GEO 386G Project

A Temporal Analysis of Major Lake Surface Areas in the Cauvery River Basin, India

Meghna Thomas

Introduction

The Cauvery river drains a large portion of southern India and its basin has a catchment area of more than 80,000 square kilometers. The river originates in the Western Ghats mountain range and drains into the Bay of Bengal, and along its course it enables irrigation, power generation, and freshwater supply to the states of Karnataka, Tamil Nadu, and Kerala as well as the union territory of Puducherry. A pressing need for more water to cater to the rapidly growing populations of major cities in the south have led to strained relations between the governing bodies that share Cauvery water – and particularly between the states of Karnataka and Tamil Nadu. Several long-standing legal battles, some extending to the Supreme Court of India, have converted the seemingly simple matter of appropriate water allocation into a thorny political issue. Additionally, as the effects of climate change can now be felt around the globe, one way it manifests in southern India is through highly variable precipitation patterns. Frequent droughts and the decreasing reliability of other water sources have heightened the importance awarded to Cauvery water. In order for state and municipal governments to plan for the future, it is important to be able to reliably predict how much water cities and states can assure their citizens, as well as devise a sustainable and cooperative water-sharing scheme.

Research Question

This project explores two questions:

(1) can we observe a trend in Cauvery river flows based on observed seasonal and permanent surface areas of major lakes in the Cauvery river basin from 1990 – 2020?

(2) do trends pertaining to lake surface areas differ based on which state the lake is located in?

For the scope of this project and based on the data available, permanent water is defined as a surface that is underwater for the entire year and seasonal water is defined as a surface that is underwater for only some portion of the year.

Data Sources

Table 1 describes the sources, characteristics, and coordinate system for each of the datasets used in this project. All data sources belonged to datum WGS 1984.

Table 1. Characteristics of project datasets.

Data file	Source	Description	File type
world_rivers, a global rivers shapefile	World-wide Hydrogeological Mapping and Assessment Programme, falling under the purview of the German Federal Institute for Geosciences and Natural Resources (BGR)	Dataset containing 687 river line features associated with 405 major river basins around the world.	Vector (.shp)

	and UNESCO (Carvalho-Resende, 2017).		
HydroBasins, a geodatabase of river basin shapefiles	HydroSHEDS website developed on behalf of the World Wildlife Fund (WWF) in collaboration with the International Union for Conservation of Nature (IUCN), the EU BioFresh project, and McGill University (Lehner and Grill, 2013).	A series of polygon layers depicting global watershed boundaries and sub-basin delineation.	Vector (.gdb)
HydroLakes, a global lakes shapefile	HydroSHEDS website (Messager et al, 2016).	A shapefile containing polygon features depicting lake boundaries.	Vector (.shp)
India political boundaries layer	Government of India GIS portal (National Informatics Centre).	A shapefile representing boundaries for the first-level administrative divisions of India based on 2011 census data.	Vector (.shp)
A. yearly *seasonality* (seasonal and permanent lake extent) rasters B. *lake_extent*, a maximum extent raster	European Commission Joint Research Centre's Global Surface Water dataset (Pekel et al, 2016).	Raster datasets depicting A. seasonal and permanent extent of water bodies for every year between 1984 - 2020; and B. maximum water body extent. Each .tif file is a 10° by 10° granule with the top-left corner at 70°E and 20°N, which corresponds to the tile containing the entirety of the Cauvery river basin.	Raster (.tif)

Data Processing and Analysis

No data preprocessing was required for this project. The following steps describe the procedure required to process the raw data using ArcMap and convert it to a form suitable for analysis:

1. Determine our area of interest and identify which lakes are important
2. Digitize boundary of each lake
3. Clip raster files to each lake boundary
4. Extract and convert relevant data from attribute tables

Question (1) and (2) were addressed by manipulating the extracted data in MS Excel.

Determining area of interest and identifying important lakes

In order to begin our analysis, it was important to first narrow the scope of the problem. The first file imported into ArcMap was the Indian political boundaries shapefile which set the coordinate system of the project as WGS 1984 and the unit as decimal degrees. The line feature depicting the Cauvery river was identified and saved as a separate layer file from the *world_rivers* shapefile by searching its attributes table for "Cauvery", switching the Table of Contents view to "List by Selection", and right-clicking the selected layer and choosing "Create Layer from Selected Features" (as shown in Fig 1).

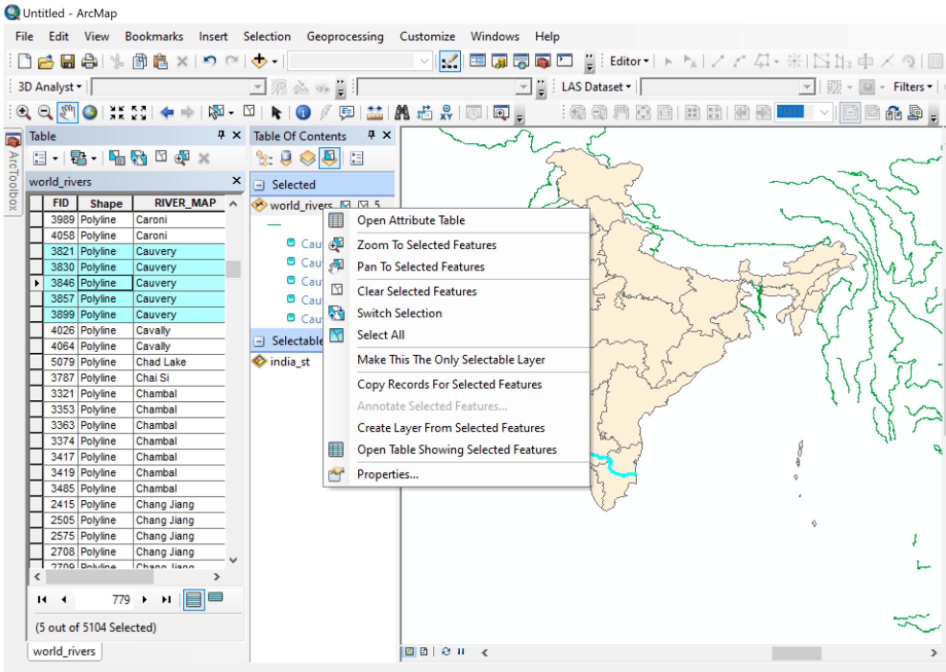


Fig 1. Creating a layer for the Cauvery river line feature.

