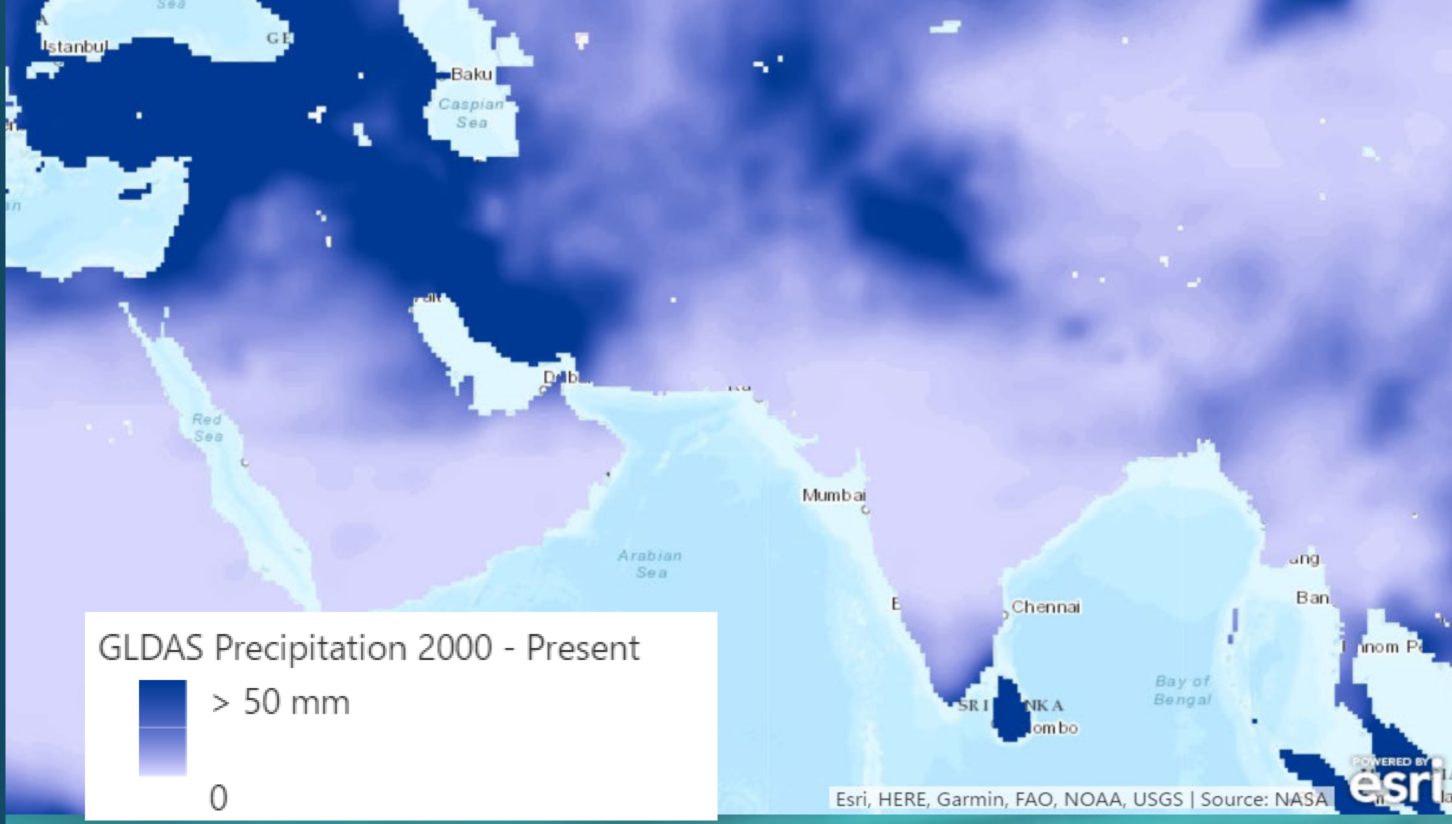
- Spatial resolution of the DEM is approximately 30 Km at the equator.

- Utilizes data collected during the 2000 Shuttle Radar Topography Mission




# Data - GLDAS

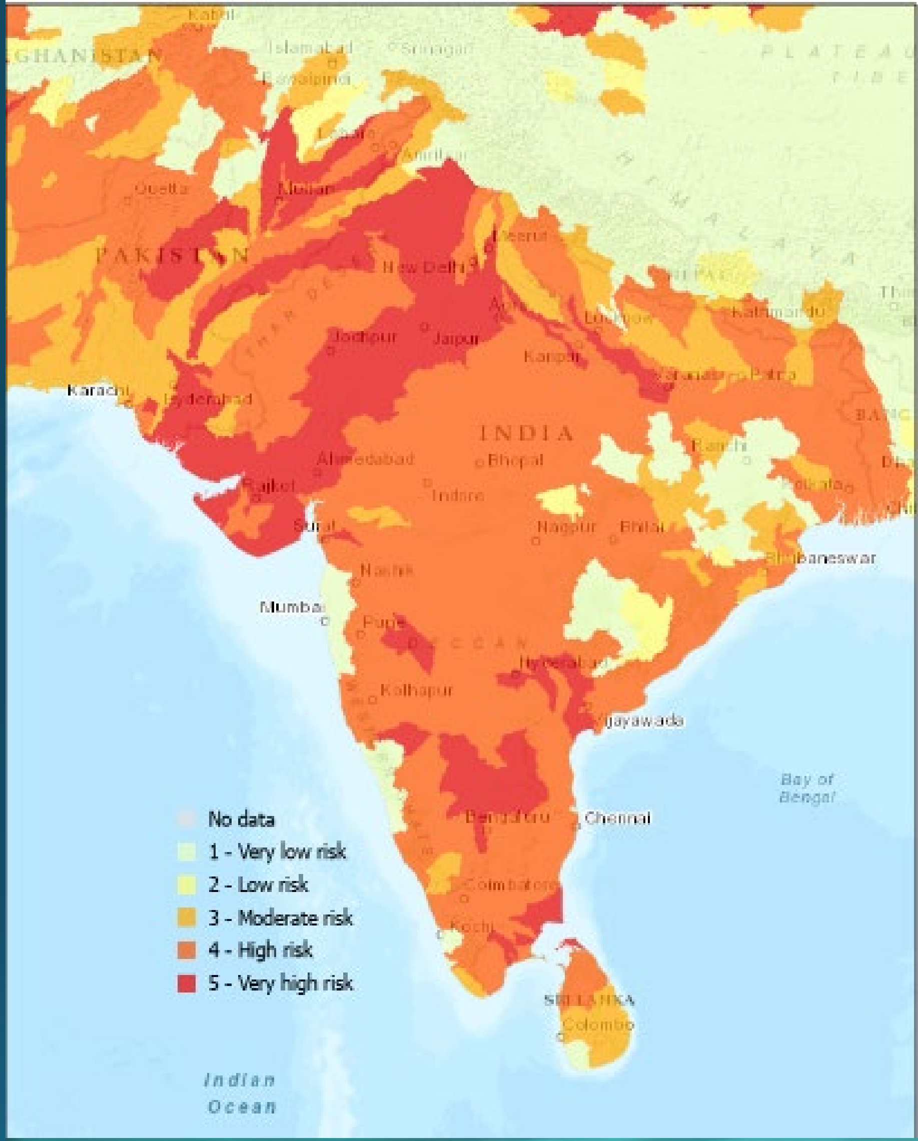
- Global Land Data Assimilation System (GLDAS) data provides global coverage of satellite and ground collected data.
- Provides multidimensional raster data for the soil moisture, temperature, evapotranspiration, and other data sets.
- Spatial resolution is 28 km
- Data is available from 2000 to 2021



# Data – WaterGap3

- WaterGap3 model was developed by Brauman, Richter, Postel, Malsy, & Flörke in 2016 .

- Model  measures the ratio between available groundwater storage and withdrawals and accounts for evapotranspiration, groundwater extraction, and surface water runoff depletion due to dams and reservoirs.



