MULTI-SPECTRAL SATELLITES AND GIS MODELING OF HYDROLOGICAL CHARACTERISTICS OF TIGHRA RESERVOIR, GWALIOR, INDIA

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Received October 05, 2013 Accepted February 20, 2014

ABSTRACT

The study aims at identifying the hydrological characteristics of Tighra Reservoir, Gwalior, India by using GIS technology and multi-spectral satellite data obtained in different periods. Landsat Thematic Mapper of the years 1973, 1990, 1999, 2000 and LISS III of 2008 were used in the study. Besides, SOI toposheets of 54F/16, 54J/4 were used to delineate the reservoir catchment area and generate drainage system. Open water spread area were extracted using modeler in ERDAS imagine software. In the present study, it was observed that Tighra reservoir in Gwalior is mainly fed through precipitation and also through Sank River and some small river-lets. The reservoir has a dendritic drainage pattern having coarse textured. The land use pattern of the catchment area is mainly comprise of agricultural fields, villages, built-up area, forest, rocky hills, open scrub and water body. Tighra reservoir has a water spread area of 19.5 sq km (4% of the catchment area) at the time of construction in the year 1926. The change detection analysis during the year 1973 to 2008 shows that the water spread area of the reservoir was 16.47 sq km (3%) in 1973, 19.114 sq km (4%) in 1990, 19.17 sq km (4%) in 1999 but started decreasing from the year 2000 with water spread area of 12.7 sq km (2%) of the catchment. Drastic drop in water spread area of 05.8sq km (1%) were observed during early months of the year 2008 respectively. The changes in water spread area were observed to be due to human intervention and unwise use of water and land encroachment in the catchment area. Besides, wastewater sewage discharge from nearby villages and built-up areas during monsoon periods leads to siltation and sedimentation of the reservoir. Therefore from this study, it is concluded that human activities like unplanned built-up and unwise utilization of water should be checked and local people should be educated towards wise use of water resources. Besides, study on the sedimentation and water quality should be done periodically for long life storing capacity of the reservoir.

Key Words: Tighra reservoir, Multi-spectral satellite, Landsat Thematic Mapper, LISS III, Hydrological characteristics

INTRODUCTION

Hydrology of wetlands refers to the inflow and outflow of water through a wetland and its interaction with other site factors.1 It is the study of the interrelationships and interactions between water and its environment in the hydrological cycle. Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. Wetlands in India are distributed in different geographical regions ranging from Himalayas to Deccan plateau and from Northeast rainforest to Western desert areas. The variability in climatic conditions and changing topography is responsible for the significant diversity of wetlands. Wetlands are biologically productive areas which sustain diverse aquatic as well as terrestrial species. They function as flood mitigation, groundwater recharging, water storage and purification, winter resorts for a variety of birds, recreational benefits etc.2 However, despite their economic and ecological importance, there are many uncertainties

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regarding their extent, distribution, ecological and physical functions. They are fragile ecosystems that are susceptible to changes even with little change to the composition of their biotic and abiotic factors and are the most endangered. Reservoir is a type of wetland that also supports large diversity of aquatic species. Reservoirs were constructed mainly for water storage for drinking and other purposes. For sustainable utilization of the reservoir, it is essential to assess and study their hydrological characteristics.

The use of satellite remote sensing and Geographic Information System (GIS) from recent times has been of immense help in monitoring changing patterns of a landscape. Frequent acquisition of spectral satellites data makes it easier to determine the type and extent of changes in the environment. GIS layering and analysis is also the best tool for examining and identifying the extent of loss of wetland areas. GIS has evolved as a highly sophisticated database management system to put together and store the voluminous spatial data typically required in hydrological modeling. Multi-source remote sensing data offer the potential for improved classification accuracy compared to the accuracy achieved by a single source classification. Liu and Zhang proposed a framework for developing a distributed hydrological model by integrating GIS and Remote Sensing. A physical-based distributed hydrological model to simulate the watershed runoff response process under climate and landcover changes were developed later in the head area of Yellow River by using remote sensing and GIS.

