

WATER CIRCULATION AND SEDIMENT TRANSPORT MODELING IN FETHIYE BAY FOR DREDGING OPERATIONS AND POLLUTION CONTROL

Bilge Karakutuk, Middle East Technical University, karakutuk.bilge@metu.edu.tr
Gozde Guney Dogan, Delft University of Technology, G.G.DoganBingoel@tudelft.nl
Ahmet Cevdet Yalciner, Middle East Technical University, yalciner@metu.edu.tr
Aysen Ergin, Middle East Technical University, ergin@metu.edu.tr

INTRODUCTION

Through the scope of this study, the changing water circulation and sediment transport patterns in Fethiye Bay, located in the Mediterranean Sea in southwestern Türkiye (Figure 1a), are investigated with different dredging activities for pollution control. The low circulation in Fethiye Bay (Figure 1b), which is a semi-enclosed shallow basin, affects in-bay pollution. Simultaneously, the direct or indirect discharge of liquid and solid wastes into the sea is further increased by inadequate waste management infrastructure and storage facilities for wastewater, sewage, chemical waste, and solid waste in shipyards. Therefore, the bay suffers from sediment and material accumulation in areas where sufficient water inflow and outflow are not observed due to seasonal changes (METU OERC, 2011).



Figure 1 - a. Location of Fethiye Bay b. Paths of streamflow in Fethiye Bay region, red arrows indicate current velocity measurement locations (Base map taken from Google Earth, 2023)

The Muğla Metropolitan Municipality and the Ministry of Environment, Urbanization, and Climate Change previously carried out numerous studies in this region, but the results have yet to be limited. Numerical simulations were performed using different hydrodynamic models such as FVCOM and MIKE-3D (Akbasoglu, 2011; Akdeniz, 2018), to demonstrate the general flow pattern (water exchange with the open sea) in Fethiye and Göcek bays under Coriolis force, tidal and wind effects using the

previously available data. These studies conclude that although wind-induced water circulation is important in the bay, the tidal effect is more dominant and the effect of in-bay circulation is minimal. Dredging is one of the potential solutions to the excessive shoaling and pollution problems of the bay and different dredging scenarios can be considered in this regard. This study is conducted for a full understanding of flow fields in Fethiye Bay under different dredging scenarios and to determine the optimum dredging area and depth to improve the in-bay circulation and water exchange between the inner bay and outside basin. Moreover, numerical modeling has been employed to examine the relationship between circulation and sediment transport induced by wind, tides, waves, and inflow from streams.

METHODOLOGY

Essential data including bathymetry, space-time variable wind input, tidal time series, and up-to-date current measurements are gathered for data preparation prior to constructing the numerical model. Using Akbasoglu (2011) and DENAR (2022) report prepared by Muğla Metropolitan Municipality, bathymetric measurements of 2007 and 2022 are compared and sediment erosion and deposition areas are identified.

Time series of hourly average wind speed and direction are obtained from Fethiye and Kızılada (an island ~5km to NW of Fethiye Bay) stations to reflect the wind condition in the region (General Directorate of Meteorology Database MEVBİS, 2023). After a comparison of the measured wind data at Fethiye and Kızılada stations, the data in Kızılada with higher wind speeds is selected to be used in the simulations. The time series of the tidal wave was obtained from the tide gauge measurements database of European Commission Joint Research Center (ISPRA, 2023) for the Marmaris station which is the nearest available station to Fethiye Bay in the database. The hourly wave characteristics (wind wave and swell) are obtained from the Climate Data Store (Copernicus Climate Change Service - C3S, 2023).

With the support of Muğla Metropolitan Municipality (DERINSU, 2023) current velocity measurements are performed at two selected points near Sovalye Island (Figure 1) to analyze the water exchange between the bay and the open sea. The measurements are conducted from 1 April to 30 June 2023. The magnitude and the velocity along the water column with 2m intervals at hourly intervals are collected. The measured data is used for calibration of the numerical model and comparison of the modeling results.