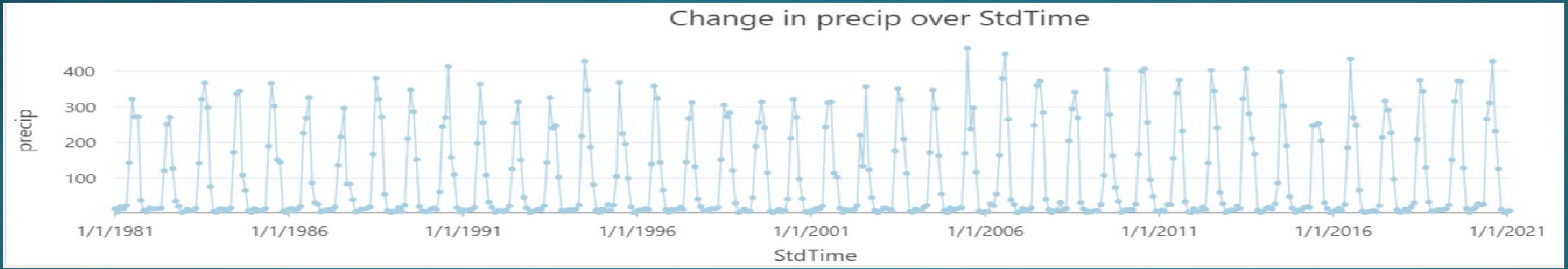
# Data -CHIRPS

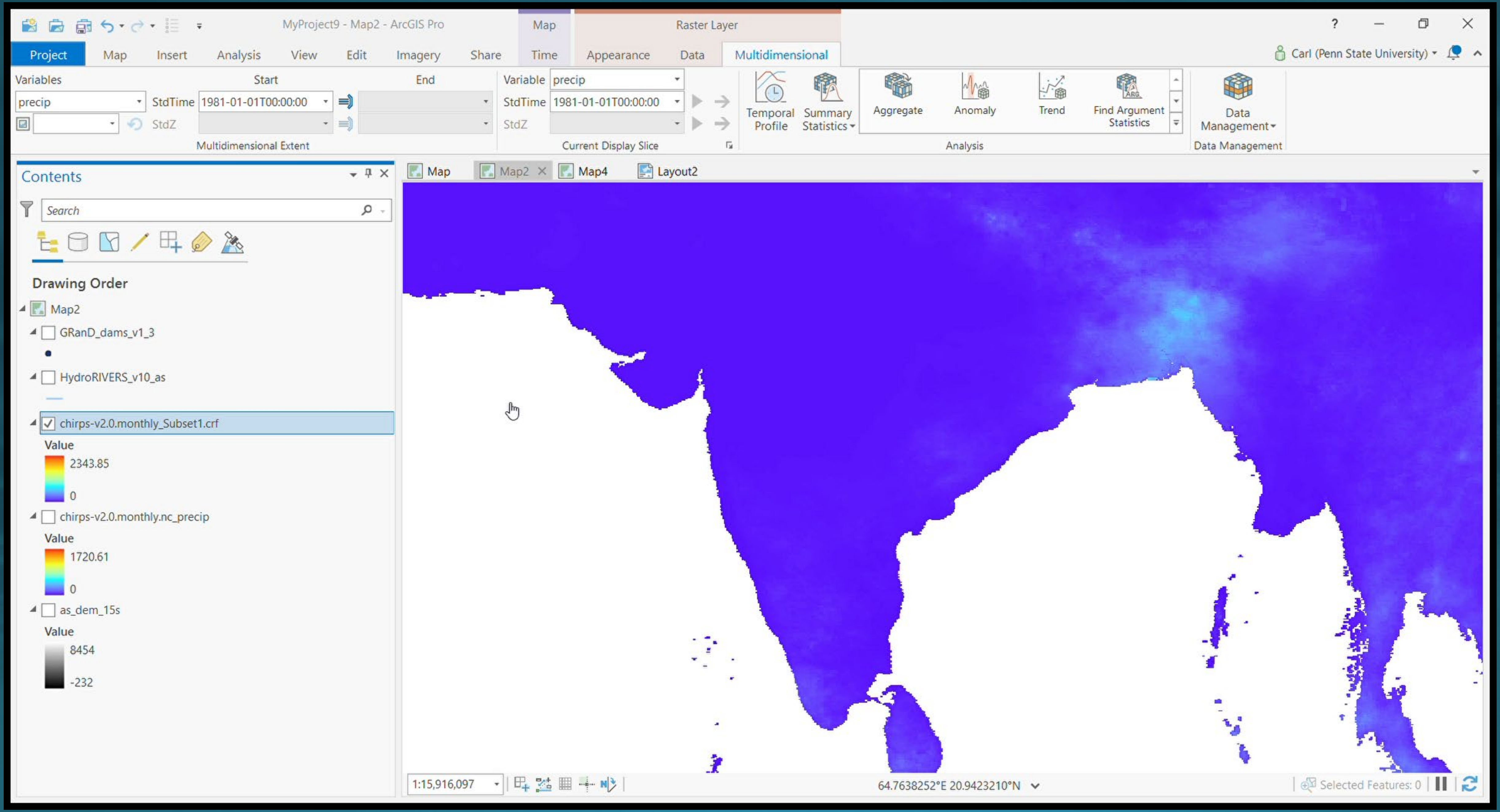
- CHIRPS is made available from the Climate Hazards Center at the University of California, Santa Barbara.

- Provides annual precipitation averages from 1981 to 2021.

- Offered at a spatial resolution of 28 km

- Below is a summary of precipitation rates in central India

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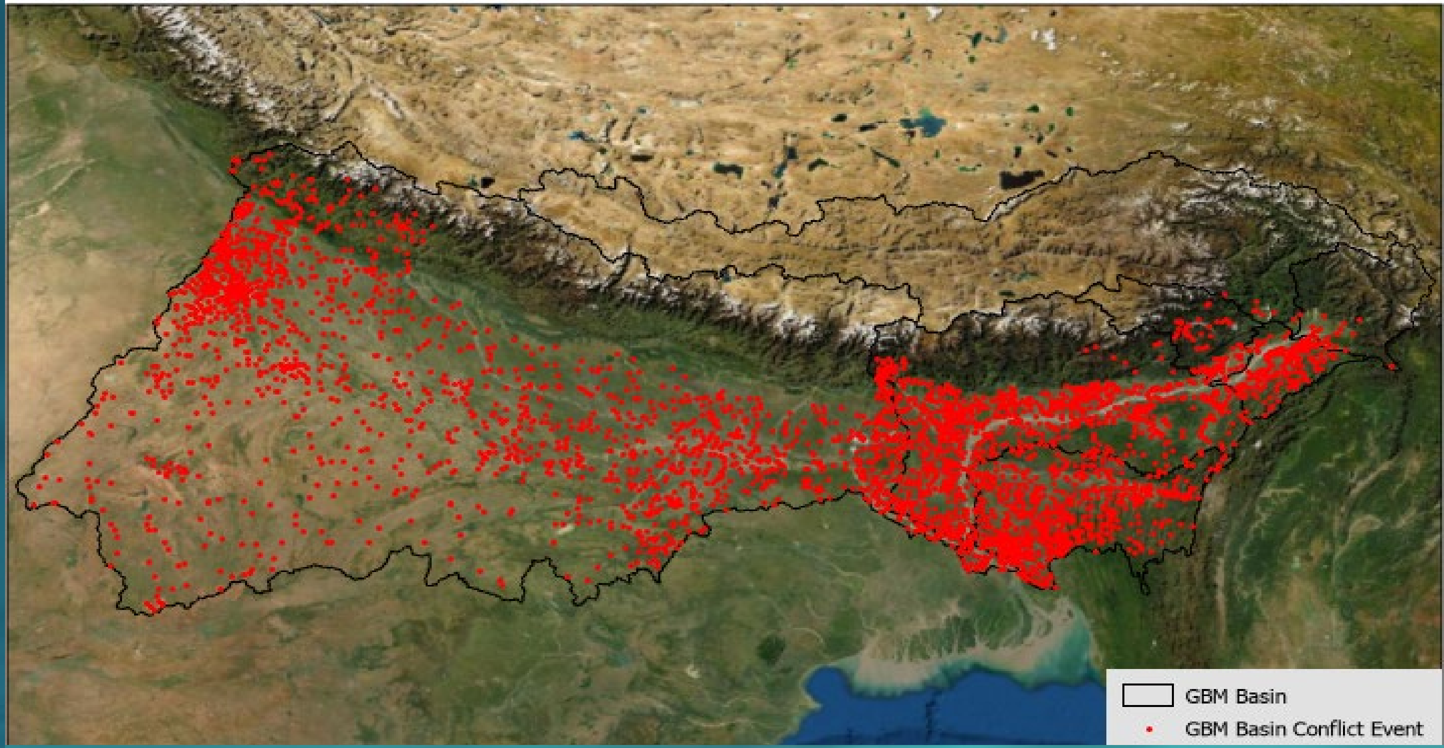
# Data – Conflict Data

- Conflict data was obtained from the Armed Conflict Location and Event Project (ACLE).