Gwalior is the fourth largest district in Madhya Pradesh with a population of about 9.83 lakhs as per the 2001 census. The district has several water bodies including Tighra reservoir. This reservoir is the main source of drinking water to the Gwalior city and therefore its detailed description of hydrological characteristic is necessary for sustainable utilization of the reservoir.

**AIMS AND OBJECTIVES**

The pattern of hydrological characteristics of Tighra reservoir analyzed by using multi-spectral satellite data obtained in different periods and GIS technology have been given.

**MATERIAL AND METHODS**

**Study area**

The Tighra dam was built upon Sank River during 1910-17 by the then late Maharaja Madhav Rao Scindia and hence was also known as Madhav Sagar Dam (Fig. 1). Tighra reservoir is located at North-western side of the Gwalior district, Madhya Pradesh, India.

![Fig. 1: Maps showing the study area (Tighra Reservoir)](image)
The dam is located 18 km west of Gwalior city in North Madhya Pradesh, India and the reservoir formed due to construction of dam in the year 1910-1917 is spread in an area of 19.425 sq km between a latitudes of 26˚12'00"N and longitudes of 78˚30'00"E. The dam was constructed in stone masonry in lime mortar and foundations were resting on the massive sandstone. It has breached in the very first filling and therefore the dam was again reconstructed by the Government of Madhya Pradesh in 1929. The reservoir was mainly constructed for irrigation, pisciculture and for supplying drinking water to the Gwalior city however at present it is used only for supplying drinking water to the city.

**Data sets**
Multi-temporal satellite data, landsat data of different sensors TM, ETM+ and LISS III IRS-P6 with acquisition dates were used in this study. The TM and ETM+ sensors have 30m and 60m resolution while LISS III IRS-P6 sensor has 23.5m resolution. The landsat images were obtained from GLCF website and IRS P6 LISS III is procured from National Remote Sensing Agency, Hyderabad, Andhra Pradesh, India. The detail characteristics of the sensor data are shown in Table 1.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>WRS: Path/Row</th>
<th>Date of acquisition</th>
<th>Spatial resolution(m)</th>
</tr>
</thead>
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<tr>
<td>Landsat</td>
<td>MSS</td>
<td>1:156/042</td>
<td>24th Jan 1973</td>
<td>30</td>
</tr>
<tr>
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<td>TM</td>
<td>2:146/042</td>
<td>05th Oct 1990</td>
<td>30</td>
</tr>
<tr>
<td>Landsat</td>
<td>TM</td>
<td>2:146/042</td>
<td>22nd Oct 1999</td>
<td>30</td>
</tr>
<tr>
<td>Landsat</td>
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<td>2:145/042</td>
<td>15th Nov 2000</td>
<td>60</td>
</tr>
<tr>
<td>IRS P6</td>
<td>LISS III</td>
<td>2:097/53</td>
<td>02nd March 2008</td>
<td>23.5</td>
</tr>
</tbody>
</table>

For the present study, ArcGIS 9.1v, ERDAS Imagine 8.6v and MapGIS software were used for processing, storing, analysis, modeling and integration of spatial data. ERDAS Imagine was used to generate false colour composite by combining red, green and NIR with bands 3, 2, 1 for all the images. The images were divided into three periods according to the date of acquisition as November-January (winter), March (summer) and October (post-monsoon). The main steps followed for hydrological models and change detection analyses of Tighra reservoir are shown in Fig. 2.

**Image processing**
Digital image processing techniques were done according to the methods given by Li et al., Remote sensing software ERDAS Imagine 8.7v and ArcGIS 9.1v were used for the processing of the images. The raw satellite images were loaded into ERDAS Imagine software and layer stacked and rectified using image to image registration and geometrically corrected to Universal Transverse Mercator with World Geodetic System (UTM WGS 84) projection. Geometric correction was carried out using Ground Control Point (GCP) obtained during field visits with the help of Global Positioning System (GPS). Atleast 10 GCP were used to geo-rectify the images and a 1st order polynomial transformation was adopted. The images were then resampled using nearest neighbor method to obtain the final images.

