Assessment of sediments and Application of hydrodynamic model for sediment management in Dal lake, India

Sunil Kumar & P Somasekhar Rao
Advanced Centre for Integrated Water Resources Management, Govt. of Karnataka, Bengaluru

Madhava
Visvesvaraya Jala Nigam Limited, Govt. of Karnataka, Tumakuru

Dheeraj Kumar,
Floodkon Consultants LLP, New Delhi

Nayan Sharma
Emeritus Professor, Indian Institute of Technology Roorkee, Roorkee

ABSTRACT :

Lakes serves as the major source of water for drinking, irrigation, domestic and industries, recreation, flood control and drought mitigation. As a consequence of changing land use patterns, rapid urbanization and industrialization, lakes are affected with large quantity of sediments and domestic and industrial effluents. Thus, the conservation and management of such degraded and polluted lakes through a sustainable and scientific efforts becomes primordial importance.

This paper focuses on the application of hydrodynamic model for managing the sediments in the lakes. Emphasis is laid on assessing the sediment load in the lake by bathymetry survey. As the flow takes place both in longitudinal and transverse direction, 2D hydrodynamic model is developed using HEC-RAS Ver 5.0.1.

The study is carried out on Dal lake in Jammu & Kashmir, India having surface area of 21 Sq.Kms. Bathymetry survey is carried out to understand the topography beneath the water surface. DEM and TIN generated from the bathymetry are used in the hydrodynamic model. Simulation is carried out for existing lake condition with observed inflow, inflow obtained from multi-satellite GPM data and hypothetical scenarios were developed considering depositing dredged material as artificial island in the lake. Volume of sediments assessed in the lake is 32.89 MCM, this high volume of sediments draw attention on the need of better management of sediments by dredging and depositing the sediments as artificial islands in and around the lake and carrying out catchment area treatment works to reduce the sediments entry to the lake for sustainable development of the region.

Hypothetical dredging scenario with a dredging depth of 3.5m and placing the material adjacent to the lake has been observed as the better scenario since the velocity of water and bed shear stress in lake observed is minimum. Using discharge data obtained from multi-satellite precipitation data (GPM) provides reliable results, hence this technique can be adopted in the data scarce regions like Dal-Nigeen lake.

Keywords: Hydrodynamic model, Bathymetry, Sediment Management, Dal lake

INTRODUCTION

In India and all over the world, natural lakes serves as a major source of water for irrigation, domestic and industrial water supply, flood control and draught mitigation, storage place for arresting the sediments (Hurdowar-Castro, et al., 2007), place for recharging the ground water table, navigation, fishing, aquatic agriculture and also serve as place for recreation and tourism to the nearby settlements.

In recent years due to rapid urbanization and industrialization, large quantity of domestic waste water, industrial effluents and solid waste generates which enters the lake and authorities are not working proactively on finding out solution for safe disposal of waste generated. Lakes are treated as sink for disposal of domestic waste water and industrial effluents, solid waste disposal. Change in land use and interrupting activities of human beings in the upstream catchment area, larger volume of soil erosion takes place and deposits in lakes with the runoff generated from the catchment. The amount of siltation is increasing every year resulting in reduction of useful life of lakes and decrease in storage capacity. When heavy intensity precipitation occurs in catchment area, due to reduced storage space in the lakes, there is no enough space to attenuate the approaching flood and excess flood creates pluvial or surface flood in the downstream areas resulting in loss of human and animal life and also damage to the properties.

Most recently, Ministry of Environment and Forests, Government of India implementing National Lake Conservation Plan (NLCP) passed in the year 2001 under IX plan of Government of India, for conservation and management of degraded and polluted lakes in urban and Semi-Urban areas since lakes are the major source of accessible fresh water, they require sustainable, well planned and scientific efforts to control the degradation and pollution. Under this act, state government has to setup a lake development authority to restore and conserve degraded lakes due to disposal of waste water and industrial effluents through integrated ecosystem approach.

Flood risk identification and its better management are the basic steps in identifying the current hazard, risk prone areas and reducing them for future flood events (Ranzi, 2011). It is necessary to analyze the behavior of flood before suggesting flood management measures, this can be done with simple method of analyzing the floods based on the observed floods (Hagen & Lu, 2011). Observed flood data may not be available always, the alternative method is to use the remote sensing like DEM and Satellite image data for flood studies (Haq, 2012).