- Data available on  global scale

- A collection of open-source information

- Data is available for download in tabular format and provides latitude and longitude of conflicts



# Data

| Data | Spatial Resolution | Available Dates |
|---|---|---|
| GRanD | NA | Current to 2016 |
| HydroSheds | 30 km | 1961-2021 |
| GLDAS | 30 km | 2000-2021 |
| CHIRPS | 28 km | 1981-2021 |
| ACLE | NA | 2010-2020 |

# Methods and Procedures

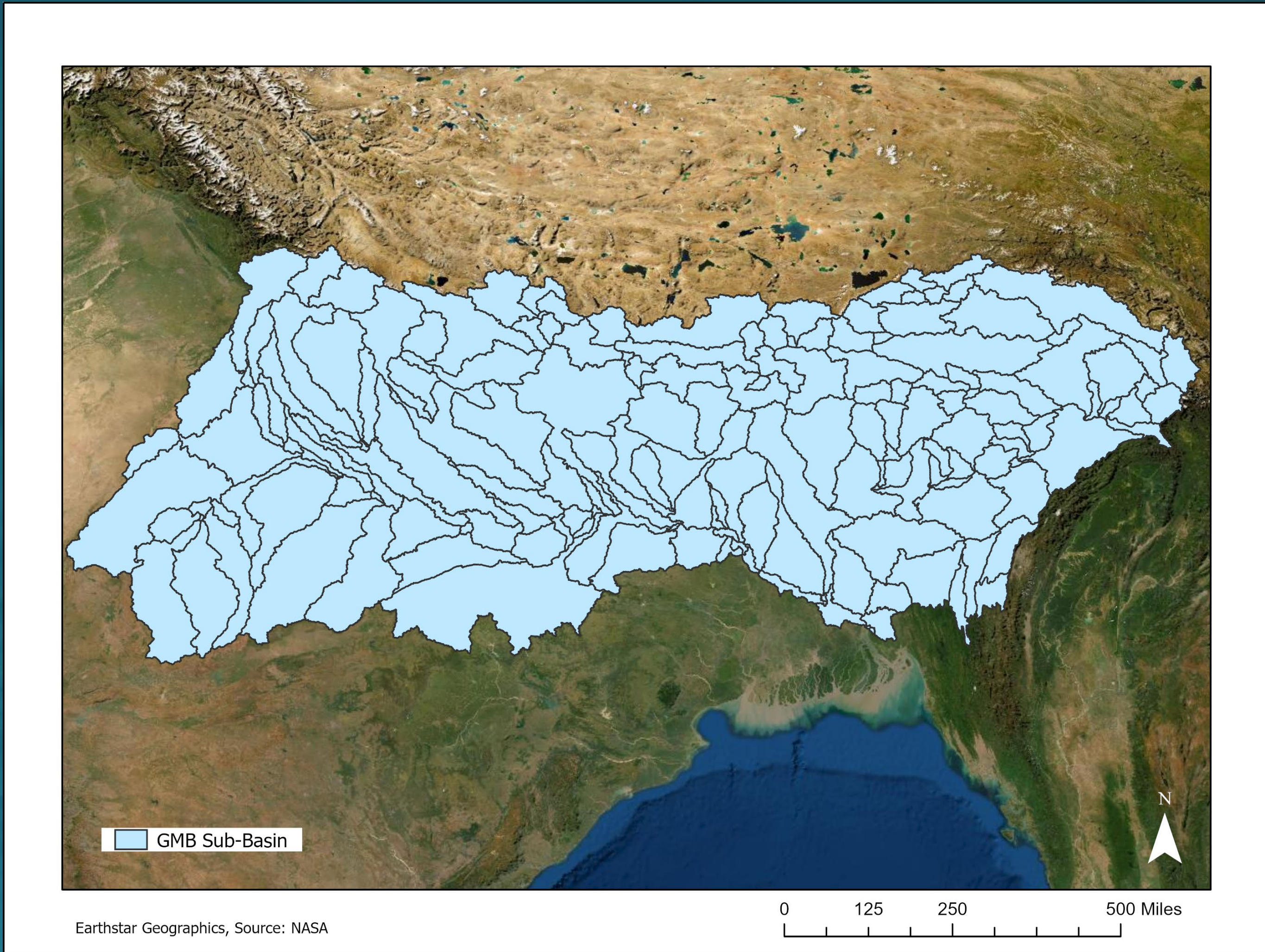
- Use climate data to determine regions with decreasing precipitation and groundwater availability, as well as increasing temperatures.
- Utilize the trend analysis tool available for multidimensional rasters
- Examine the cumulative degree of regulation for each sub-basin within the study area
- Evaluate the statistical relationship between areas with a high risk of water scarcity and occurrence of conflict.

# Methods and Procedures – Data Manipulation

- Attribute query of the HydroSheds database to determine polygons associated with the study area.

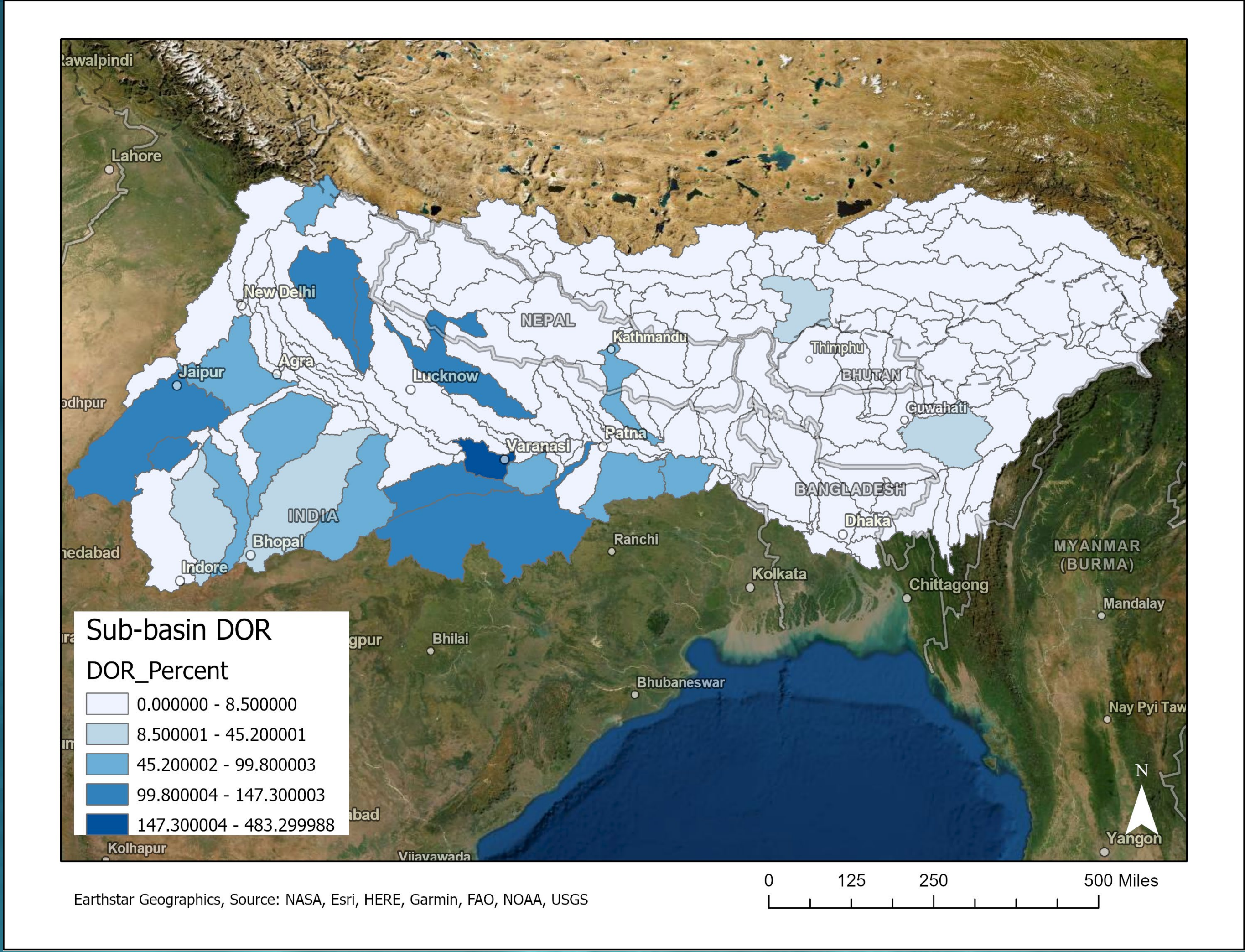
- Conduct a join of HydroShed data with GranD database by  the attribute HydroID to obtain the DOR values stored in the Dam database

