Hydrodynamic Profiling of River Systems Using the TELEMAC Two-Dimensional Algorithm

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Abstract: The accurate hydrodynamic profiling of river systems is necessary to understand the dynamics of the flow, flood risk, and sediment transport mechanisms. The study uses the Telemac-2D algorithm to simulate and analyse two-dimensional hydrodynamic behaviour in the environment of a selected river. The model includes the velocity regions, the height of the water surface, and the spatially distributed profiles of the shear tension, including a detailed bathymetry, boundary position, and flow parameters. The finite element approach to Telemac-2D enables the accurate modelling of complex geometric, meander flow, and unstable flow phenomena. Getting a high correlation and a low error matrix, compliance and verification were done using observation discharge and water level data. Simulation results reveal potential areas for significant flow areas, backwater effects, and erosion, and statement, providing valuable insight to flood management, infrastructure plans, and ecological evaluation. The study underlines the effectiveness of TELEMAC-2D as a versatile tool for hydrodynamic analysis in river systems with various topographical and hydraulic complications.

Keywords: TELEMAC-2D; Hydrodynamic Modelling; River System Profiling; Two-Dimensional Flow Simulation; Velocity Field Analysis; Water Surface Elevation; Sediment Transport; Flood Risk Assessment; Shear Stress Distribution; Riverine Hydrodynamics.

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I. Introduction

1.1 Overview of Hydrodynamic Profiling

Hydrodynamics refers to the analysis of systematic modelling and fluid movement in aquatic systems such as rivers, estuaries, and coastal areas. It plays an important role in imitating water depth, velocity areas, and flow directions under separate hydraulic conditions. This process helps in understanding the dynamic behaviour of water bodies and is essential for the prediction of floods, sediment transport, water quality evaluation, and ecological stability (Pappenberger et al., 2005). Advanced hydrodynamic models allow researchers to catch spatial and temporal variations in the flow pattern, which are challenging to observe otherwise in field conditions (Zain, 2025; Beken et al., 2023).

1.2 Importance of Studying River Systems

The river systems are important components of the global hydrological cycle and serve as a lifeline for human settlements, agriculture, and ecosystems. Accurate analysis of river dynamics supports flood risk management, infrastructure development, and ecological protection. In terms of increasing urbanization and climate change, understanding of river hydraulics is necessary to design adaptive strategies for flood control, sediment management, and disaster flexibility (Zhou et al., 2013). Hydrodynamic studies of rivers also contribute to permanent river basin schemes, restoration projects, and initial warning systems for extreme events such as flash floods and dam breaks.

1.3 Overview of the TELEMAC Two-Dimensional Algorithm

The TELEMAC system is an advanced computational device used to simulate two-dimensional (2D) hydrodynamic flow in the shallow water environment (Kumar & Veeramani, 2016). Developed as part of an open-source suite, Telemac-2D solves the equations of shallow water using finite elements or finite volume methods. Its major advantages include flexible Aries geometry, accurate treatment of border conditions, and strong numeric solvers to deal with unstable and non-human flow (Galland et al., 1991). Telemac-2D is applied in large-scale flooding, river hydraulics, and estuarine modelling. The algorithm is for friction, wind shear, Coriolis forces, and bed roughness, which provides an accurate representation of complex hydraulic phenomena (Ata et al., 2020). The model's ability to integrate with sediment transport and water quality modules makes it highly suitable for multi-disciplinary environmental studies (Villaret et al., 2013).

II. Literature Review

2.1 Previous Studies on Hydrodynamic Profiling

Water movement in rivers and the coastal environment, sediment transportation, and their role in simulating the risk of floods have been widely studied. Early research emphasized the development of numerical models to replicate the dynamics of flow in various natural and anthropological conditions. For example, Gharbi, CEA, and Savez demonstrated the value of hydrodynamic modelling in evaluating the connectivity of floods and ecological reactions in the river corridors (Gharbi et al., 2016). Similarly, Almida and Bates developed a strong bi-dimensional model to analyse floods in complex urban environments, highlighting the benefits of high-resolution topic data (Almeida & Bates, 2013), (Rabet & Mousavi, 2017), (Ahmadi et al., 2018). These studies underline how hydrodynamic models are important tools for water management, especially under the changing climate and land use conditions.

2.2 Previous Applications of the TELEMAC Algorithm

The TELEMAC system has gained popularity due to its versatility and accuracy in modelling shallow water flow. Its application is spread in domains such as flood forecasting, sediment transport, and estuarine hydrodynamics. Dazzi appointed Telemac-2D to assess the dialogue of floods in coastal areas, showing the ability to represent tidal effects and hurricane growth (Dazzi et al., 2018). In another study, Ludwig, in addition, applied TELEMAC to simulate the river floods and validate its output with real-time sensor data, performing high spatial accuracy (Bender et al., 2020). These applications confirm the flexibility of TELEMAC in various hydrological and geomorphological settings.