Sensitivity analysis is also performed which helps to study the relationship among the different hydraulic parameters involved in the development and analysis of the hydrodynamic model. Two types of model sensitivity analysis such as numerical sensitivity by varying the Theta implicit factor and physical parameter sensitivity by varying the Manning's roughness coefficient and varying grid size of the hydrodynamic model will be carried out.

1.1 Objective of the study

The objective of the present study is to;

a) Conducting Bathymetry survey to understand the topography of lake beneath the water
b) Generation of Digital Elevation Model (DEM) and Triangular Irregular Network (TIN) using ArcGIS software.
c) Develop a two-dimensional(2D) hydrodynamic model of the lake using HEC-RAS hydraulic software
d) Conducting Sensitivity analysis of the developed hydrodynamic model
e) Determining the hydraulic parameters such as Water levels, Depth of water, Velocity of flow and Bed shear stress in the lake.

STUDY AREA

2.1 Location

Dal and Nigeen lake in Srinagar city of Jammu and Kashmir is considered for the present study. Dal lake is a Warm monomictic second largest urban lake in the region is located at a Latitude of $34^0$4'30"N to $34^0$9'0"N and Longitude of $74^0$49'30"E to $74^0$53'0"E.

2.2 Topography

Dal and Nigeen lake comes under Zabarwan mountain valley situated in foothills of Shankaracharya hills having catchment area 311.00 sq.kms surrounded by hills on three sides and one side with Srinagar city. The average surface elevation of the lake is 1583.37m and Water depth ranges from maximum 5.77 to minimum 0.43m. The Maximum length and width of the lake is 7.20km and 3.00km respectively and the total surface area of Dal lake is 21.00 sq.kms.

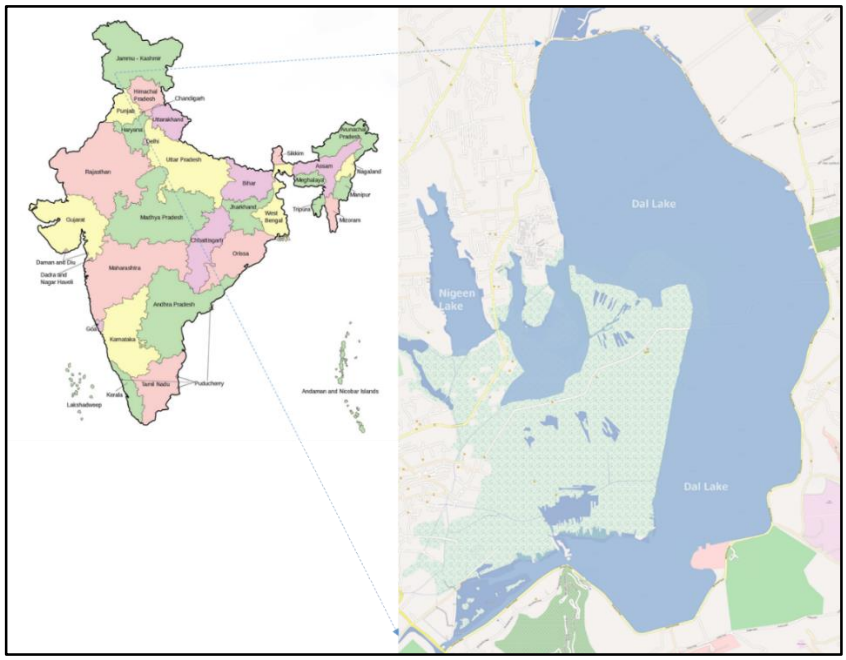

Figure 1 : Location map of Dal-Nigeen lake in Jammu & Kashmir

2.3 Geology

Various studies have been conducted on the origin of the lake. One such study indicates that, the lake is formed by remnants of post-glacial lake which has undergone drastic changes in size over number of years, whereas the other study describes it as fluvial origin from the flood channel of Jhelum river. Lithologically, various rock types have been discerned namely igneous, metamorphic and sedimentary rocks. Dal lake area comes under zone-V of seismic zoning map of India.

2.4 Drainage

The lake is open drainage lake fed by four perennial flow streams namely, Telbal Nallah, Boutkal Nallah, Peshpaw Nallah and Marekshaw Nallah out of which 80% of the inflow is contributed from Telbal Nallah alone and remaining 20% from all other streams. The Lake has 2 Outlet streams namely Amir Khan Nallah and Dal gate Nallah. Dal gate is controlled by Weir and lock system.