Similarly, the layer containing the Cauvery river basin polygon was extracted and saved separately from the appropriate river basins shapefile. *HydroBasins* contains twelve different shapefiles, each with different levels of sub-basin delineation, and each shapefile was examined in order to find the most appropriate Cauvery basin extent for this project. The boundaries of the states of Karnataka and Tamil Nadu, derived from the political map shapefile, were also saved as separate layers using a similar process. The two state boundary shapefiles were provided in the "Clip Features" option in order to use the "Clip" tool to demarcate which portions of the Cauvery river basin fell within each state (see Fig 2).

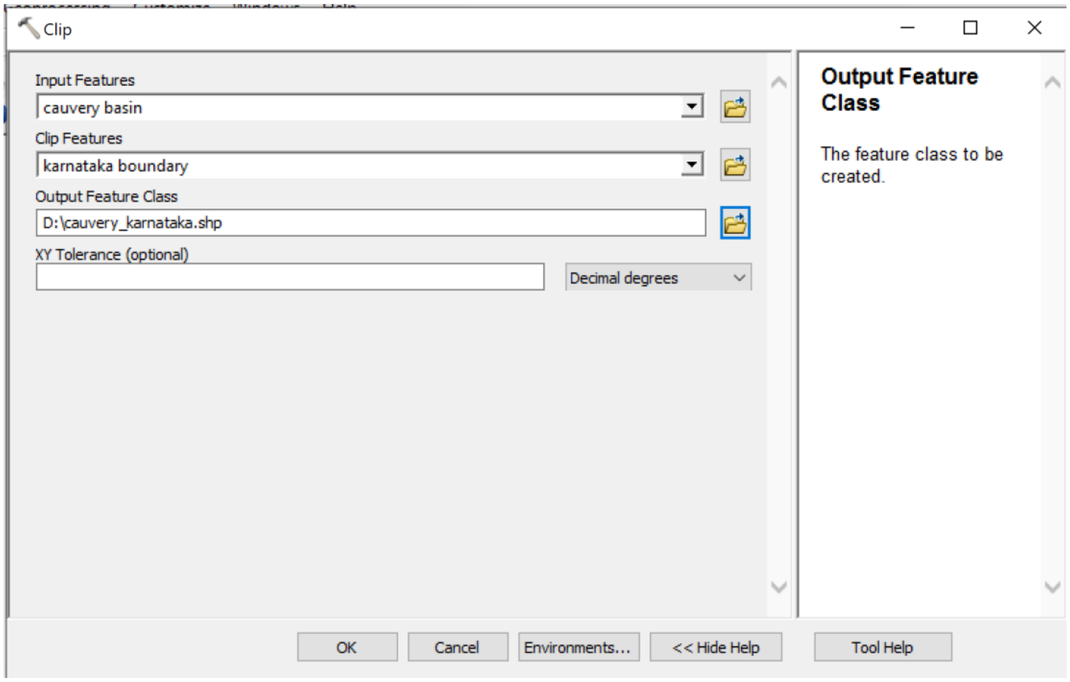


Fig 2. Clipping the Cauvery river basin to the Karnataka state boundary.

Digitizing lake boundaries

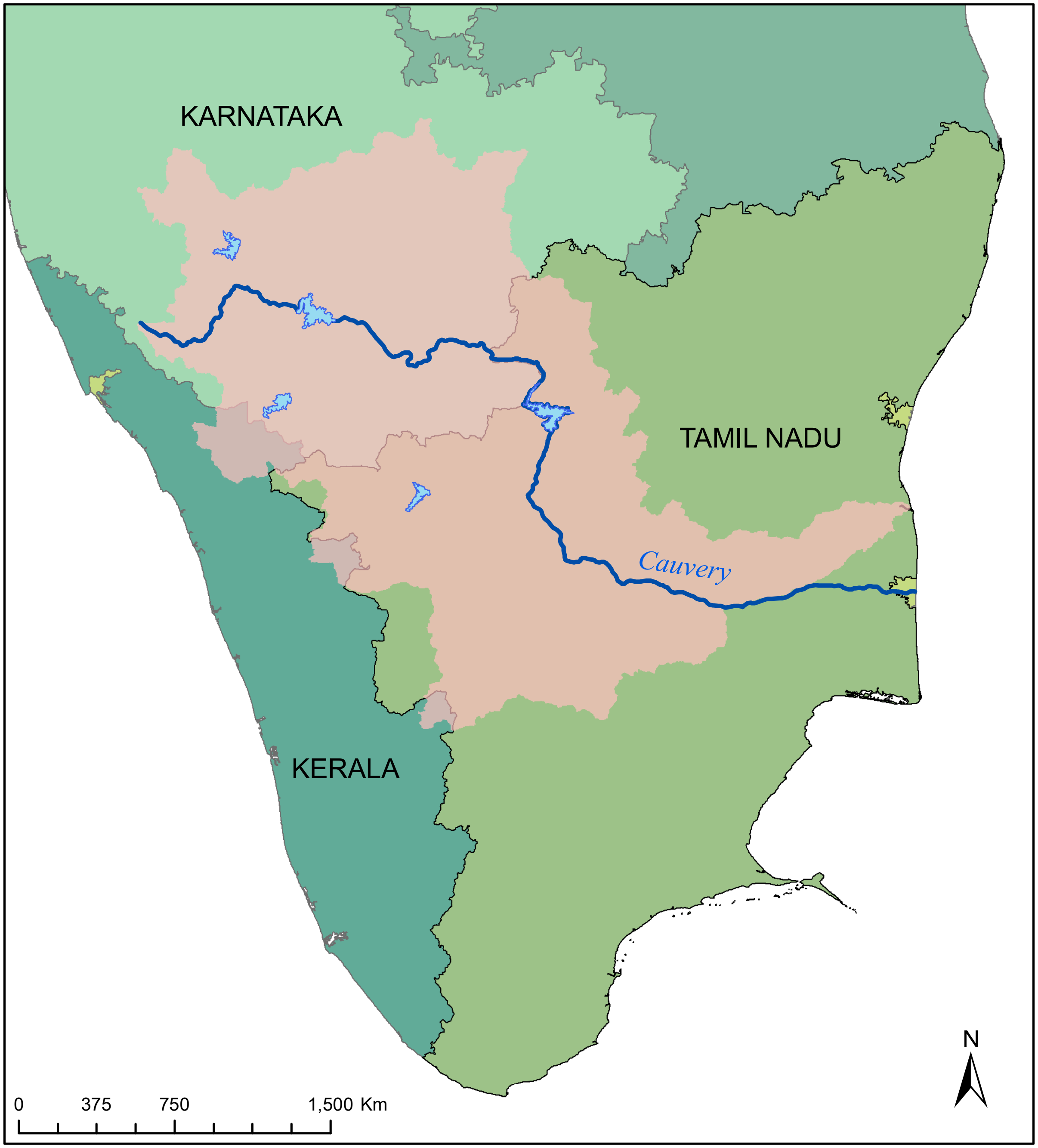
Next, the *HydroLakes* file was placed into the layer to enable choosing the most significant lakes in the Cauvery basin by visual inspection. Fig 3 shows the location of the Cauvery river and river basin within the Indian mainland. Fig 3 also displays the five largest lakes and reservoirs in the basin, and these lakes lie in the following states:

Karnataka: Hemavati dam, Krishna Raja Sagara lake, Kabini lake

Tamil Nadu: Mettur dam, Bhavanisagar dam

The *lake_extent* raster file was imported into ArcMap to provide as an approximate outline for the maximum extent of each lake in conjunction to the *HydroLakes* file (Fig 4).

Fig 3. Map of The Cauvery River Basin



Legend

Cauvery river

Cauvery river basin

Major lakes in Cauvery river basin

GCS WGS 1984
Meghna Thomas, May 5 2022

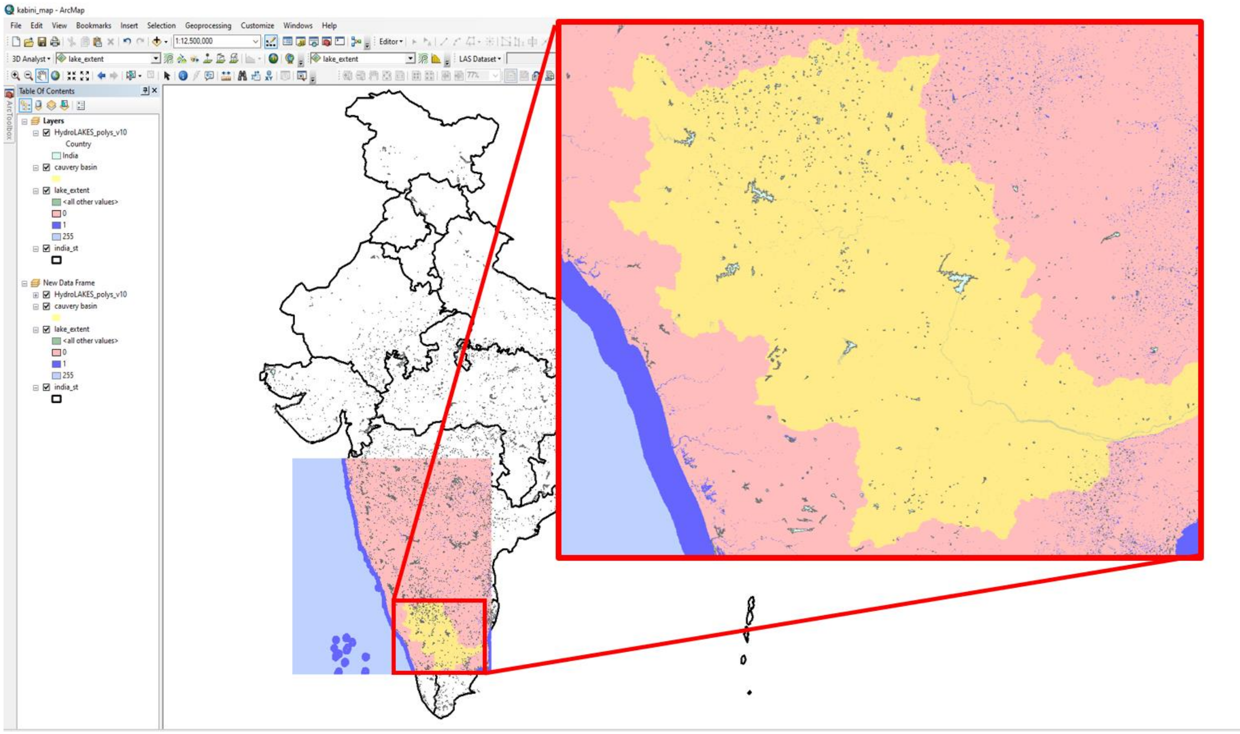


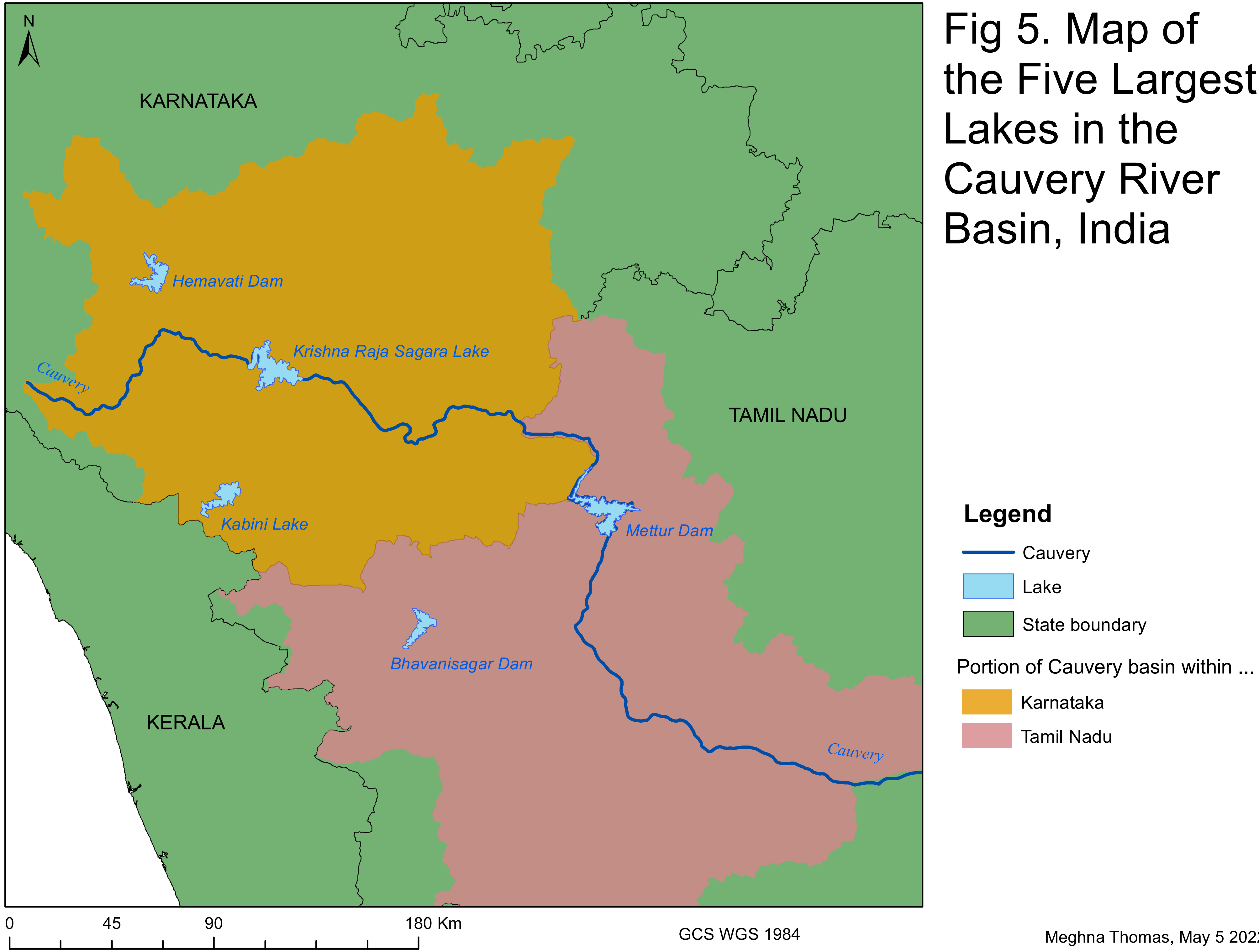
Fig 4. Overlaying the *HydroLakes* shapefile and *lake_extent* tile files to visually determine the largest lakes in the Cauvery basin.

The Polygon tool from the Drawing toolbar was selected and used to trace a rough outline of each lake at a scale of 1:50,000. The resultant polygons were then converted to separate layer files by clicking on the “Convert Graphics to Features …” option under the Drawing button in the Drawing toolbar for each of the chosen lakes. Fig 5 displays the location of the five major lakes within the Cauvery basin and within the states of Karnataka and Tamil Nadu.