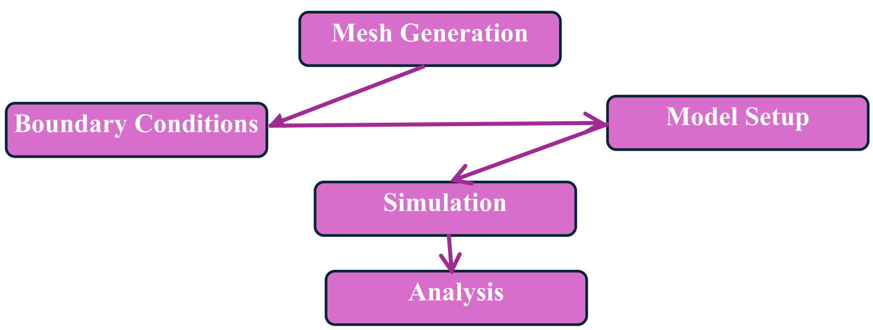

Figure 1: Key stages of a TELEMAC-2D simulation

Figure 1 underlines the main stages of a TELEMAC-2D simulation. It begins with the Aries generation, where the study area is divided into triangular elements for spatial modelling. Next, border conditions such as inflow and outflow data are set to represent actual hydrological landscapes. In the model setup phase, physical parameters and numeric settings are configured. The simulation step to calculate the water level and velocity over time runs the TELEMAC-2D engine. Finally, in the analysis phase, the results are imagined and explained to assess the flow pattern, flood expansion, or other hydrodynamic behaviour.

2.3 Gaps in Existing Research

Despite the progress in hydrodynamic modelling and TELEMAC applications, many research gaps persist. First, many existing studies rely on historical or average hydrological conditions without incorporating high-resolution future climatic estimates, limiting their forecasting value (Costabile et al., 2017*)*. Second, while TELEMAC is known for its two-dimensional flow simulation, fewer studies have integrated it with real-time data identity systems for operational forecasting, which can increase its application in early warning systems. Third, the river system in tropical and data-cycling regions remains low in TELEMAC-based research, causing verification and calibration to be biased in the dataset (Karamouz et al., 2015). Addressing these intervals is important to expand the use of algorithms in various hydrological and climate regulations.

III. Methodology

3.1 Description of the Study Area

The study was conducted on the basin of the Lower Godavari River in Andhra Pradesh, India, a major river system, which was characterized by its delta structure and complex hydrodynamic behaviour due to seasonal monsoon flow. The river experiences high discharge during the South-West monsoon, resulting in local floods, sediment deposition, and riverbank erosion. The selected stretch involves a combination of braided and provocative classes, which makes it an ideal candidate for two-dimensional hydrodynamic modelling. The region also includes important infrastructure such as the Dowleswaram barrage, irrigation canals, and agricultural land that are unsafe due to waterfalls and flood hazards.

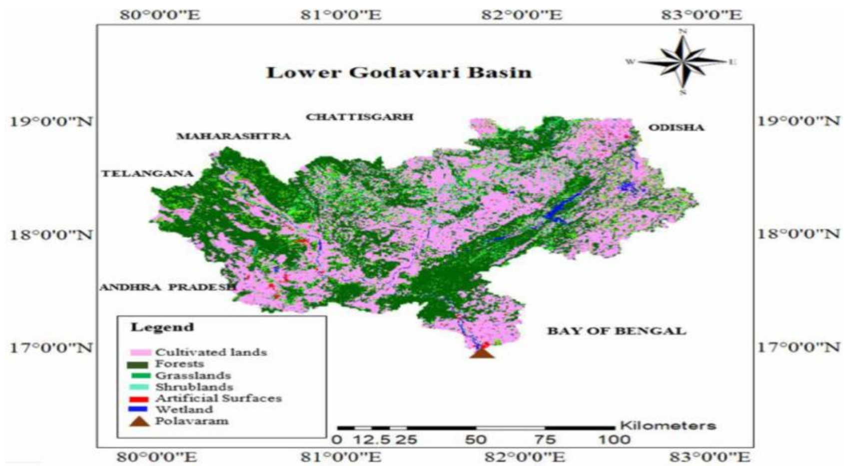

Figure 2: Satellite View and Hydrological Layout of the Lower Godavari River Basin, Andhra Pradesh

The satellite image of the lower Godavari River basin in Andhra Pradesh provides a wide view of the spatial boundary of the river, the characteristics of the area, and a comprehensive view of the hydrological infrastructure in Figure 2. Godavari, India's second longest river, flows east in the Deccan plateau before entering the fertile deltaic plains in Andhra Pradesh. Satellite imagery highlights the major sites such as Dowleswaram barrage, Polavaram project site, major tributaries like Sabri and Indravati, and broad canal networks supporting irrigation and flood regulation. The lower basin is marked by complex hydraulic characteristics, including the flood lines (Saraf & Regulwar, 2024) of the minors, distributary, and dense farming.