- All datasets use in the analysis clipped to the GMB Study Area



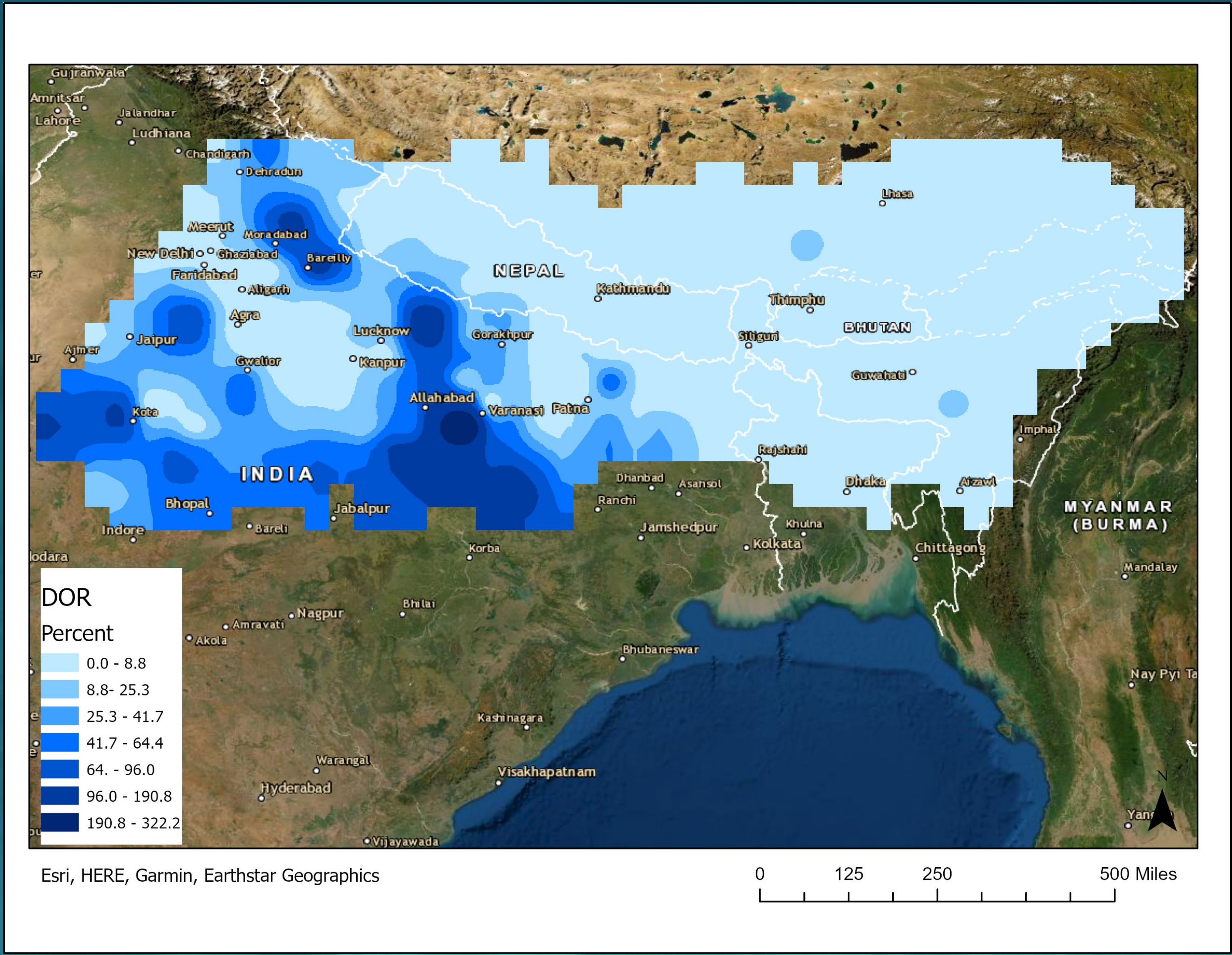
# Methods and Procedures – Determining DOR

- Pfafstetter Level 6 to was used determine the sub-basin areas.
- Utilize Summarize Within analysis tool to calculate the cumulative DOR for each sub-basin.



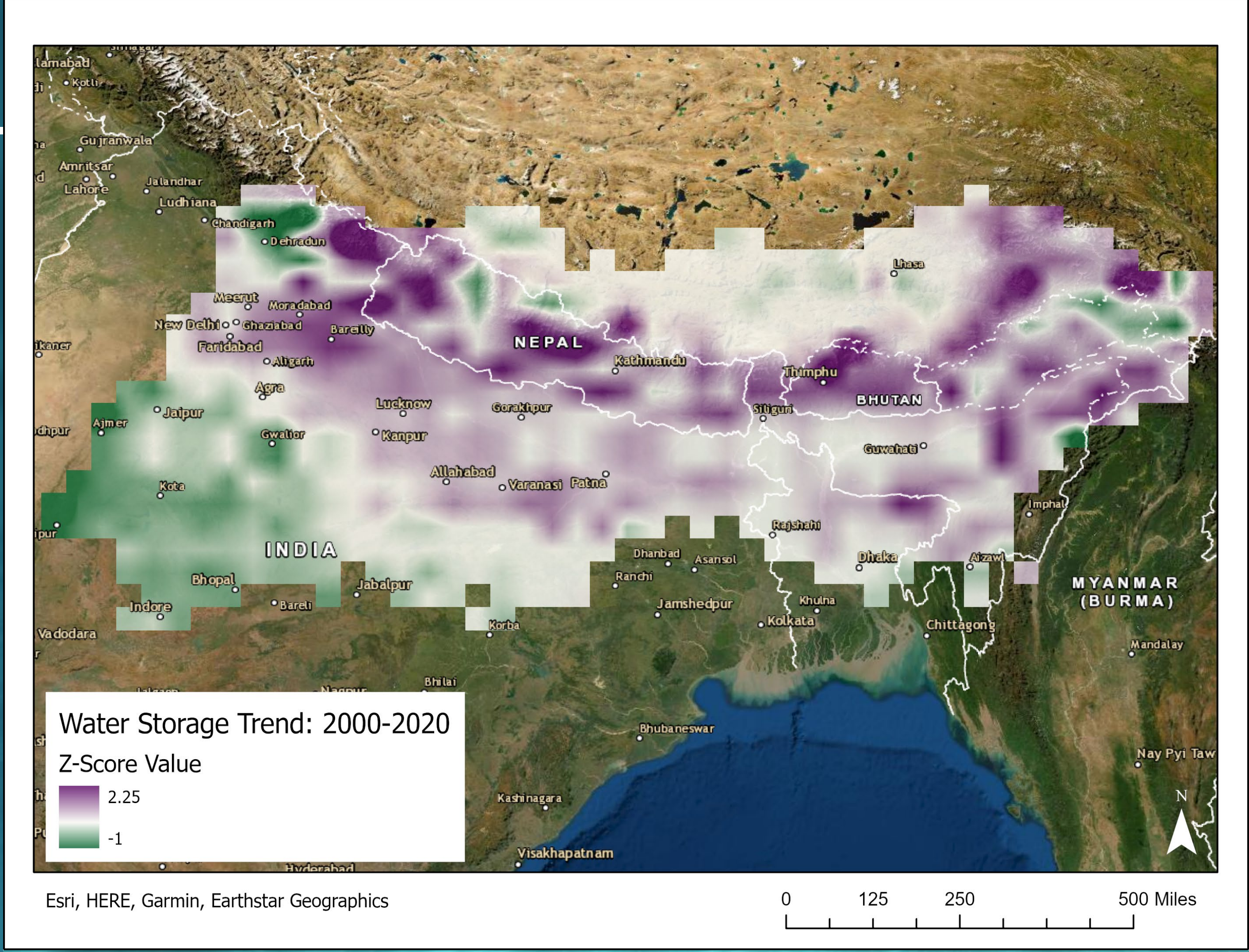
# Methods and Procedures – Determining DOR

