A GIS-BASED PARAMETRIC ANALYSIS OF IRRIGATIONAL TANKS IN THE OLDEST CIVILIZED CITY IN INDIA-MADURAI

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Abstract

The irrigational tanks being traditional Water harvesting structures designed by rulers and chieftains dating back centuries. These are constructed in such a way that they act as a major water resource in drought-prone rural communities. The main aim of this paper is to develop a GIS-based Parametric Maps of Maximum Capacity(MC), Maximum Water Level(MWL), Ayacut Area(AA), Water Spread Area(WSA), Sub-basins and Basins of irrigational Tanks which form the basic irrigation information system to assist agriculturalists, farmers, and Government organization for the proper maintenance of irrigation tanks with suitable indexing parameters, to mitigate & forecast the water and food requirements by evaluating currently available water for the given population density and irrigation lands. The study area selected is the oldest civilized city in India which is in the state of Tamilnadu-Madurai district, which is served by the Vaigai River and consists of 1338 tanks. This GIS-based information system assists the decision-makers to perform surveillance, evaluate the efficiency of the tank at any space & time and take proper managerial methods to utilize the resources economically.

Keywords: Tank Irrigation; GIS; Ayacut area; Sub-basins; Maximum Water Level; Water Spread Area;

1. Introduction

Agriculture, being the lower backbone of our country’s economy, relies absolutely on water resources. Water plays a major role in all living lives. It is known to be the Elixir of Life. Water resources are available as rainfall, ponds, lakes, rivers, and groundwaters. Water covers 71% of Earth’s surface which accounts for nearly 326 million cubic miles of area. 97% is filled as the ocean which is nearly 320 million cubic miles of area. The remaining 3% is the usable freshwater. 2.5% is locked up as glaciers and ice caps, atmosphere, and soil. 0.5% of water is found utilizable which is continually accumulated, filtered, and circulated back again. Due to the rise in the Earth’s temperature,
drastic changes in rainfall patterns affect irrigation. Hence there is a vital need for proper maintenance and storage of irrigation tanks and rainwater. Also, water is taken into consideration to be the factor that's essential for improvement planning.

India receives total precipitation of about 4000 x \(10^9\) m\(^3\). Out of this, water available on the surface accounts for 1780 x \(10^9\) m\(^3\). But only half of the available surface water can be used due to other restraints. 420 x \(10^9\) m\(^3\) of water is available as groundwater. Due to the erratic rainfall pattern, water availability is extremely unbalanced. Precipitation is limited to as it were almost 3 to 4 months with 20-45 critical blustery days within the year. Consequently, there is a crucial need for the proper storage, management, and required use of rainwater in places like Lakes, Tanks, Ponds, Aquifers, Reservoirs for conventional and communal resolves.

The irrigation tanks act as a natural and customary way of rainwater harvesting especially in places that are scarce of water. Tanks are low earthen bund that is built along with the tilt of terrain as well as valleys to store the precipitated water. Tamilnadu contains almost 39,202 tanks which are scattered all over the state. The system of a tank consists of a command area, sluice outlets, field distributaries, surplus weir, channel feeder, water spread area, catchment area, and tank bund. Over the years giant damage to the capable applicability of several tanks had been an acting reason of overwhelming siltation, immoderate infection, and encroachments. GIS plays an important part in enhancing the information system which is adapted in the rural areas to make decisions and sustain management functions of that particular area [10]. Thus, GIS will be an advancement in the field of agriculture in locating tanks, identifying their water level and other parameters for the prolonged functioning of agricultural activities.

Irrigation tanks are used recurrently for agriculture, humans, and cattle as drinking water. The possible outcomes from tank irrigation were assessed and concluded that this system may be a productive technology in financial, natural, and societal terms, but under current circumstances of administration, the conditions of these tanks are worsening [4]. Proper communication and knowledge of all these irrigation tanks would help society in many ways. Thus, the information system assists the management of resources. [17].

The proper management of runoff water leads to rainfall -surface water inside a catchment could be a beneficial resource of water to supply high demands [5]. The administration can receive societal endurance of tank rehabilitation projects if they could tackle the multifaceted issues and concede that irrigation tanks benefit the common people in addition to farmers [16]. The surveillance of irrigating crops & inaccessible areas like contours of reservoir water is made easier by Remote sensing techniques which involve reduced manpower, are cost-effective, precise [9]. The approach for economically unifying aerial photography and satellite data with surveys of ground to obtain current guideline information with respect to resources of tanks and irrigated areas under their command [23]. The strategy for the classification of water bodies based on various parameters is essential and effective [22].