Clipping seasonality rasters to lake outlines

Only *seasonality* raster files from the years 1990 – 2020 were used in this analysis because of inconsistencies in the data of earlier years. Each seasonality raster file corresponds to one year’s data for the raster tile within which the Cauvery basin lies, and an example of how data for each raster is symbolized by default is shown in Fig 6.

Fig 5. Map of the Five Largest Lakes in the Cauvery River Basin, India



GCS WGS 1984

Meghna Thomas, May 5 2022

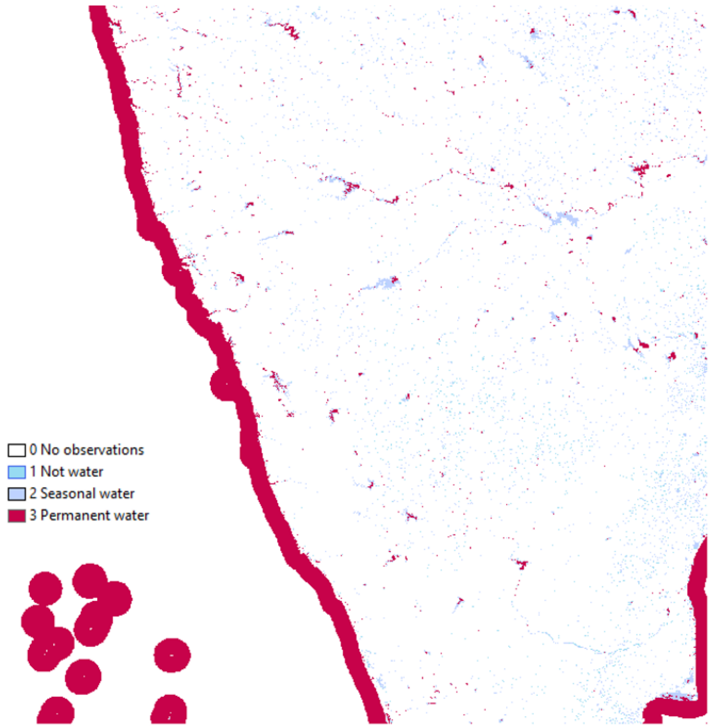


Fig 6. The *seasonality* raster file for year 2003.

A new raster depicting the seasonal and permanent extent of each lake in each year was created by right-clicking the “Extract by Mask” tool and selecting “Batch,” which allows the user to clip a large number of rasters to a single layer in one go (see Fig 7).