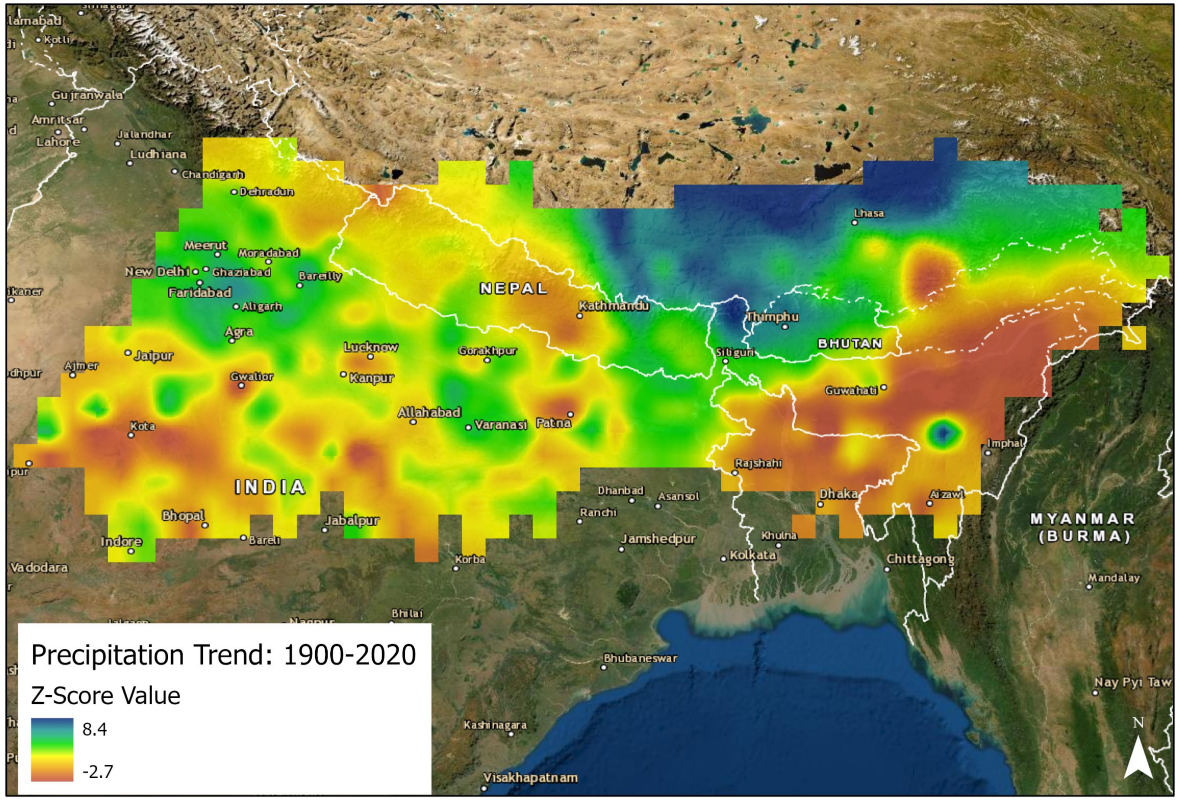
- Convert the sub-basin polygons to points
- Utilize Inverse distance weighted interpolation to create a DOR raster surface layer.



# Methods and Procedures – Climate Trend Analysis

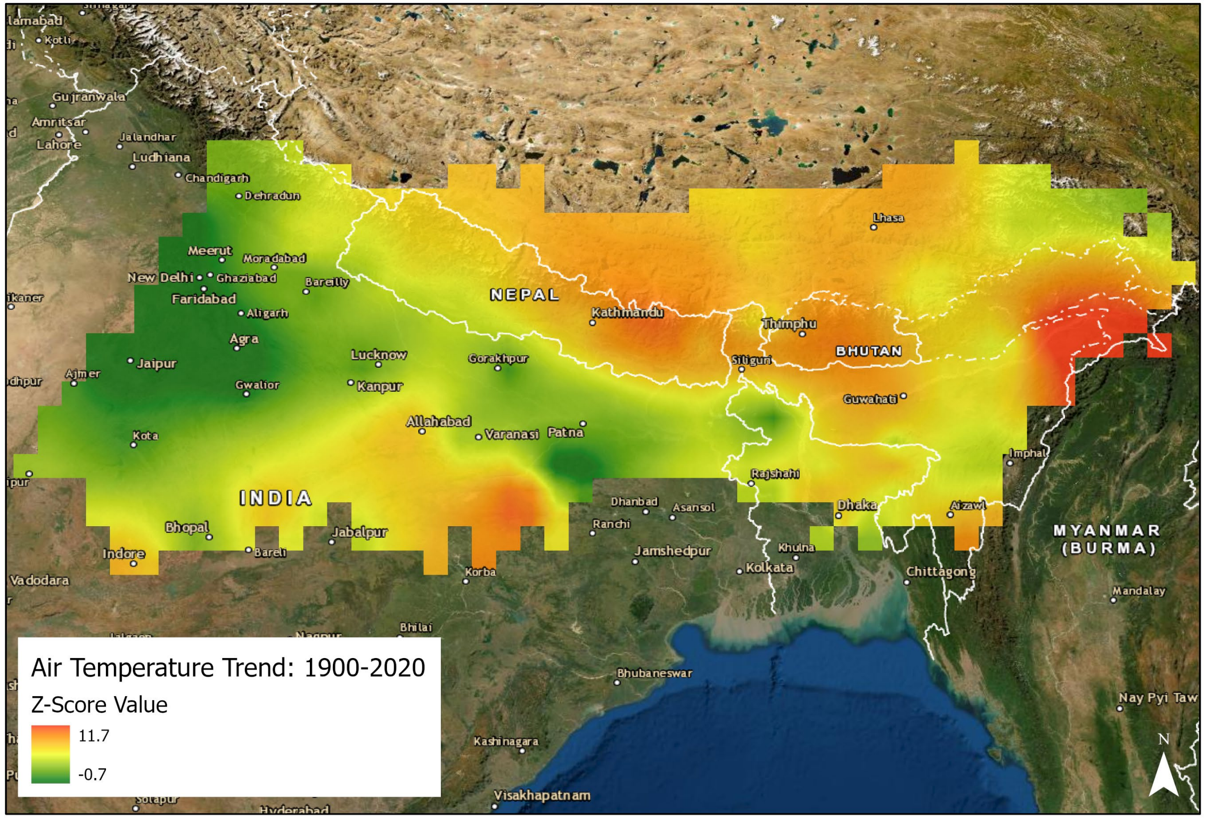
- Temperature, Precipitation, and Groundwater Storage Trends were created using the Trend Analysis Tool for multidimensional rasters
- Seasonal-Kendall model was used to ensure desired statistical values as the output.