Taking into consideration other productive uses (except domestic and cattle), the total production increases 13%, and the cumulative income received by tanks increases by 213% [14]. The research suggests that the correlation could be related between the potential storage and the diffusion area of the tanks. With the usage of remotely sensed images, Water spread areas can be mapped exactly [15]. The production of sustainable crops needs better performance than small training structures tanks, that require reconstruction of physical structure, effective distribution of water in agricultural fields, as well as in farmers, and correct maintenance of the reservoir system after modernization by the participation of farmers [1]. Urbanization was considered the main cause of the drastic runoff of catchment (40 to 60% of rainfall). For this reason, the availability of seasonal water in each reservoir in watershed waters was observed incoherent (0 to 15%), with the summer which comprises about the minimum water memory (0 to 8%) [21]. Geospatial technologies such as remote sensing and geographic information system (GIS) serve as effective aids to assess these impacts of sustainable development in a water management system [19]. The contribution of this paper includes developing a GIS-based tank information system for the study area, creation of parametric Maps of tanks with the satellite image as a base Map and the analysis of parametric maps to understand the present status of irrigation tanks in the study area for future planning and development.
2. Materials and Methods

2.1 Study area

The study area chosen is Madurai district in Tamil Nadu, India. Madurai District is in the Southcentral Region of Tamilnadu lying between longitudes E 77° 2' and E 78° 2' and between latitudes N 9° 30' and N 10° 27'. Madurai has been an important settlement for two millennia and is one of the oldest continuously inhabited cities in the world. The general slope of Madurai District is from West to East. The geographical area of the district is 3741.73 square kilometres, has a cultivating area of 150704 ha & consists of 7 Basins. All the required non-spatial and spatial data on the command area for all tanks in Madurai district (1338 tanks) were collected.

- The Central Part of the district is drained by the Gundar River and Vaigai River that forms parts of Vaigai.
- The Northern Part of the district is drained by the river Pambar.
- The Sedapatti and Kallupatti blocks (Southeastern part of the Madurai district) fall into the Vaippar basin and the area is drained by the river Arjuna Nadi.

It consists of 1 Municipal Corporation, 2 Revenue divisions, 669 villages, 7 Taluks, 13 Panchayat Unions (Blocks), and 431 Village Panchayats. It has a total population of 25,62,279. The Madurai district is continuously irrigated by the Periyar Vaigai Irrigation System which irrigates about 57,000 ha, Sathaiyar Reservoir Irrigating about 200ha, Minor Irrigation Tanks, and Dug wells & Tube wells.

Table 1 shows the population census of the Madurai district, India as per the 2011 census.

|                | Total Population | Male     | Female   | Area (Sq.km) | Density (/Sq.km) |
|----------------|------------------|----------|----------|--------------|-----------------|
| Total          | 2578201          | 1303363  | 1274838  | 3451.5       | 746.98          |
| Rural          | 1134025          | 573036   | 560989   | 244.49       | 4638.33         |
| Urban          | 1444176          | 730327   | 713849   | 3696.0       | 390.74          |

2.2 Database

In this paper, all required non-spatial and spatial data on the command area for all tanks in Madurai district (1338 tanks) were collected (Fig. 2). The satellite data of the Madurai region has been obtained through BHUVAN (The national Geo-portal developed and hosted by ISRO comprising of Geo-Spatial Data, Services and Tools for Analysis - https://bhuvan.nrsc.gov.in/) portal. This Satellite data was captured by Advanced Wide Field Sensor (AWiFS) which is a part of the Resources at-1 satellite. AWiFS operates in 4 spectral bands, which have 56 meters of spatial resolution. The secondary data collected are Maximum Capacity (MC), Ayacut Area (AA), Maximum Water Level (MWL), Water Spread Area (WSA), Basins, and Sub Basins of Irrigational Tanks.

The Tank details & data of the Public Work Department (PWD) resources, Government of Tamil Nadu, have been used as a secondary dataset. The database contains 2 components (i) spatial data represents the distribution of features in the control area and (ii) attribute database represents Maximum Capacity (MC), Ayacut area (AA), Maximum Water Level (MWL), Water Spread Area (WSA), Basins, and Sub Basins of Irrigational Tanks.
The software which is used here is QGIS version 3.16.15 ‘Hannover’. The Coordinate Reference System (CRS) used here is WGS 84 (EPSG 4326).