METHODOLOGY

3.1 Data Collection

Digital Elevation Model (DEM) of 10 m resolution for the study area is obtained from the National Remote Sensing Center (NRSC), Hyderabad to delineate the catchment area and stream network and LandSAT-8 satellite image of 30 m resolution is obtained from the United States Geological

Survey (USGS) to prepare the LULC map of the study area. Daily rainfall of study area and daily discharge data of four perennial streams namely Telbal nallah, Boutkal nallah, Peshpaw nallah and Marekshaw nallah which contribute flow to the lake is collected for a period of 2001 to 2014 from the Lake and Waterways Development Authority (LAWDA) of Jammu & Kashmir. Bathymetry survey of both Dal and Nigeen Lake is conducted over a grid size of 100m x 100m.

Table 1 : Description of data and Source of the data

Sl No.	Data type	Source	Description
1	Digital Elevation Model	National Remote Sensing Center, Hyderabad	CartoSAT DEM of 10 m resolution
2	Satellite image	www.earthexplorer.usgs.gov	LandSAT-8 Satellite image of 30 m resolution
3	Soil data	www.fao-org/soils-portal/en	Soil map of Food and Agriculture organization of UN in1: 150000 scale
4	Precipitation data	Lake and Waterways Development Authority (LAWDA)	Daily precipitation data of Dal lake catchment area is obtained for a period of 14 years from 2001 to 2014.
5	Stream inflow discharge data	Lake and Waterways Development Authority (LAWDA)	Daily discharge of 4 perennial streams such as Telbel nallah, Boutkel nallah, Preshpaw nallah and Marekshwa nallah are obtained for a period of 14 years from 2001 to 2014.
6	Topography of Dal lake	Bathymetry data	Bathymetry survey is conducted with a grid size of 100 m X 100 m for entire the total Dal – Nigeen lake area.

3.2 Data map preparation

The catchment area of Dal lake is delineated and the stream network map is prepared using the Digital Elevation Model. Various input data maps that were required in hydrodynamic model like water depth map, contour map with interval of 0.5m, triangular irregular network maps are generated from the data obtained from bathymetry survey in GIS platform. LULC map of the study area is generated using the satellite image of 30 m resolution. Daily rainfall data of the study area and discharge data of four perennial streams contributing to Dal lake were analyzed. The maximum observed flow was found to be 59.27 m^3/s at Telbal nallah which contributes 80% of inflow to the lake and remaining flow is from Peshpaw nallah, Boutkal nallah and Merakshaw nallah. The outputs obtained from multi-satellite precipitation data based hydrological modelling have been used for the calibrated hydrodynamic model and outputs have been analysed.

3.2.1 Soils

According to the Food and Agriculture Organization of the United Nations (FAO) of United States of America, the catchment area of Dal lake has two type of soil categories namely Be79-2a which constitutes for about 60% of the catchment area and I-B-U soil classification covering 40% pf the study area.

3.2.2 Rainfall & Climate

Dal lake is open drainage, shallow warm monomictic lake with an average annual rainfall of 750mm. Inflow to the lake is also contributed from the spring sources and snow melt from surrounding hills also contribute in large quantity to the lake during summer season (Figure *4*).

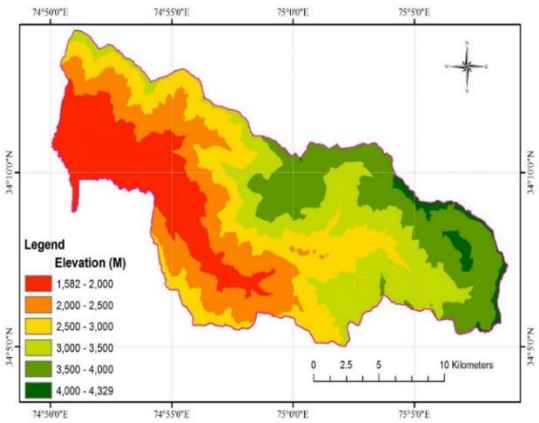

Figure 2 : Digital Elevation Model (DEM) of Dal-Nigeen lake catcment area.