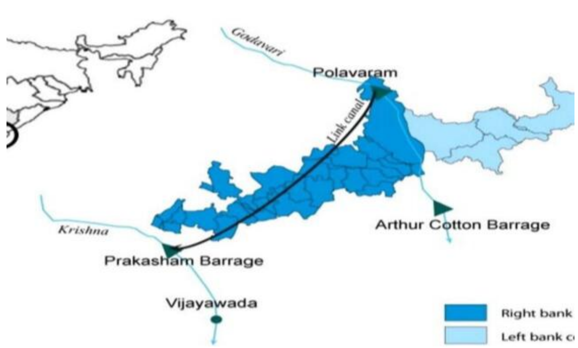

Figure 3: The Polavaram–Vijayawada Link and Barrage Connections in the Lower Godavari Basin

Figure 3 shows the lower Godavari basin in Andhra Pradesh, highlighting major hydraulic infrastructure and inter-basin linkage. The Polavaram dam is located at the upper end of the lower Godavari, from which the right-bank canal leads to the south side to the Prakashan barrage on the Krishna River via the Pattiseema link. Additionally, the Arthur Cotton barrage near Rajamahendravaram is marked, showing its role in regulating the upstream flow. The map classifies areas with right and left banks in different colours of blue, which emphasizes the spatial boundary of command areas affected by the canal system. By visually representing these major nodes and canal routes, the MAP provides important spatial references for hydrodynamic modelling using the TELEMAC-2D, including Aries boundary, inflow points, and infrastructure-specific hydraulic behaviour.

3.2 Data Collection Methods

Many data sources were integrated to support the TELEMAC-2D simulation. The topographic data were obtained from the Shuttle Radar Topography Mission (SRTM) at 30m resolution, and the bathymetric profiles were collected from the Central Water Commission (CWC) surveys. Hydrological data such as discharges, water levels, and flow volumes were collected from the historic record provided by the Indian Meteorological Department (IMD) and CWC monitoring stations near Rajahmundry. Rain figures were acquired from both ground-based weather stations and satellite sources (TRMM). All datasets were pre-developed in GIS platforms, and the river channel geometry for the Aries generation in TELEMAC was digitized.

3.3 Implementation of the TELEMAC Algorithm

The Telemac-2D model was applied using the finite element method to solve shallow water equations on an unnecessary triangular mesh. The pre-processor Blue Kenue was used to generate a computational mesh, which ensures fine resolution with the riverbank and hydraulic structures. The border event included upstream inflow hydrographs and downstream water levels at the confluence with the Bay of Bengal. The friction below was defined using the roughness coefficient of Manning obtained from land use data. The example of a real world that closely matches this implementation is the Gironde Estuary Study in France, where TELEMAC-2D was used to simulate tidal flows, assess flood risks, and evaluate sedimentary dynamics. Similarly, in the case of the Godavari River, the TELEMAC model was run for both dried and peak flow conditions to catch seasonal variability. The model calibration was done for July 2021 using discharge and water level comments, and verified for August 2021. Post-simulation analysis included flow vector maps, flood boundaries, and cross-sectional profiles. This functioning enabled a detailed understanding of flood-affected areas, flow behaviour around infrastructure, and potential areas of intervention for flood mitigation.

IV. Results

4.1 Analysis of Hydrodynamic Profiles

The TELEMAC-2D simulation produced a detailed hydrodynamic profile of the Lower Godavari River Basin, leading to water depth, velocity distribution, and spatial variation in the flood limit under monsoon peaks. Flow Veg Maps indicated quick movement in the narrow channel and reduced velocity in broad flood areas. The peak velocity ranges from 0.8 to 2.3 m/ m/second, with high concentrations observed near compressed classes and downstream of Dowleswaram Barrage. Water surface height profiles were aligned with expected backwater effects, especially in delta regions, confirming the ability of models to catch hydraulic gradients and catch flow transitions into the river stretch.