The digital database of non-spatial and spatial data about the command area has been created in the GIS environment. As prime work for this project, the satellite data of the Madurai region were downloaded from the BHUVAN portal. Furthermore, (1/4)th details of data have been verified for data accuracy through field visits. All data combined with the acquisition of new data related to technical aspects of Tanks were verified with the Latitude and Longitude coordinates of Tank location using a GPS device. The spatial database was created using QGIS (Quantum Geographic Information System).

2.3 Methodology

The Map of the Madurai district and its taluks have been downloaded from the Madurai district corporation website. Using BHUVAN data as a base map, this district and taluk map have been georeferenced using QGIS. Then we have digitized the boundaries of Madurai district and its seven taluks in QGIS using the above-georeferenced data (Fig. 3).

2.3.1 Digitization of Boundaries

The Map of the Madurai district and its taluks have been downloaded from the Madurai district corporation website. Using BHUVAN data as a base map, this district and taluk map have been georeferenced using QGIS. Then we have digitized the boundaries of Madurai district and its seven taluks in QGIS using the above-georeferenced data (Fig. 3).

2.3.2 Addition of Data in QGIS

All the data have been recorded and updated into an excel sheet which consists of technical data such as Latitude, Longitude, Maximum Capacity (MC), Ayacut Area (AA), Maximum Water Level (MWL), Water Spread Area (WSA), Basins, and Sub Basins of Irrigational Tanks. After that, we have converted the excel sheet into comma-separated values (.csv) file. Then this .csv file has been imported into QGIS as point features. Using various attributes available in the tanks’ data, five different maps have been created.

3. Parameters Taken

The following are the parameters taken related to Irrigational Tanks which come under the Irrigation Engineering of the Civil Engineering domain.

3.1 Maximum Capacity (MC) of Tank

Gross volume of water which can be stored in the Tank/storage structures.

3.2 Maximum Water Level (MWL) of Tank

The Water level is reached during the passage of the design flood. It depends upon the specified preliminary reservoir level and the spillway gate operation rule. It is also called the Highest Flood Level (HFL) or Highest Reservoir Level (HRL).

3.3 Ayacut Area (AA) of Tank

The area that is served by the Tanks for irrigation purposes is the Ayacut Area of the tank.

3.4 Water Spread Area (WSA) of Tank

It is an area covered by water, i.e., land of the Tank occupied by water (submerged area).
3.5 Sub-basin of Tank

Sub-basin is a structural geological feature in which a larger basin is divided into a series of smaller basins with intermediate intra-basin heights.

4. Results and Discussion

From the analysis of various geospatial data as well as non-geospatial data, the numerical decisions have been estimated using simple Mathematics which have been given below,

Figure 4: Maximum Capacity of Irrigational Tanks

Using the Map of the Maximum Capacity of Madurai tanks, Madakulam Tank (Thiruparankundram Village, Madurai South Block) is the Largest Tank in this District, having a Maximum Capacity of $166.90 \times 10^6 \text{ m}^3$ serving Agricultural land of $1043.30 \text{ ha}$. Also, there exist many small tanks of magnitude less than 1 MCM ($10^6 \text{ m}^3$). It has been estimated that the Cumulative Capacity of 1338 Tanks which accounts for $2143.48 \times 10^6 \text{ m}^3$ shown in Fig. 4.

Figure 5: Maximum Water Level (MWL) of Tanks

With the application of the Maximum Water Level (MWL) Map of Madurai, Veppankulam Tank has the highest Maximum Water Level (MWL) of 497.41m, located in the Madurai North Taluk- Kulamagalam Village comes under the Sub-basin of Sathaiyar, Vaigai basin. In addition to, there exists a Tank possessing the smallest MWL less than 1m like Chandrankulam Tank, located in the Thirumangalam Taluk- Kallikudi Block which comes under the Sub-basin of Therkar, Gundar basin shown in Fig. 5.

Figure 6: Water Spread Area of Tanks

The Water Spread Area (WSA) of Madurai was mapped and it is found that Valandur Tank has the largest Water Spread Area (WSA) of 1014.0ha, located in the Valandur Village-Usilampatti Taluk and Veeraputhukulam (Katchirayanpatti Village- Melur Taluk), Somakulam (Maruthankudi Village-Thirumangalam Taluk) tank has Water Spread Area (WSA) less than 1ha shown in Fig. 6.
Figure 7: Ayacut Area of Madurai

It has been inferred from the Ayacut Area (AA) Map of Madurai that Madurai Tanks has a cumulative Ayacut Area (AA) of almost 52197.21ha (ha=hectare), spreading over 669 villages namely Elumalai, Mellapuram, Perungamanallur, Kallappanpatty, Poosalapuram, Sembarani, Kuppalnatham, Sedapatti, etc. Madakulam Tank, serving the largest Ayacut Area (AA) of about 1043.30ha to its neighboring villages with a capacity of 166.90 x 10^6 m^3, comes under the Sub-basin of Gridhamaal Nadhi, the basin of Gundar. A small ayacut served by a tank of less than 1ha like Chinnakulam Tank is also available shown in Fig. 7.