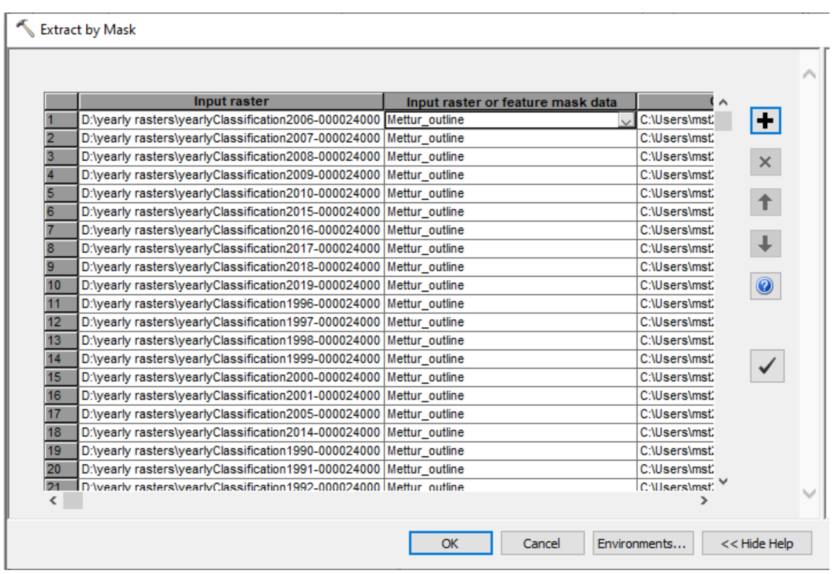


Fig 7. Extracting a separate raster to depict the seasonality of Mettur lake for each year.

Extracting and converting relevant data

In order to derive meaningful insights about trends in lake surface areas, the next step was to extract data from the new clipped rasters. Each clipped raster (corresponding to a lake and a year) possessed an attribute table such as shown in Fig 8. The “Value” and “Rowid” fields represent the seasonal classification as symbolized in Fig 6. The value under “Count” in the first two records (when “Rowid” is 0 and 1) represents the number of cells with no observations or with data points that are not water. The value of “Count” when “Rowid” is 2 represents cells depicting seasonal water area (area that is not underwater the entire year) and a “Rowid” of 3 represents permanent water area (area that is underwater the entire year). We are interested in the seasonal and permanent area data, so the attribute table of each clipper raster was converted to an Excel file and merged in order to perform data analysis in Excel. Fig 9 displays the properties corresponding to a clipped raster layer and informs us that the edge length of each cell is equivalent to 0.00025 decimal degrees. Given that cell size = 0.00025 * 0.00025 degrees, and one decimal degree = 111 km, we can calculate that each cell represents 0.00025^2 [$degrees^2$/cell]* 111^2 [km^2/$degrees^2$] = 0.00077 [km^2/cell]. This formulation was applied in Excel to convert each “Count” value with “Rowid” = 2 or 3 into an approximation of the surface area of the permanent and seasonal extent of each lake for every year in the 30-year period.

k_1989

Rowid	VALUE	COUNT
0	0	125553
1	1	50361
2	2	41814
3	3	54022

Fig 8. Attribute table for *seasonality* raster for year 1989 clipped to Kabini lake.

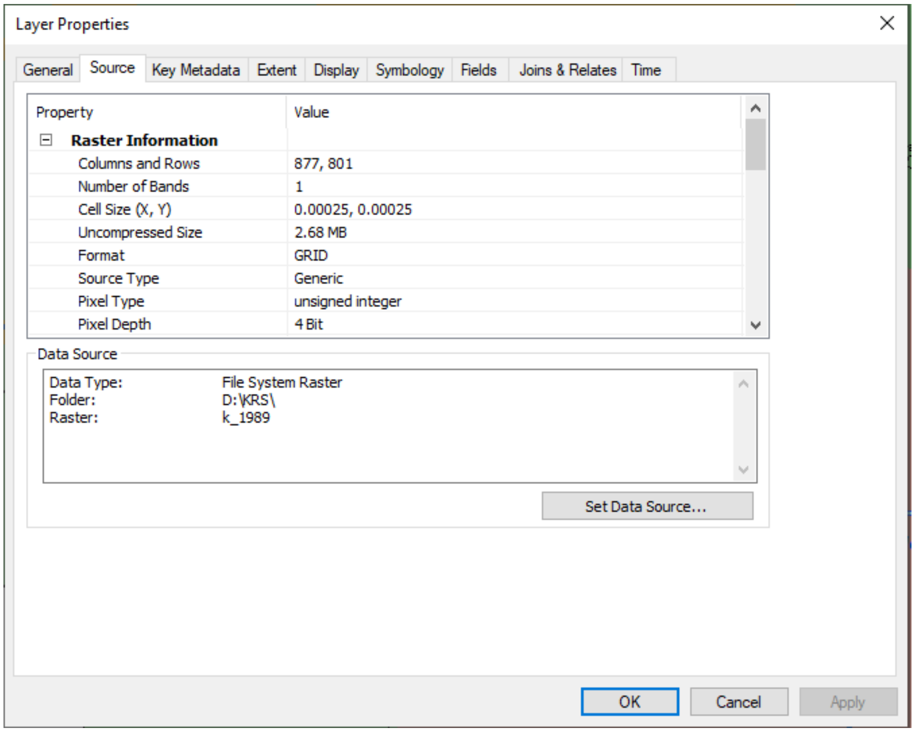


Fig 9. Layer properties for *seasonality* raster for year 1989 clipped to Kabini lake.

Results and Discussion

Fig 10 reveals the difference in the seasonal and permanent extent of each lake's surface area between years 1990 and 2020. Fig 11 highlights the maximum and minimum extent of the seasonal and permanent area of each lake over the course of the entire observation period. From the maps in Fig 10, it appears that lakes in Tamil Nadu exhibit a stark difference in seasonal and permanent lake boundaries at the beginning and end of the observation period, whereas lakes in Karnataka seem to have seen little change in their seasonal and permanent area boundaries between the two years. It is possible to observe in Fig 11 that for all five lakes, the minimum seasonal area along the entire observation period is negligible especially compared to the maximum seasonal area. However, lakes in Karnataka seem to have less variation in their maximum and minimum permanent surface area extents whereas permanent surface areas of the lakes in Tamil Nadu differ widely. These map observations are further confirmed by results in Table 2 and time series data plotted in Figs 12 and 13.