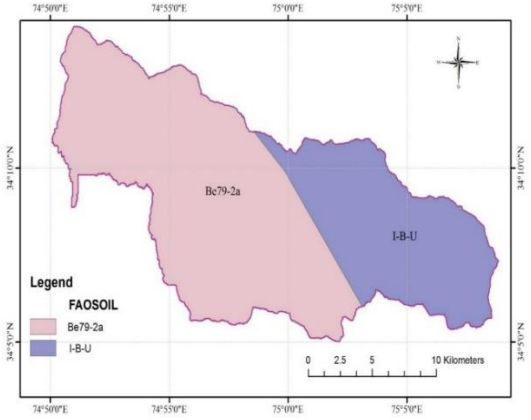

Figure 3 : Soil map of Dal – Nigeen lake catchment area in Jammu & Kashmir

Dal lake area has a humid subtropical climate. This area is cooler than rest of the India due to its high elevation and northern position, winters are cool with an average day time temperature of 7^{O}C with freezing temperature at night and summers are warm with July day time average temperature of 31^{O}C. Highest temperature recorded is 38.3^{O}C and lowest temperature recorded is -20^{O}C.

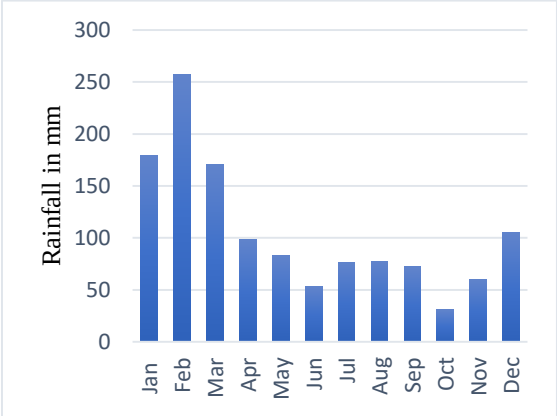

Figure 4 : Average rainfall chart of Dal - Nigeen lake area

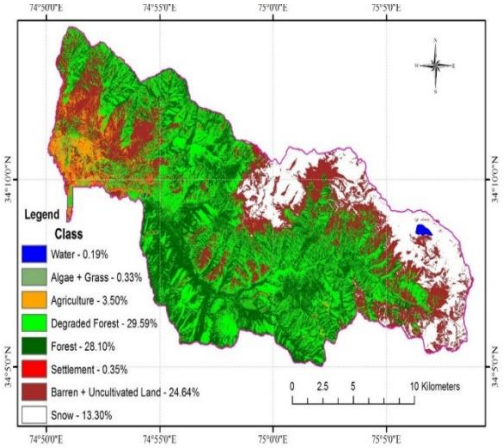

Figure 5 : LULC map of Dal - Nigeen lake catchment area in Jammu & Kashmir

3.2.3 Land Use - Land Cover

Land use is an important signature of watershed that derives the infiltration, erosion and evapotranspiration. Major Land use classification of the Dal lake catchment area are degraded forest and barren & uncultivated land which covers 54.23% of the area and contributes to the sediment deposition in lake and sewage & industrial effluents from the urban settlement also contribute in sediment deposition to the lake. Other land use classifications are agriculture, plantation, mixed forest, orchards, lake vegetation, evergreen forest and open water (Figure 5).

3.3 Bathymetry survey

Knowledge of Lake Morphometry provides critical information for understanding and managing lakes and impoundments. Bathymetry provides maximum and mean depth of lake which are necessary for understanding lake stratification and functioning of biological and chemical dynamics in stratified and mixed systems. The information on lake area combined with depth provides knowledge of lake volume, which combined with hydrological data, allows for calculation of hydraulic residence time.

Another important factor in managing lakes and impoundments is knowledge of the sediments. Sediments have the potential to strongly influence the chemical properties of the water column through various diagenetic processes. Sediments can be especially important in impoundments because of the high trapping efficiency of lakes and their obvious location on riverine systems. High rates of sediment accumulation can lead to premature filling of impoundments with considerable loss in usable capacity for storage.

3.3.1 Bathymetry methodology

The Dal-Nigeen lakes are shallow water lakes hence "Shallow water bathymetric survey system" is used. This method is useful to measure the silt accumulation in the lake and helps in understanding the topography of lake beneath the water. The system consists of consumer grade GPS, depth sounding instrument and GIS software. End result of the bathymetry survey is Water depth and Contour map of the lake. The Dal-Nigeen lake area is digitized using ArcGIS software with 100 x 100m grid position (Figure *6*). Survey is conducted using handheld GPS and sounding rod on a 20.0 ft long Deep Vee hull wooden boat (Shikara) is used as data collection platform (Figure *7*).

Individual depth readings were converted into bathymetric contour map. Fancier interpolation technique namely "Inverse Distance Weighting" was employed to create smooth surface of the bottom of Dal-Nigeen lake from the individual depths. The depths are classified at regular interval and presented in Figure. The deepest elevation of 1577.21m and shallowest elevation of 1582.56m from mean sea level is observed. 3D analyst routine in GIS software is used to create a Triangular Irregular Network (TIN) of the data points.