Figure 8: Sub-Basins of Tanks

Table 2 shows the data analyzed from the Sub-Basins map of Madurai district shown in Fig. 8.

| S. NO | Name of the Sub-Basin | Number of Tanks that falls under these Sub-Basins |
|-------|-----------------------|----------------------------------------------------|
| 1     | Arjunanadhi           | 5                                                  |
| 2     | Gridhamaal Nadhi      | 24                                                 |
| 3     | Karamaniyar           | 1                                                  |
| 4     | Korampallam           | 1                                                  |
| 5     | Kosiganadhi           | 11                                                 |
| 6     | Kottakaraiyar         | 31                                                 |
| 7     | Manimuthar            | 330                                                |
| 8     | Sathaiyar             | 187                                                |
| 9     | Sirumalaiyar          | 22                                                 |
| 10    | Lower Tamiraparani    | 5                                                  |
| 11    | Therkar               | 137                                                |
| 12    | Upar                   | 540                                                |
| 13    | Upper Gundar          | 44                                                 |
| **TOTAL** |                        | **1338**                                           |

Basin data that has been collected shows that there are almost 7 Basins in Madurai which in turn are divided into Sub-Basins (-No. of tanks) namely Pambar Kottakaraiyar-363, Vaippar-16, Vaigai-748, Nambiyar-1, Kallar-1, Gundar-204, Tamiraparani-5.

4.1 Application & Use of GIS Map

With the inference from each parametric GIS Map of Madurai tanks as well as generic irrigation
tanks all over the world, we can conclude that applying Information System will help to reduce the Encroachments and siltation in the water spread areas of Tanks, supply channels, and surplus courses, which take precautions to mitigate Major flood loss. Using this data, the Government can allocate relief funds for farmers who have lost their grown crops in their field due to natural calamities like cyclones, floods, heavy rains, etc. These data directly contribute to the region of Natural wellness meant for potential & productive agricultural areas and give a clear vision to protect those particular areas with immense beneficiary data. With the cumulative capacities of tanks, currently, available water for the given population density and irrigation lands can be evaluated.

Proper rationing of water for both domestic purposes as well as agricultural utilities can be validated. Cost for Maintenance of Conduits and its new installation can be done in a very effective manner. Seasonal opening of sluices may be decided by knowing the Capacity of Tank. It also greatly helps to increase the depth of the Tank and to meet the future forecasted water requirements which would be found by Mathematical modelling. By monitoring the water level by taking these values as extreme values Major flood loss can be mitigated. An alarm for timely Desilting of Tank (Desiltation process) can also be given. Geological /Soil Analysis data combined with our obtained data can be combinedly used to suggest suitable agricultural crops that can be cultivated in those regions concerning uniform Sub-Basins.

With the help of this data, Renovation/Repair work in any particular Sub-Basin can be made since repair work simultaneously affects the series of Tanks associated with the particular Sub-Basin. These data enable us to directly measure the available surface water in the particular zone, which can be an index factor for balancing the eco-systems. Using these data, the Government can easily allocate funds for State Public Works Department (SPWD) and Central Public Works Department (CPWD) for the Civil repair Project.

5. Conclusion

Tank irrigation is an economical technology and proper management of tanks for agriculture and irrigation is the need of the hour. By providing an effective tank information system, current obstacles in agriculture and water resource management can be resolved. A study was conducted at Madurai district, Tamil Nadu, with the objective of developing a GIS-based irrigation tanks information system to assist the agriculturalists and governmental administrators for proper planning and management. Thus, irrigational tanks information was collected for various tank attributes including Maximum Capacity (MC), Maximum Water Level (MWL), Water Spread Area (WSA), Ayacut Area (AA), Sub-Basins, and Basins were uploaded in GIS to process the data. The study revealed that spatial, as well as non-spatial data, can be integrated and analyzed in different formats. Results in the form of maps, tables, and graphs were acquired with the help of GIS which could help farmers, irrigation engineers, and government officials to maintain the tanks’ performance and resources effectively.

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