Esri, HERE, Garmin, Earthstar Geographics

0 125 250 500 Miles




Esri, HERE, Garmin, Earthstar Geographics

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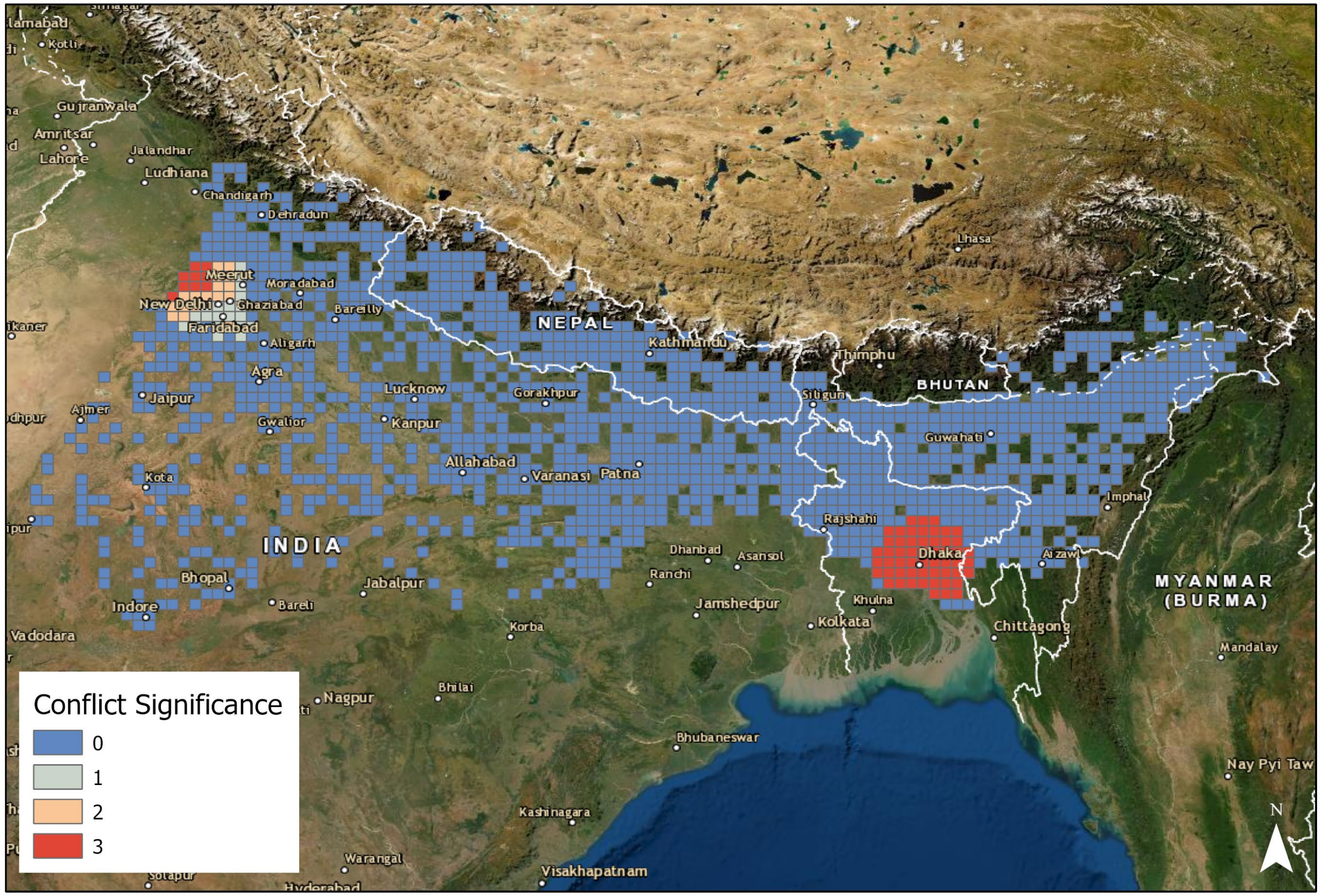
# Methods and Procedures – Conflict Data

- Prior to running analysis, the conflict data was examined for spatial autocorrelation using Moran's I and optimized hotspot analysis.
- The conflict data was heavily influenced by spatial autocorrelation

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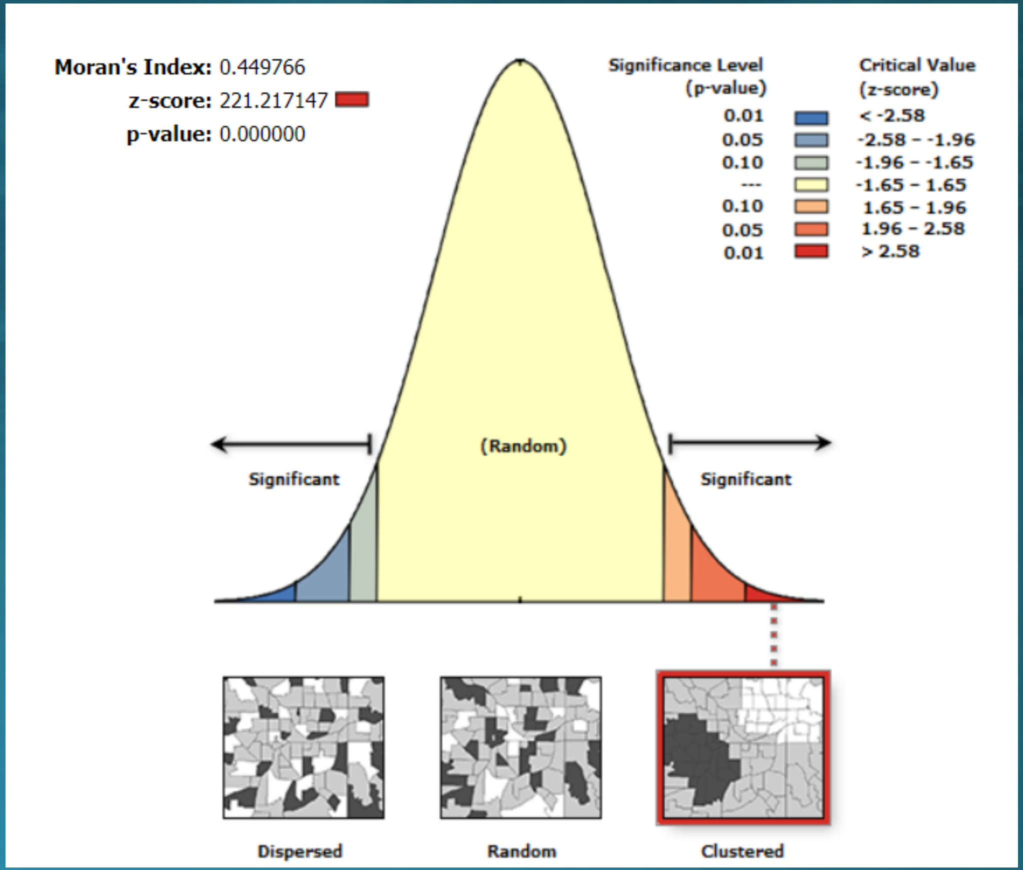
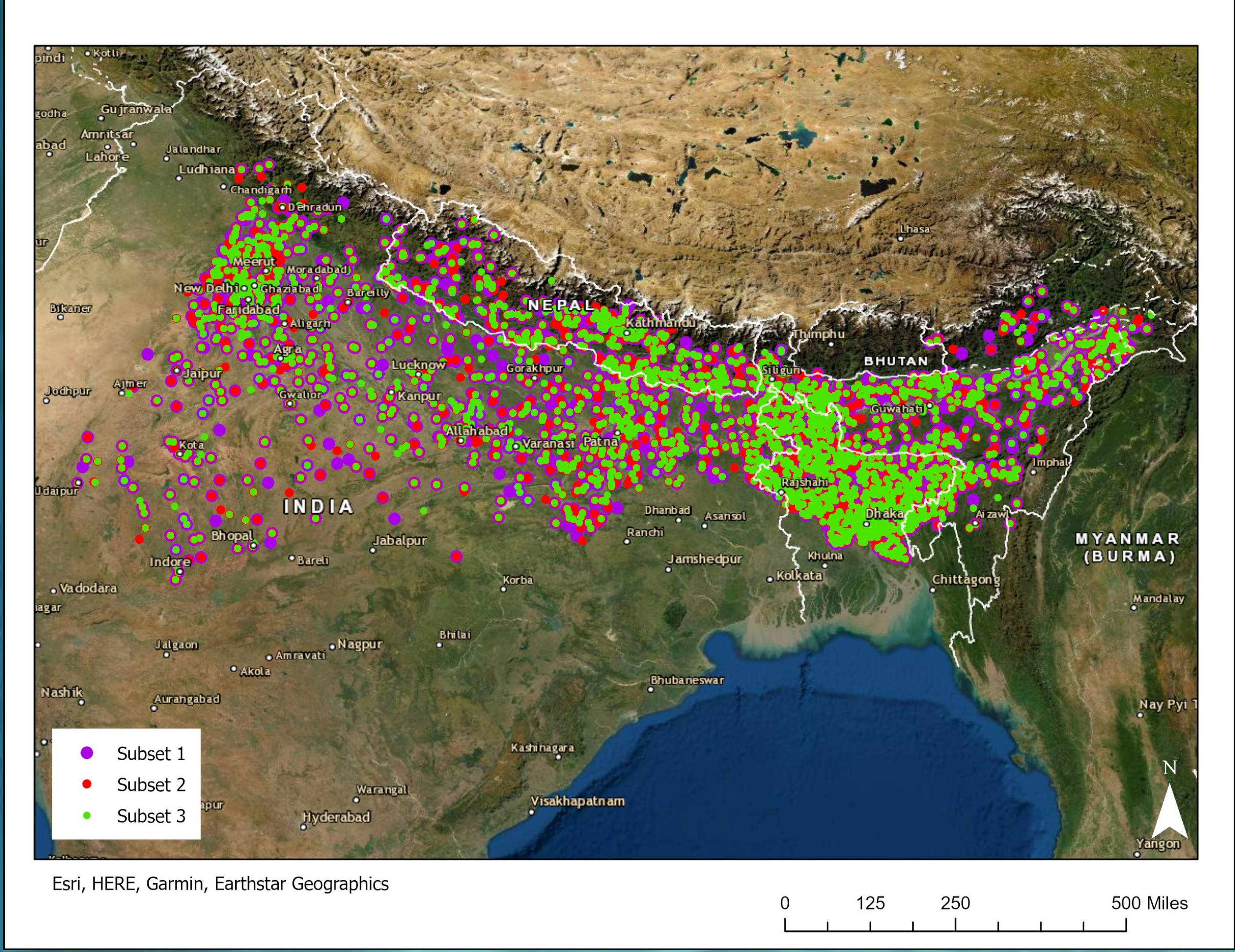