For the modeling phase, Delft3D, an open-source numerical modeling system developed by Deltares, allows hydrodynamic calculations by taking into account wave and current effects in coastal areas and consists of various modules for different purposes such as hydrodynamic flow, sediment transport, morphodynamics, water quality, and ecology (Hsu et al., 2008) have been selected. To observe the wind and tide-induced flow patterns with the effect of waves, Delft3D-FLOW and Delft3D-WAVE modules have been run together with two-way (online) coupling. This way, the combined effect of wind, tide, and waves on the water circulation and their non-linear interactions and effect on the consequent sediment transport have been taken into account.

The model is calibrated and validated by using the measured bathymetry, current magnitude/direction at the two measurement points, time series of wind and tide data, and wave conditions of the region. The wave characteristics from the deep water to the model area are computed by the Delft3D-WAVE. In the model calibration, continuous data of wind, tide, and wave in the one-month duration (April 2023) are used and the computed current magnitudes/directions are compared with the measured data at the specified two points for the respected water column. In this process, wind stress coefficients, roughness parameters, tidal components, boundary conditions, and wave spectrum parameters of the model are selected to represent the real-life behavior in the model for the study region. The optimal time step and mesh resolution are determined to find a balance between simulation stability and computational efficiency.

RESULTS AND DISCUSSIONS

The two most recent bathymetry measurements in Fethiye Bay (2007, Figure 2a and 2022, Figure 2b) are compared and the change of water depth in the bay is calculated. The analysis shows significant water depth decrease, mostly in front of the stream mouths.

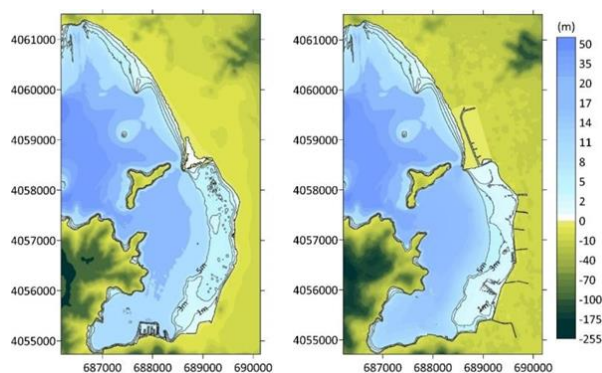


Figure 2 - a. 2007 bathymetry map (METU OERC, 2011) b. 2022 bathymetry map (DENAR, 2022)

Especially at the mouth of the Murt River and the mouth of the T2 Channel, the decrease in water depth reached about 3 meters. This is an important shoaling problem not only for circulation and pollution but also for boat traffic and navigation. Considering these problems, dredging has emerged as one of the important solutions. However,

the dredging operations must be performed based on the outcomes of the detailed numerical investigation to identify the parameters that cause deposition areas, determine the most suitable dredging depth and locations, and evaluate the sediment transport and circulation level in the bay. In this direction, different dredging scenarios are generated considering the sediment deposition areas near the mouths of the streams and those are simulated by Delft3D using different wind, tide, and wave data representing the daily, weekly, monthly, seasonal, and annual conditions of the region. For every scenario and respectively selected simulation condition, the water exchange rates between the inside and outside of the bay are calculated and cumulative erosion/deposition areas are determined. It is observed that long-term sediment input to the bay caused deposition and decrease of water depth locally, affected circulation pattern, and consequently influenced the water quality in the bay. The model results indicate that the water exchange near Sovalye Island between the inner and outer bay is not strong enough and needs to be increased by possible solutions such as dredging operations due to proper dredging plan and prevention of poorly controlled sediment and contaminant input through the rivers. In conclusion, before the costly dredging operations that are planned for the bay, the optimum dredging scenario is determined through this study under numerical models considering the in-bay water circulation and sediment transport, with a cost-effectiveness analysis.

KEYWORDS

Fethiye Bay, circulation modeling, sediment transport, dredging operations, Delft3D model

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