Area-Depth-Elevation curves of Dal - Nigeen lakes were plotted by taking depth in X-axis and Area and Capacity in Y-axis. These curves give incremental area and capacity between two elevations. Water spread area, water storage volume, average depth, minimum depth and maximum water depth of Dal-Nigeen lakes and wetland areas of Dol-Demb were calculated by plotting the curve and using GIS tool. Details are listed in the Table 2. Depth tends to be higher in upper part of Dal Lake as well as Nigeen lake and the shallower near the banks and center of the lake.

Table 2 :Bathymetry survey details of Dal - Nigeen lake and Dol Demb area

Location	Minimum Depth (m)	Maximum Depth (m)	Average Depth (m)	Area (Sq Kms)	Volume (MCM)
Dal Lake	0.43	4.55	2.49	13.91	26.86
Nigeen Lake	0.75	5.77	3.26	0.75	1.99
Dol Demb	0.59	3.95	2.27	2.40	4.37

3.4 Application of two-dimensional hydrodynamic model

The present study of hydrodynamic modelling of Dal-Nigeen lake is carried out using HEC-RAS Ver.5.0.1 with two-dimensional capability for assessing the behavior of lake and sedimentation. 2D hydrodynamic model is used since the overflow locations were unknown and flow takes place both in longitudinal and transverse direction. The study used two types of boundary conditions such as flow hydrograph and normal depth are used as the upstream and downstream boundary conditions. Flow hydrograph boundary condition is considered where the flow from the four streams enters the lake and energy slope that is used for distributing the discharge over the cells are specified. The normal depth boundary condition is used at the outlet points of the lake where water is flowing outside the lake. In order to ensure the stability of the model, the time step was estimated according to the Courant–Friedrichs–Lewy condition

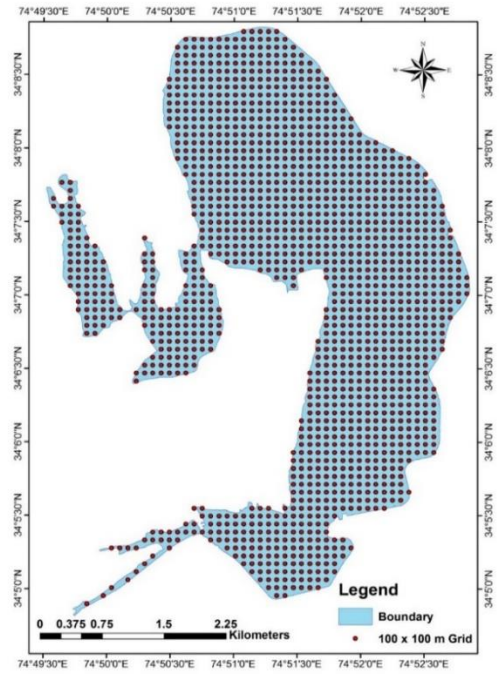

Figure 6 :: 100 x 100-meter grid of Dal and Nigeen Lake for Bathymetry Survey

Figure 7 : Bathymetry survey support boar (Shikara)

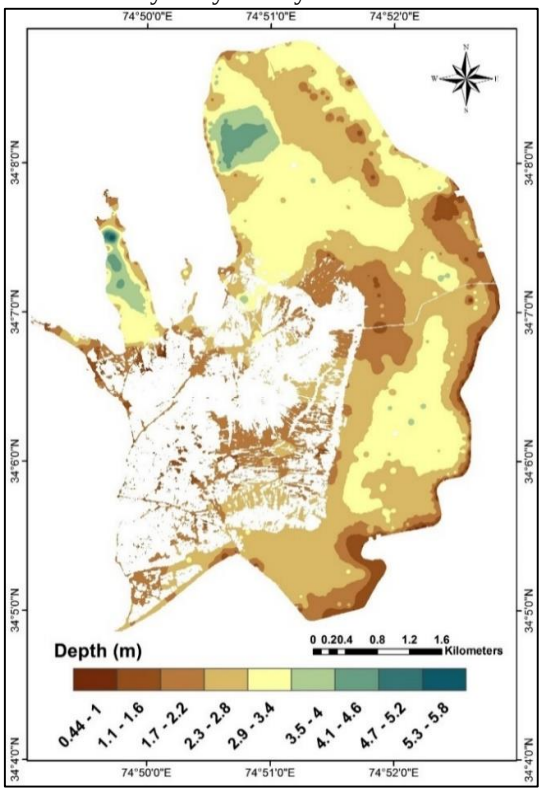

Figure 8 : Interpolated Bathymetry map (msl) generated using shallow water bathymetric mapping system