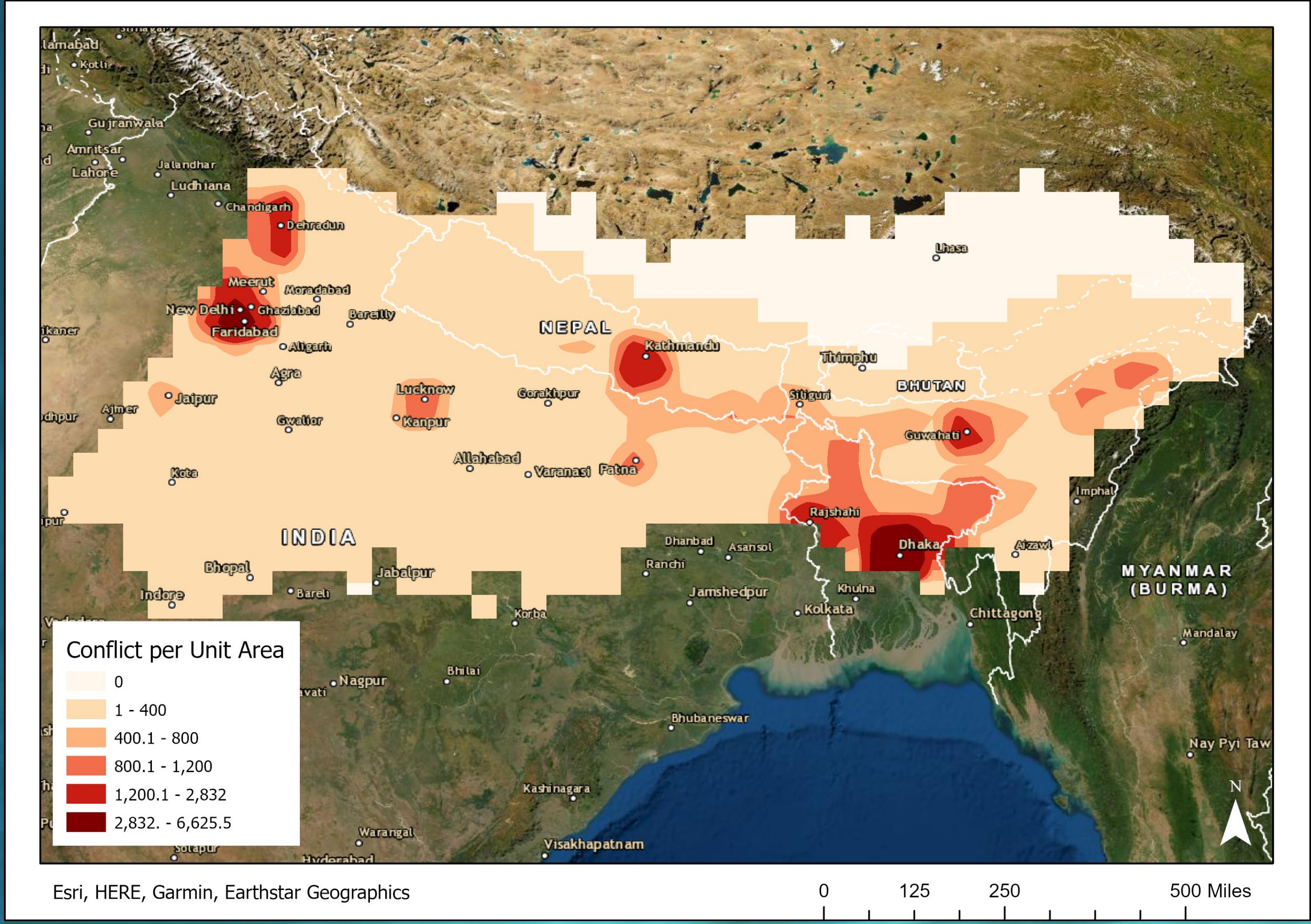
# Methods and Procedures – Conflict Data

- To account for the effects of spatial autocorrelation, three random subsets of conflict data was created using 50% of data points.



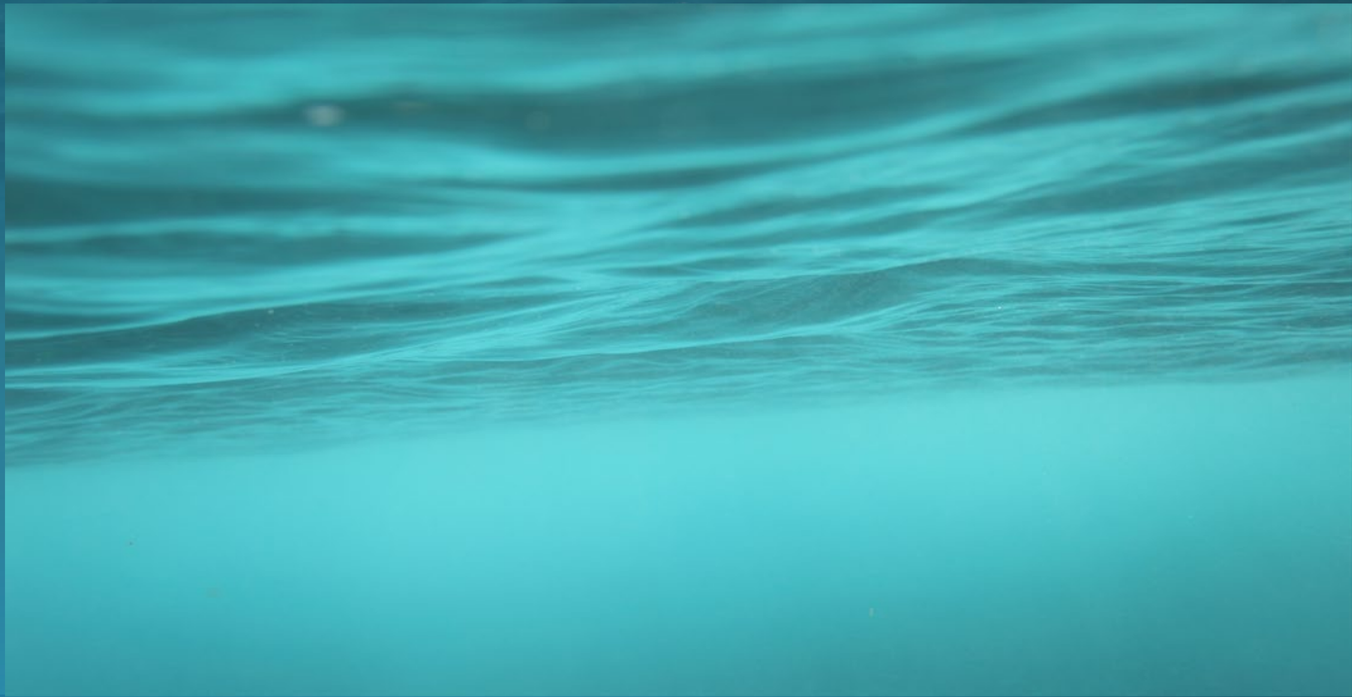
# Methods and Procedures – Conflict Data

- Conflict data did not contain any quantitative numbers to compare to other variables in the project
- Kernel Density tool created a quantitative value representing the occurrence of conflicts over a given unit area.
- The higher the kernel density value, the higher the instances of conflict for the area.