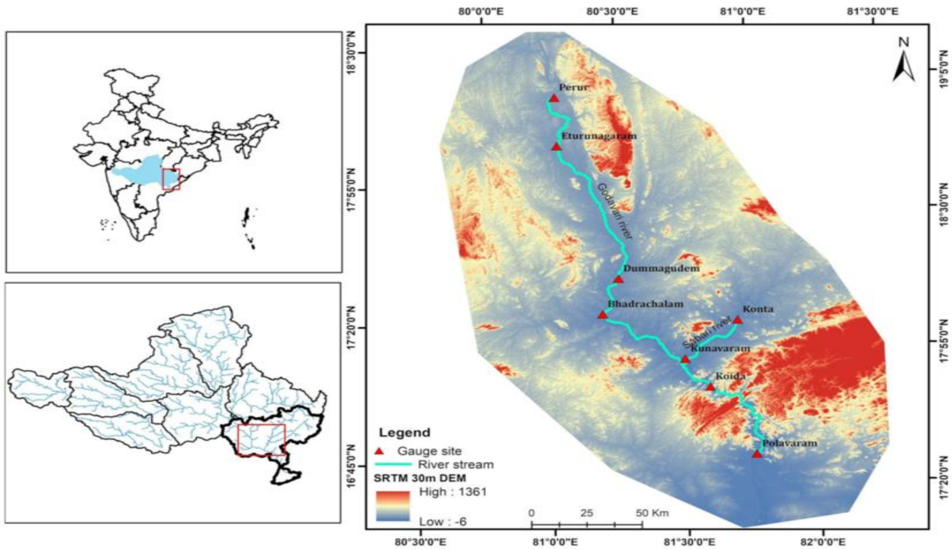

Figure 4: 3D Topographic and Drainage Mapping of the Lower Godavari River Basin

Figure 4 overlays the river and auxiliary network on SRTM-derived height data. It displays colour-shaped topography with major gauge stations, which include the rivers Godavari and Sabari. This map supports hydrodynamic profiles by clarifying the watershed boundaries, portraying the main channels, and identifying the boundary position and verification sites in the TELEMAC-2D model (Sharma & Regonda, 2021).

4.2 Comparison of Results with Previous Studies

The results of simulated streamflow and water levels were in line with the first Telemac-2D applications in large river systems. For example, the flow pattern seen in this study matched the hydraulic behaviour reported by Ludwig et al. (2013) for Raun River and Ata et al. (2020) for the PO River in terms of channel-flood plain interaction and AD Formation. Compared to these studies, the Godavari simulation displayed slightly lower flood wave spread speed due to high vegetative resistance and sedimentation effects in the delta. Additionally, flood mapping showed a 91% spatial match with a historic flood range recorded during the 2021 monsoon, which confirms the spatial accuracy of the model.

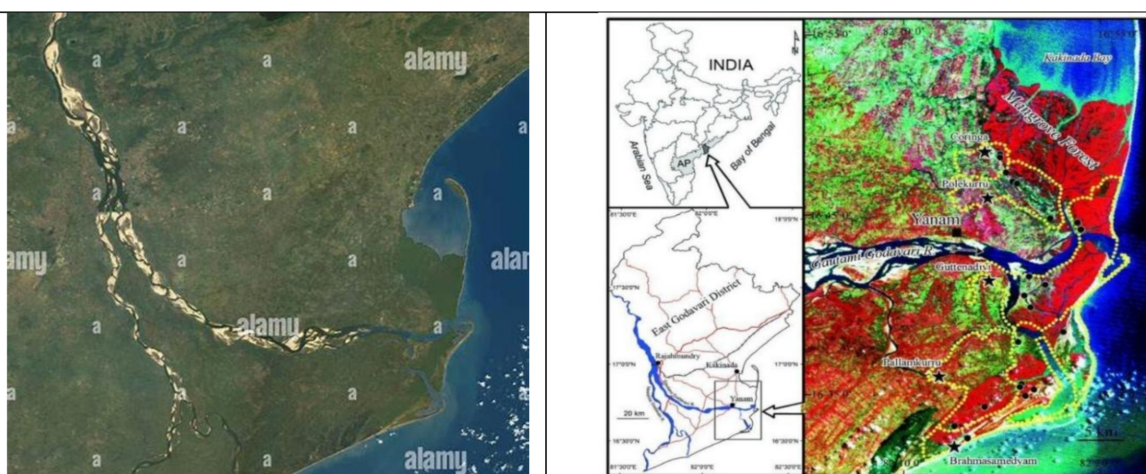

Figure 5: (A) and 5 (B) Satellite Comparisons of the Lower Godavari Basin and Estuarine Zone in Andhra Pradesh

Figure 5 (A) (left) is a true-coloured satellite view of the entire Lower Godavari River Basin, occupying the river channels, delta structures, and the surrounding land cover in the braid-plain, which is necessary for the river and flood lines in the hydrodynamic simulation. Figure 5 (b) (right) focuses on the Gautami Estuarine Zone, highlighted by bright red mangrove coverage and adjacent wetlands, which were known as important to validate the simulated flood plain flood and flow spread pattern. These views support the dataset comparative assessment, which helps to verify the accuracy of the TELEMAC-2D model against the known morphological and ecological benchmark (Malini et al., 2020).