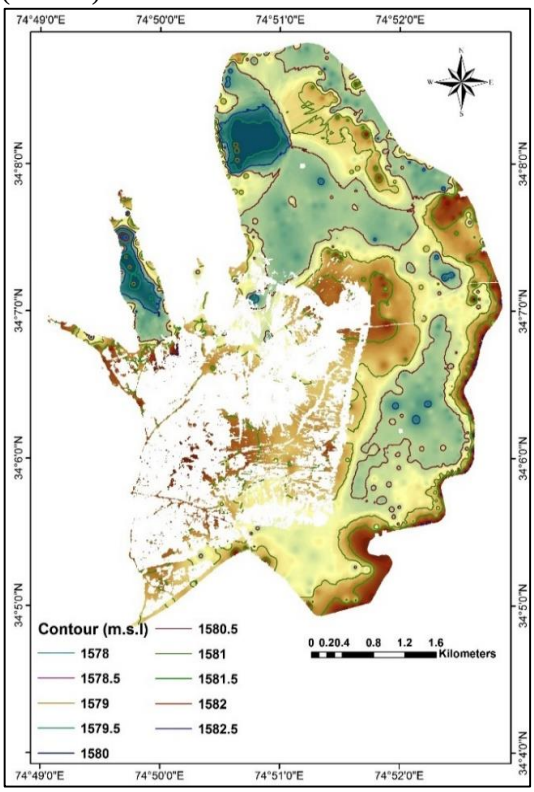

Figure 9 : Contour map with interval of 0.5m generated using interpolated bathymetry map

3.4.1 Scenarios Created

Hypothetical dredging scenarios were created based on the dredging depth and disposal of dredged material at the different locations of Dal lake area. For each hypothetical scenario, hydrodynamic model studies were carried out.

Figure 10 : Scenario-1&2 (With present Dal lake condition

Figure 11 : Scenario-3 (With dredging depth of 3.5m)

Figure 12 : Scneario-4 (With dredging depth of 3.5m)

Figure 13 : Scenario-4 (With dredging depth of 3.5m)

Table 3 : Scenarios created for Hydrodynamic Studies

Scenario Number	Dredging Depth (m)	Dredged Material Placement Area	Figure No.
1	---	Nil	10
2	---	Nil with GPM Data	10
3	3.50	Dole Demb	11
4	3.50	Lake+Dole Demb	12
5	3.50	Dole Demb Adjacent	13

3.4.2 Model Calibration

Calibration is the process of adjusting the parameters so that the simulation of model will give a result to an acceptable accuracy in comparison with the observed data. Calibration of the model is carried out by varying the Manning's roughness coefficient 'n' in such a way that, hydraulic variables such as velocity, water surface elevation, water depth determined by simulating the model approximately matches with the observed hydraulic variables in the lake.

3.5 Results & Discussion

Hydrodynamic model simulation is carried out for the existing condition of the lake without disturbing the physical properties of lake (Figure *10*) and hypothetical scenarios were created i.e., dredging lake bed for a depth of 3.5 m and various combinations of depositing the dredged material in lake as artificial island, depositing in adjacent area of lake and depositing in water logged Dol demb area (Figure *11* to *Figure 13*) represents the five hypothetical scenarios created under extreme hydraulic conditions. Result obtained from HEC-RAS hydrodynamic model for various scenarios have been illustrated in *Figure 14* to *Figure 16*.