Fig 10. Seasonal and Permament Extent of Lakes in Different States within the Cauvery River Basin, India

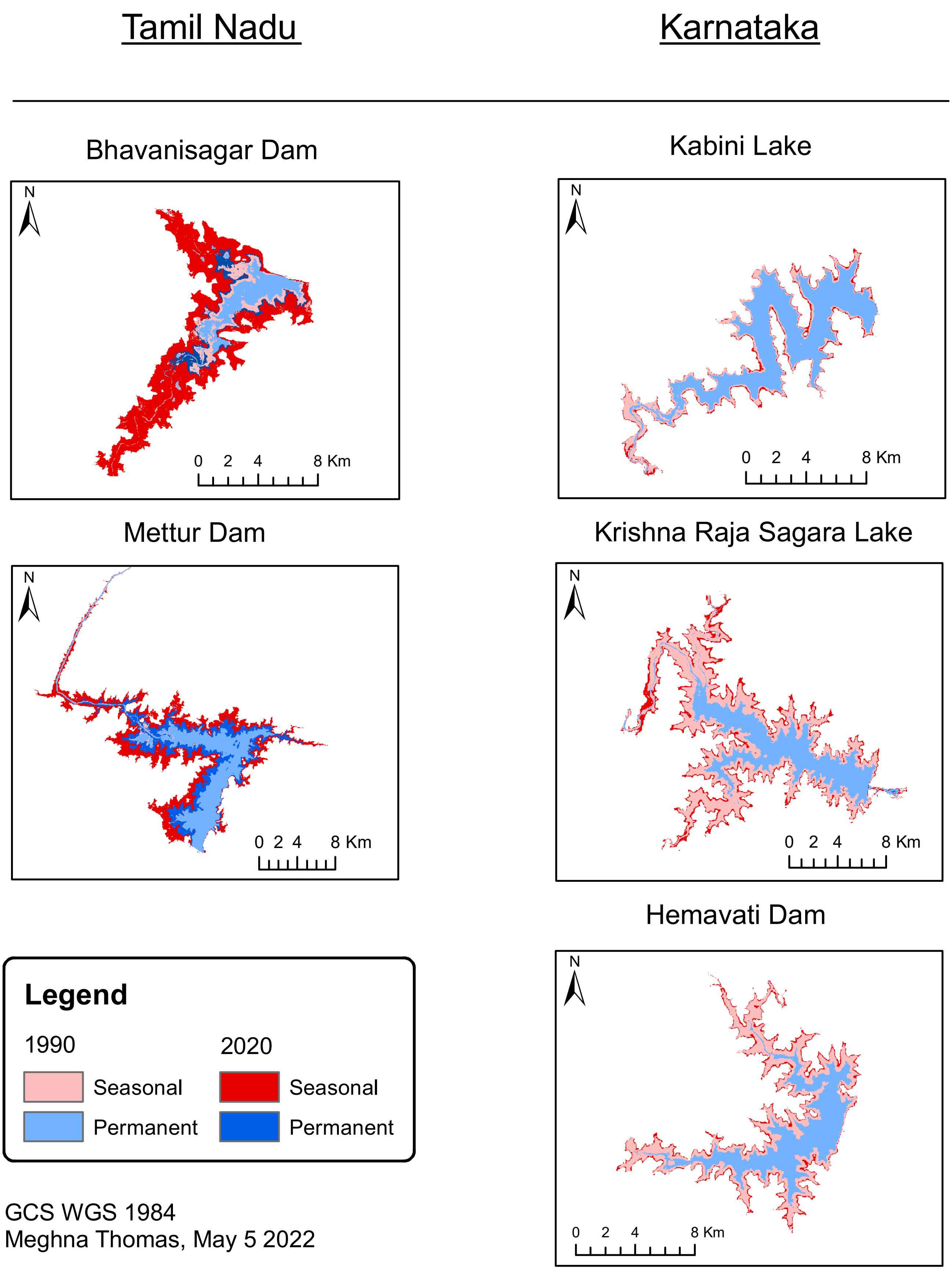


Fig 11. Minimum and Maximum Seasonal and Permament Extent of Lakes within the Cauvery River Basin, India