**Delineation of study area**
A Shuttle Radar Topography Mission (SRTM) DEM data of Gwalior district was used for modeling of watershed area using advanced watershed modeling in Map Window GIS. The watershed boundaries were generated for each individual drainage system using the SRTM DEM data. The generated SRTM is imported to ERDAS Imagine and the interested boundary area is delineated with AOI using subset image from data preparation techniques.
Extraction of open water area

The open water boundary were vectorised in ERDAS Imagine and then converted to arc coverage for easy calculation of the open water area of the different periods. For hydrological change detection analysis, image overlaying and comparisons of statistics methods were used. The extracted water boundaries of different periods were overlay in ArcGIS for easy identification of the changes in open water area.

![Methodology for generation of hydrological models and change detection analysis](image)

**Change detection**

The methods used for change detection analysis of hydrology were (i.) classification comparisons of open water area statistics and (ii.) Image overlay. The area statistics for each of the open water were derived separately from the classification of the images for each year of the data used. Then the area derived by each water bodies for the various periods (winter, summer and post-monsoon) were overlaid and compared and the changes were determined.

**RESULTS AND DISCUSSION**

**Hydrological characteristics of Tighra reservoir**

Tighra reservoir has catchment area of 414.24 sq.km at the time of reconstruction of the dam in the year 1926. The catchment area of Tighra reservoir is shown in **Fig. 3(a)**. The catchment area as obtained from visual interpretation mainly comprises of agricultural fields, villages, built-up area, forest, rocky hills, open scrub, water bodies, etc. The drainage reservoir and the river-lets sub-catchments are shown in **Fig. 3(b)** and **Fig. 3(c)**. The reservoir has a dendritic drainage pattern having coarse textured. The reservoir is mainly drain by Sank River which flows from south to the north-east direction. Some small river-lets like Aam ka nala, Patiala, Boarka, Khar and Koyal join the Sank River on the midway to the reservoir. Precipitation also contributes significantly to overall water inflow into the reservoir at the time of monsoon seasons (mid-June to September). The 3D of the catchment area of Tighra reservoir is shown by the digital elevation model in **Fig. 3(d)** and inflow of water during precipitation periods of the catchment is shown, **Fig. 3(e)**. All the small river-lets flowing into the Sank River are non-perennial. **Fig. 3(f)**. Show the sub-basin of the water in-lets streams of the catchment area. The inflow of river-lets to Sank River and Tighra reservoir is greatly influence by its river-lets sub-basin which is very much affected by the topography of the area.
Change detection analysis
Tighra reservoir has a water spread area of 19.5 sq km (4% of the catchment area) at the time of reconstruction in the year 1926 by the Government of Madhya Pradesh, India. The most significant estimated change of the Tighra
reservoir during these five decades is the difference of the water spread area during the different periods. The water spread area was 16.47 sq km, 19.114 sq km, 19.17 sq km, 12.7 sq km and 5.8 sq km in the year 1973, 1990, 1999, 2000 and 2008 respectively. During winter seasons (November-January), the water spread area was 3% of the catchment area in 1973 and 2% of the catchment area in 2000 respectively. While the water spread area in 1990 and 1999 during post-monsoon (October) was approximately 4%. During 2008 summer seasons (March), the open water extent was reduced to only 1% of the catchment area Fig. 4.

Fig. 4 : Changes in open water area of Tighra Reservoir during a). winter seasons of 2000 vs 1973, b). post-monsoon seasons of 1999 vs 1990, c). summer of 2008 vs winter of 2000

Gwalior district experiences a maximum temperature of 48°C during summers and a minimum of 3°C to 1°C in the months of winter. The average annual rainfall of the Gwalior district is 780mm. Rainfall data shows significant variations during the periods of 36 years (Fig. 5) from 1972 to 2008.