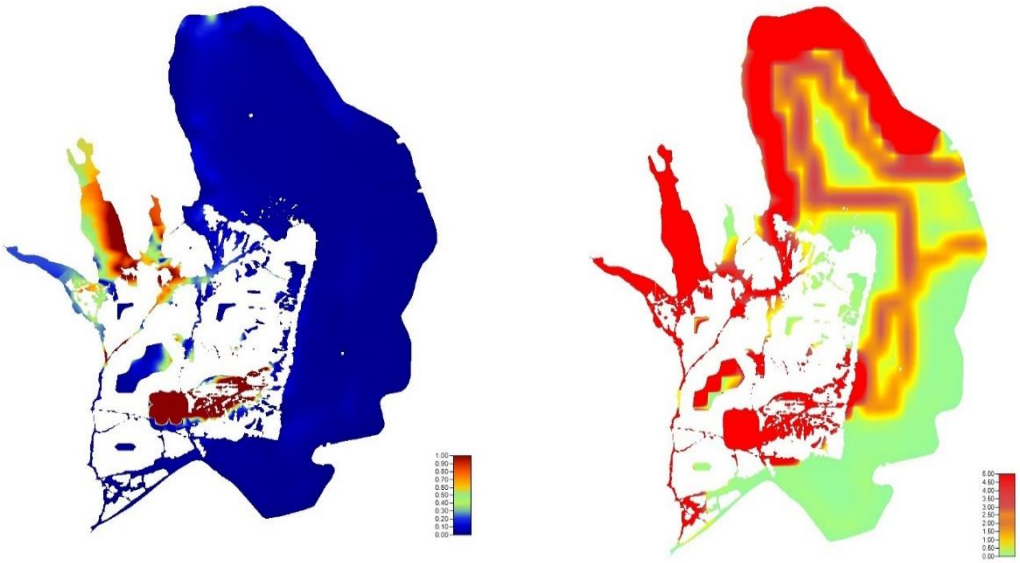

Figure 14 : Velocity (m/s) and Shear stress (N/m^2) distribution in the Lake area for Scenario.3

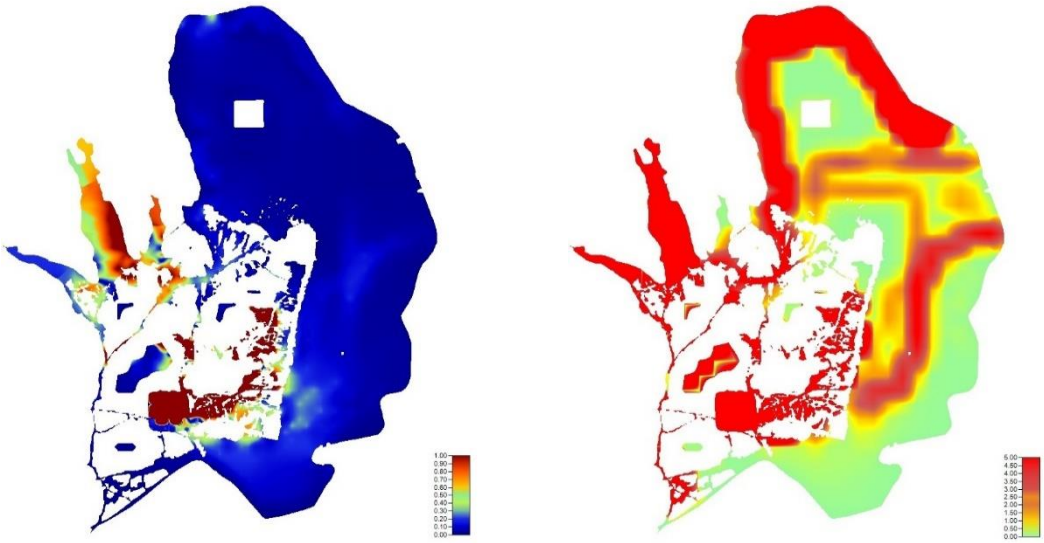

Figure 15 : Velocity (m/s) and Shear stress (N/m^2) distribution in the Lake area for Scenario.4

Scenario-1 shows the existing condition of the lake and Scenario-2 created for existing lake condition with rainfall data obtained from multi-satellite precipitation technique (GPM) and calculating the runoff of all the inflow streams shows similar results compared to scenario-1. These two scenarios were used for calibration and validation of the model. Hypothetical scenario-3 with dredging depth of 3.5m in lake and placing the dredged material in the dol-demb area shows higher velocity near outlet and Nigeen lake inlet reaches and bed shear stress seems to be

high in the lake (Figure 14). Hypothetical scenario-4 created with dredging depth of 3.5 m and placing the material partially in lake as artificial islands and remaining in dol demb area also shows higher shear stress near inlet and outlet reaches of the lake indicating the transportation of sediments in the lake (Figure 15). Minimum velocity and bed shear stress was observed in hypothetical scenario-5 (Figure 16) which involves depositing dredged material along the adjacent areas of lake.