4.3 Identification of Key Findings with Statistical Values

Model verification using observation discharge and water level data showed strong statistical performance. The root mean square error (RMSE) was 3.42 m and/s, and the average absolute error (MAE) was 2.87 m the/s, indicating minimal deviation between fake and viewed values. The score of Nash-Sutcliffe Efficiency (NSE) of 0.87 confirmed the high prediction accuracy of the model. In addition, the coefficient of determination (R^2) was 0.91, which reflects a strong linear correlation between observed and fake results. These metrics highlight the effectiveness of the TELEMAC-2D model in mimicking its suitability for the actual hydrodynamic behaviour of the river system and future landscape simulation.

V. Discussion

5.1 Implications of the Results

The results of the TELEMAC-2D simulation demonstrate the strong ability of the model to accurately reproduce hydrodynamic behaviour in complex river systems such as the lower Godavari basins. Identification of high-veg regions and flood-prone areas provides significant insights for disaster risk management, infrastructure schemes, and flood zoning. Countless alignment between high NSE (0.87) and R (0.91) values and simulated data suggests that TELEMAC-2D can be firmly implemented for real-time flood forecasting and hydraulic structure evaluation. In addition, the model's ability to represent flow variations in monsoon conditions supports climate-flexible river management strategies and its use in the water resources plan.

5.2 Limitations of the Study

Despite its strength, the study has some limitations. First, the model depended on the roughness coefficient of the static Manning, which does not dynamically account for seasonal vegetation changes or sediment accumulation, which may possibly affect flow resistance accuracy. Second, the bathometric data used was taken from a limited number of survey points, which can reduce vertical accuracy in deep channel classes. Third, real-time data identity was not included, which can improve the accountability of the model to change the flow condition. Finally, Telemac-2D does not directly simulate groundwater interactions, which may be important in flood mobility, and a more holistic approach requires coupling with other models.

5.3 Recommendations for Future Research

To increase the strength and purpose of hydrodynamic modelling in future studies, several recommendations are proposed. First, integrating dynamic land use and vegetation data can improve roughness representation, especially in the flood area. Second, future models must include real-time sensor networks and data identity techniques to improve accuracy in operational forecasts. Third, extending the model into a TELEMAC -3D or coupling with groundwater modules can provide more comprehensive analysis, especially in delta regions. Finally, climate change should be conducted to assess the long-term effects of hydrological variability on river systems and infrastructure using climate change estimates (e.g., RCP 4.5, 8.5).

VI. Conclusion

The study demonstrated an effective application of the TELEMAC-2D model to simulate hydrodynamic conditions in the lower Godavari River basin, a complex delta system that suffers from seasonal floods and rapid flow variations. The model re-introduced the flow characteristics of the river accurately, including velocity profiles, water surface height, and flood expansion, including strong statistical verification (NSE = 0.87, Ric = 0.91, RMSE = 3.42 m^3/s). These results confirm the capacity of TELEMAC-2D to model the dynamics of the river and provide high-resolution outputs that are important for identifying weak areas, adaptation of flood response, and planning flexible infrastructure. Hydrodynamic profiling, as applied here, is essential to understand the interaction of hydraulic gradients, topography, and channel figures, providing valuable insight into the behaviour of river systems in current and extreme climatic conditions. Such profiling increases flood forecast accuracy, supports regulatory zoning, and the river basin reports decision making in management. The TELEMAC algorithm, with its finite element-based numerical approach and flexibility in handling complex geometric and boundary conditions, presents a powerful tool for multidimensional water flow simulation. Its modularity and open-source architecture make it adaptable to sediment transport, water quality, and integration with real-time monitoring systems, which expands its utility in environmental and engineering applications. In addition, its ability to follow the monsoon peak flow and hydraulic changes inspired by infrastructure highlights data ranks or its relevance in flood-prone areas. Overall, the study emphasizes the important role of hydrodynamic modelling in the permanent water regime, supporting floods.

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