Fig. 5 : Annual rainfall data of Tighra catchment area from 1972 to 2008
Maximum rainfall was observed during the year 1990 with rainfall of 1311 mm. Minimum rainfall of 441 mm recorded in the year 2007. Climatic condition is one of the parameter that affects the hydrology of the reservoir however it also depends on the human intervention and topographical influences in the catchment. Remote sensing can be used to estimate the areal extent and water content of surface water-bodies, as well as the changes in water regimes. Duadze\textsuperscript{11} presented a method for analyzing the surface water system in plain areas with the help of GIS, DEM and Remote Sensing.\textsuperscript{12} In the present study, it was observed that Tighra reservoir in Gwalior, India is mainly fed through precipitation and also by flow of Sank River and some small river-lets. The reservoir has a dendrite drainage pattern having coarse textured. The land use pattern of the catchment area is mainly compose of agricultural fields, villages, built-up area, forest, rocky hills, open scrub and water body. The change detection analysis during the year 1973 to 2008 shows that the water spread area of the reservoir started decreasing from the year 2000 and drastic drop in water spread area were observed during early months of the year 2008. Climatic factor and topology of the region have great influenced on the water quality and availability of the reservoir. Dagnachew et. al in their study of hydrological modeling of the impact of climatic and land use change on water resources in data scarce Tropical Africa confirmed that a 10% decrease in rainfall produced a 30% reduction on the simulated hydrologic response of the catchment, while a 1.5\textdegree{}C increase in air temperature would result in a decrease in the simulated discharge of about 15\%.\textsuperscript{13} However, unwise extraction of water for different uses such as agriculture, extraction of water for household activities contributes to a large extent. Encroachment of land for agriculture is another major factor that leads to decrease of water spread area. During dry summer seasons, the farmers use the wetlands area of the reservoir thereby reducing the storing capacity during monsoon seasons. Besides, wastewater sewage discharge from nearby villages and built-up areas during monsoon periods leads to siltation and sedimentation of the reservoir. Therefore an unplanned urbanization profile with insufficient infrastructure has anticipated a direct negative impact on the overall water quality and tropic status of a reservoir.\textsuperscript{13} This shows that water spread area of the reservoir reduces with sedimentation at different levels which needs to be study thoroughly. From visual interpretation analysis and ground truthing, it was also observed that the landuse pattern in the catchment area has change during the last decades. A study state that land use patterns although do not completely describe disturbance levels, but are usually highly correlated with landscape and wetland conditions.\textsuperscript{14,15}

**CONCLUSION**

Remote sensing satellite data with integration of GIS technology are very effective in hydrological modeling of the Tighra reservoir. Multi-spectral satellite data of Landsat TM and ETM+ and LISS III for the year 1973, 1990, 1999, 2000 and 2008 with high classification accuracies served quite well in detecting the remarkable changes in water spread area within the years. The study highlights the decreasing trend of water spread area of the reservoir from the year 2000 but drastic decrease in water spread area was noticed during early months of the year 2008. The changes in water spread area were observed to be due to human intervention and unwise use of water and land encroachment in the catchment area. The unplanned urbanization with insufficient infrastructure in the catchment has a negative impact on the reservoir. The importance of this reservoir lies in supply of drinking water to the whole Gwalior city and also in supporting a large number of aquatic species including winter migratory birds. Therefore from this study it is concluded that human activities like unplanned built-up and unwise utilization of water should be checked and local people should be educated towards wise use of water resources. Besides, study on sedimentation and water quality should be done periodically for long life storing capacity of the reservoir.

**ACKNOWLEDGEMENT**

We are thankful to Madhya Pradesh Council of Science and Technology (MPCST), Bhopal, Madhya Pradesh, India for financial help through a Research Project to Dr. R.J. Rao.
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Environment is Nature’s gift, preserve it