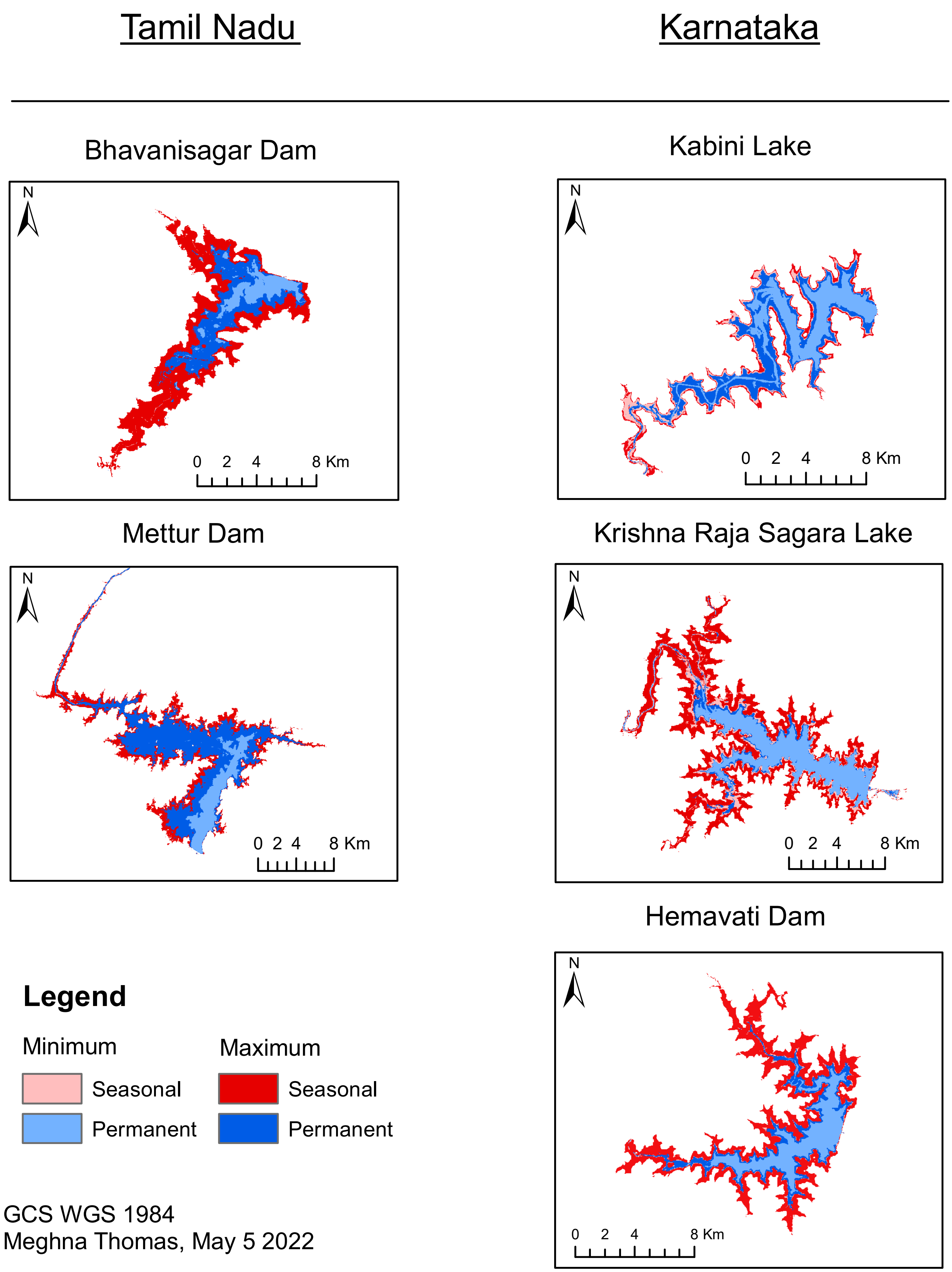


Table 2. Summary of minimum and maximum surface area data for major lakes in the Cauvery river basin between 1990 and 2020.

	Seasonal	Permanent
KARNATAKA		
Kabini		
Min	9.0	18.8
Max	38.4	38.9
Krishna Raja Sagara		
Min	19.5	35.3
Max	82.8	43.5
Hemavati		
Min	5.9	16.4
Max	43.9	27.2
TAMIL NADU		
Bhavanisagar		
Min	0.2	7.3
Max	45.8	23.6
Mettur		
Min	3.2	20.2
Max	105.9	91.5

In conclusion, for lakes within the Cauvery river basin, it appears that there is less spatial and temporal variability in the surface areas of lakes in Karnataka while there is high variability in the surface areas of lakes in Tamil Nadu. The reason for this difference could be because of different state governing practices, or because of the fact that the lakes in Karnataka are upstream of the lakes in Tamil Nadu and can restrict flows out of the state. It is also crucial to note that this project examines only the Cauvery watershed in isolation and is neglecting to factor in seasonal rainfall patterns, water table levels, smaller connected drainage basins, and state water resource management and allocation practices. Historically low water levels due to droughts in the years 2003 and 2016 -2 018 explain the significant drops in surface area in Figs 12 and 13.

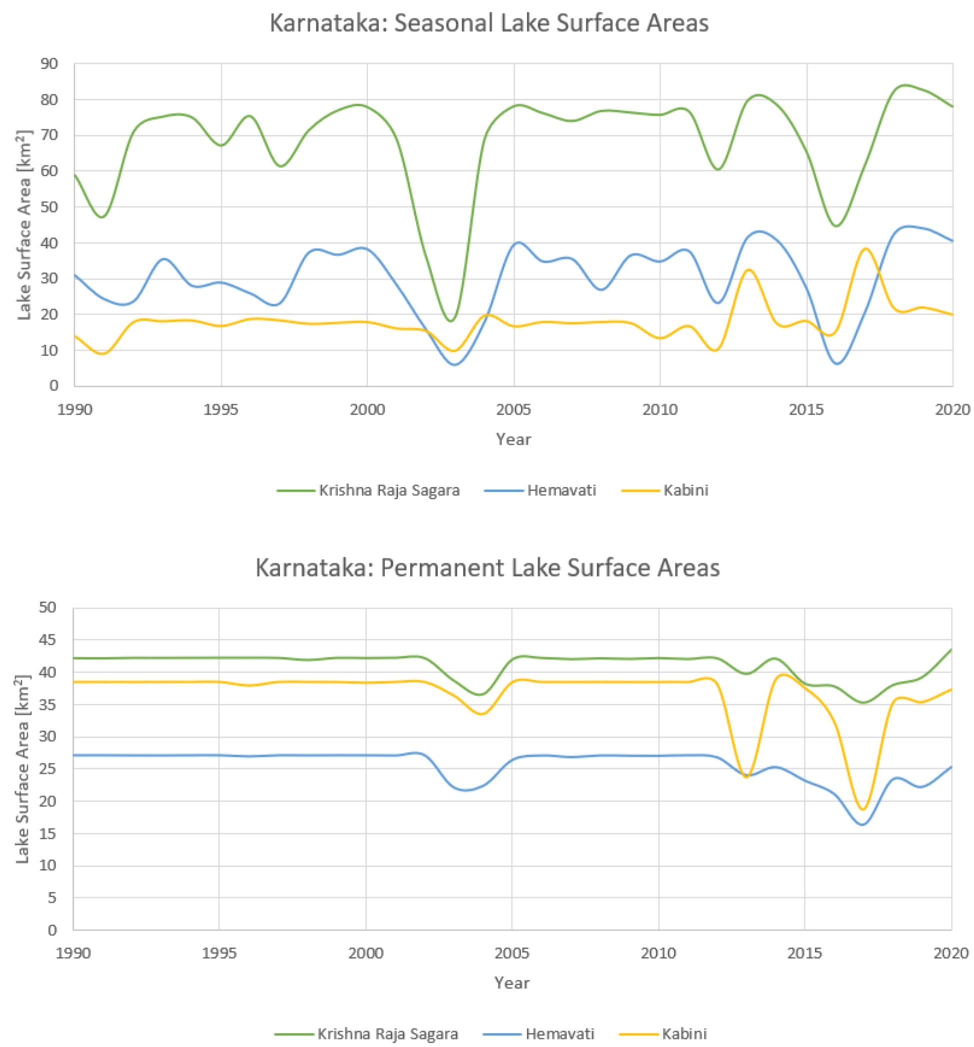
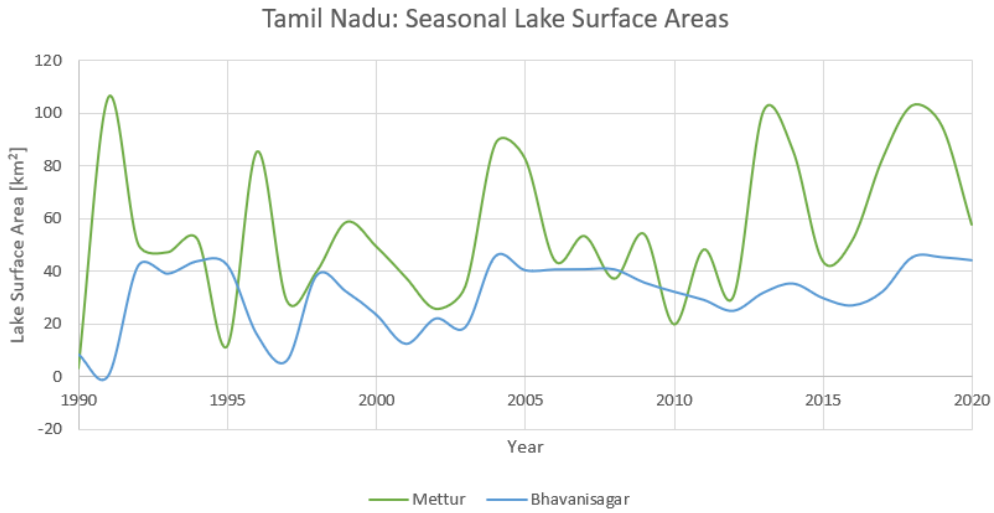