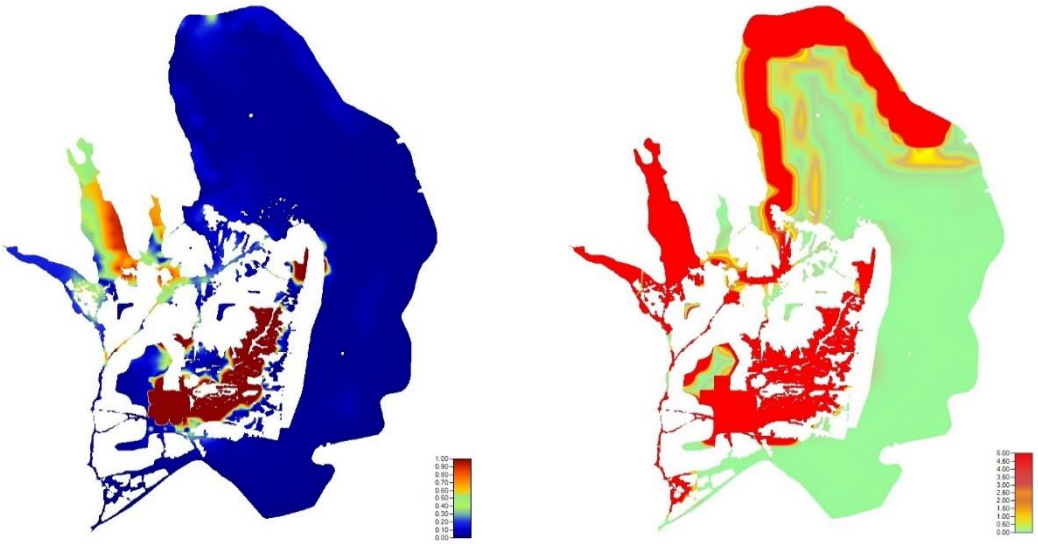

Figure 16 : Velocity (m/s) and Shear stress (N/m^2) distribution in the Lake area for Scenario.5

3.6 Conclusion

Following conclusions were drawn from the hydrodynamic studies carried out on Dal and Nigeen lake; Minimum shear stress was observed in scenario-5 for a maximum dredging depth of 3.5 m, dredging depth beyond 3.5m is not found suitable for dredging. Depositing the dredged material in the Dal lake area in the form of artificial islands in scenario-4 generally creates higher bed shear stress in the lake. Scenario-5 has been observed as the best scenario among all the three hypothetical scenarios considered since the observed velocity of water in the lake is almost equal to zero and the bed shear stress is minimum in the lake. Discharge data obtained from hydrological modelling using HEC-HMS using multi-satellite precipitation data (GPM) are tested in scenario-2 and results obtained are coherence with scenario-1, which shows multi-satellite precipitation technique can be adopted in data scarce regions like Dal-Nigeen lake. Overflow from Dal lake is not observed even after considering the extreme inflows from intense precipitation in the catchment area and creating artificial islands in the lake.

From the study carried out, it was observed that, HEC-RAS two-dimensional model is a reliable tool in conducting sediment analysis of the lake. It is also observed that HEC-RAS model can be used in data scarce regions by integrating hydrological model such as HEC-HMS and using the multi-satellite precipitation data like GPM and TRMM. Calibration of the model shows that the HEC-RAS hydrodynamic model is extremely sensitive to the manning's roughness coefficient, hence 'n' value has to be ascertained and incorporated in the model. Catchment area treatment plan has to be developed to minimize the soil erosion from the catchment. The methodology of analysis and management of sediment in natural lake may be adopted for better management of the sediments in the reservoirs.

REFERENCES

Baldassarre, D., Schumann, G., & Bates, P. (2009). A technique for the calibration of hydraulic models using uncertain satellite observation of flood extent. *Journal of Hydrology, 367*((2-4)), 276-82.

Brunner, G. (2016). *"HEC-RAS River Analysis System User's Manual, Version 5.0"*. Institute for Water Resources, U.S Army Corps of Engineers. Davis, California: Hydrologic Engineering Centre.

CISMHE. (n.d.). *Environmental Management Plan - Dam Break Analysis & Disaster Management Plan.*

Hagen, E., & Lu, X. (2011). Let us create flood hazard maps for developing countries. *Nat.Hazards, 58*, 841-3.

Haq, M. (2012). Techniques of remote sensing and gis for flood monitoring and damage assessment : a case study of Sindh provincem, Pakistan. *Egypt Journal of Remote sensing space sciences, 15*(2), 135-141.

Kumar, S. (2017). *Development of Lake Hydrodynamic Model - Case Studies.* Indian Institute of Technology Roorkee, Water Resources Development & Management, Roorkee.

Ranzi, R. (2011). *Critical review of non structural measures for water related risks in Kulturisk. Delft, The Netherlands.*