# Methods and Procedures –

- To identify the relationship between conflict occurrence and DOR, Temperature , Precipitation and Groundwater Storage, an ordinary least squares regression was conducted on each of the three subsets of data.



# Results

The results of the analysis were consistent with the literature reviewed as part of this project. Specifically, that the processes leading to conflict are more complex than water scarcity alone leading directly to conflict.

- Moderately Low $R^2$ between the dependent and independent variables, with an average of .21 for all iterations of the analysis.

- Groundwater Storage had the strongest relationship with conflicts, with a $R^2$ value of approximately -.25 in subset two and an average of -24

**Subset1 ($R^2$ = .22)**

| Variable | Coef | StdError | t_Stat | Prob | Robust_SE | Robust_t | Robust_Pr | StdCoef |
|---|---|---|---|---|---|---|---|---|
| Intercept | 3.055307 | 0.018301 | 166.946132 | 0 | 0.019213 | 159.0262 | 0 | 0 |
| DOR | -0.01104 | 0.000323 | -34.217564 | 0 | 0.000876 | -12.5974 | 0 | -0.35768 |
| WATER_STORAGE | -0.250589 | 0.010153 | -24.680353 | 0 | 0.013325 | -18.8054 | 0 | -0.25763 |
| PRECIPITATION | -0.029695 | 0.003691 | -8.044556 | 0 | 0.003399 | -8.73681 | 0 | -0.0906 |
| TEMPERATURE | 0.014618 | 0.002988 | 4.8919 | 0.000002 | 0.003171 | 4.609402 | 0.000006 | 0.055661 |

**Subset2 ($R^2$ = 0.21 )**

| Variable | Coef | StdError | t_Stat | Prob | Robust_SE | Robust_t | Robust_Pr | StdCoef |
|---|---|---|---|---|---|---|---|---|
| Intercept | 3.039718 | 0.018381 | 165.37352 | 0 | 0.019769 | 153.764 | 0 | 0 |
| DOR | -0.01082 | 0.000322 | -33.637858 | 0 | 0.000927 | -11.6658 | 0 | -0.35283 |
| WATER_STORAGE | -0.244294 | 0.010228 | -23.884739 | 0 | 0.013516 | -18.0749 | 0 | -0.25176 |
| PRECIPITATION | -0.030154 | 0.00366 | -8.238859 | 0 | 0.003199 | -9.42731 | 0 | -0.09256 |
| TEMPERATURE | 0.016228 | 0.002999 | 5.411295 | 0 | 0.003234 | 5.017227 | 0.000001 | 0.061822 |

**Subset 3 ($R^2$ = 0.2)**

| Variable | Coef | StdError | t_Stat | Prob | Robust_SE | Robust_t | Robust_Pr | StdCoef |
|---|---|---|---|---|---|---|---|---|
| Intercept | 3.071369 | 0.018381 | 167.090704 | 0 | 0.019744 | 155.5618 | 0 | 0 |
| DOR | -0.011478 | 0.00034 | -33.73842 | 0 | 0.000919 | -12.4924 | 0 | -0.35499 |
| WATER_STORAGE | -0.232967 | 0.010152 | -22.947227 | 0 | 0.013238 | -17.5989 | 0 | -0.24216 |
| PRECIPITATION | -0.027253 | 0.003657 | -7.45286 | 0 | 0.003319 | -8.21191 | 0 | -0.08442 |
| TEMPERATURE | 0.011558 | 0.002991 | 3.864408 | 0.000122 | 0.003246 | 3.560655 | 0.000387 | 0.044414 |

# Conclusions

# Questions?

## References

Banerji, A. (2021, April 9). India Must Settle the Teesta River Dispute With Bangladesh for Lasting Gain. *The Diplomat*.

Bhattacherjee, K. (2021, March 27). Millions depend on Teesta waters: Hasina tells Modi. *The Hindu*.

Brauman, K. A., Richter, B. D., Postel, S., Malsy, M., & Flörke, M. (2016). Water depletion: An improved metric for incorporating seasonal and dry-year water scarcity into water risk assessments. *Ecology and Earth Systems*.

Busby, J. (2017). *Water and US National Security.* New York: Council on Foreign Relations.

Damkjaer, S., & Taylor, R. (2017). *The measurement of water scarcity: Defining a meaningful indicator.* Royal Swedish Academy of Sciences.

Funk, C., Peterson, P., Landsfield, M., Pedreros, D., Verdin, J., Shukla, S., . . . Michaelsen, J. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data*.

Gleick, P. H. (1993). *A Guide to the World's Freshwater Resources.* Cambridge: The MIT Press.

Gleick, P. H. (2014). Water, Drought, Climate Change, and Conflict in Syria. *American Meteorolgical Society*, 2-17.

Hendrix, C. S., & Glaser, h. M. (2007). Trends and triggers: Climate, climate change and civil conflict in Sub-Saharan Africa. *Political Geography*, 695-715.

# References cont.


Homer-Dixon, T. F. (1994). Environmental Scarcities and Violent Conflict: Evidence from Cases. *International Security*, 5-40.

Hoque, M. A.-A., Pradhan, B., & Ahmed, N. (2020). Assessing drought vulnerability using geospatial techniques in northwestern part of Bangladesh. *Science of the Total Environment*, 2-13.

Intelligence Community Assessment. (2012). *Global Water Security.* Washington D.C.: United States Department of State.

J, O., Grill, G., & Hartman, J. (2015). *The Power of Rivers: Finding balance between energy and conservation in hydropower development.* Washington D.C.: The Nature Conservancy.

Jaafar, H., Ahmad, F., Holtmeier, L., & King-Okumu, C. (2020). Refugees, water balance, and water stress: Lessons learned from Lebanon. *Ambio*, 1179–1193.

Jägerskog, A., & Swain, A. (2016 ). *Water, migration and how they are linked.* Stockholm: Stockholm International Water Institute.

Klare, M. T. (2020). Climate Change, Water Scarcity, and the Potential for Interstate Conflict in South Asia. *Journal of Strategic Security*, 109-122.

Lehner, B., Liermann, C. R., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., . . . Wisser, a. D. (2011). High-resolution mapping of the world’s reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment*, 494-502.

# References cont.


Lehner, B., Verdin, K., & Jarvis, A. (2008). New global hydrography derived from spaceborne elevation data. *EOS, Transactions*, 93-94.

National Intelligence Council. (2012). *Global Water Security.* Washington D.C.: Office of the Director of National Intelligence.

Oroji, B. (2019). Groundwater vulnerability assessment with using GIS. *Applied Water Science*.

Raleigh, C., & Urdal, H. (2007). Climate change, environmental degradation and armed conflict. *Political Geography*, 674-694.

Reuveny, R. (2007). Climate change-induced migration and violent conflict. *Political Geography*, 656-673.

Rijsberman, F. R. (2006). Water scarcity: Fact or fiction? *Agricultural Water Management*, 5-22.

Rodell, M., Houser, P. R., Jambor, U., Gottschalck, J., Mitchell, K., Meng, C.-J., . . . Toll, D. (2004). The Global Land Data Assimilation System. *Bulletin of the American Meteorological Society*, 381-394.

Stalley, P. (2003). Environmental Scarcity and International Conflict. *Conflict Management and Peace Science*, 33-58.

Sullivan, C., Meigh, J., Giacomello, A., Fediw, T., Lawrence, P., Samad, M., . . . King, J. (2003). The Water Poverty Index: Development and application at the community scale. *Natural Resources Forum*, 189-199.

The Armed Conflict Location & Event Data Project. (2020). Retrieved from The Armed Conflict Location & Event Data Project: https://acleddata.com/#/dashboard

# References cont.

Uexkulla, N. v., Croicua, M., Fjeldea, H., & Buhaugb, H. (2016). Civil conflict sensitivity to growing-season drought. *Proceedings of the National Academy of Sciences*, 12391-12396.

United Nations Refugee Agency. (2016). *Global Trends:Forced Displacement 2016.* Geneva: United Nations.

Wang, Z., Nixon, R., Erwin, A., & Ma, Z. (2020). Assessing the Impacts of Large-Scale Water Transfer Projects on Communities: Lessons Learned from a Systematic Literature Review. *Society & Natural Resources*.

Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L., & Tockner, K. (2014). A global boom in hydropower dam construction. *Aquatic Sciences, 77*, 161-170.