Fig 12. Surface Area Trends for Lakes in the Cauvery River Basin within Karnataka between 1990 and 2020.



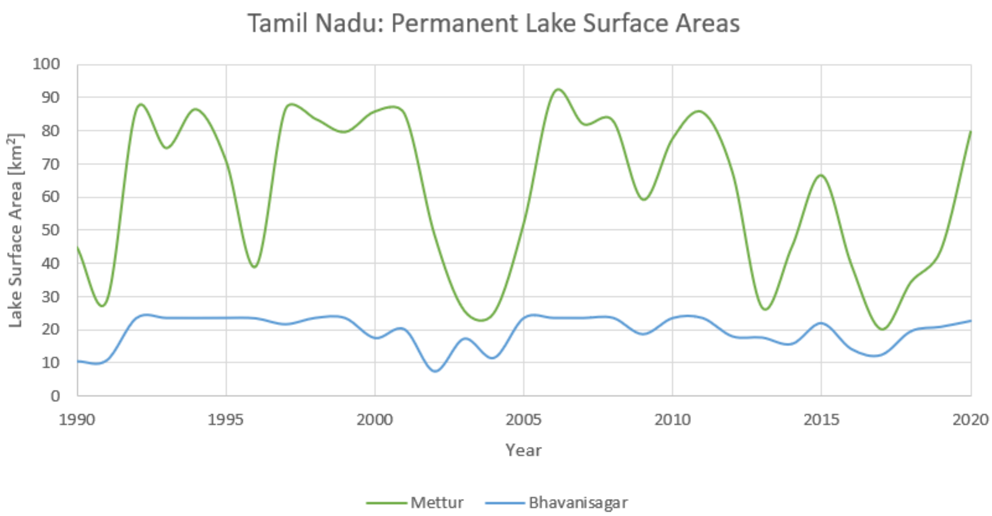


Fig 13. Surface Area Trends for Lakes in the Cauvery River Basin within Tamil Nadu between 1990 and 2020.

A major limitation of this project work was the dependence on Excel to combine and compare yearly data for each lake. Join and relate operation for records across raster files seems to work for only two files at a time, which hinders our ability to batch process large quantities of files as is required here. Alternative methods involving creating raster catalogs and raster mosaics were also investigated but did not produce appropriate end products. Further development of this work could entail the exploration of better tools or a more systematic methodology to reduce processing time and manual effort, as well as attempt to draw correlations between the seasonal and permanent lake surface data. It is very important to note that for the purpose of this study, surface area is taken to approximate lake volumes. In reality, it would be important to also factor into calculations lake DEM data as well as weather and demand uncertainties to make more robust conclusions.

References

Jean-Francois Pekel, Andrew Cottam, Noel Gorelick, Alan S. Belward. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature* 540, 418-422. (doi:10.1038/nature20584)

Lehner, B., Grill G. (2013). Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrological Processes*, 27(15): 2171–2186. https://doi.org/10.1002/hyp.9740. Data is available at www.hydrosheds.org.

Carvalho-Resende, T. (2017). World Rivers dataset. BGR and UNESCO. "River and Groundwater Basins of the World." Data is available at http://ihp-wins.unesco.org/layers/geonode:world_rivers

Messager, M.L., Lehner, B., Grill, G., Nedeva, I., Schmitt, O. (2016). Estimating the volume and age of water stored in global lakes using a geo-statistical approach. *Nature Communications*, 7: 13603. https://doi.org/10.1038/ncomms13603

National Informatics Centre, Government of India. (n.d.). Bharat Maps. Retrieved May 5, 2022, from https://bharatmaps.gov.in/