Chapter 5
Simulation of the Hydrodynamic Regime of Aquaculture Development Zones Within Binh Dinh, Vietnam

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Abstract Binh Dinh province is suitable for fishery, such as brackish seafood, because the province has a long coastline and many lagoons. However, its brackish seafood farming has been impacted by sea level rise, drought and salinization caused by climate change. For example, both low and high salinity negatively affect the growth of many brackish populations. In this research, the hydrodynamic regime and salinity spreading in the coastal areas are estimated based on the MIKE 21 model, a numerical model. The model is calibrated against tide levels and salinity records from 1st June 2010 to 11th June 2010. The validation period is from 1st June 2016 to 11th June 2016. The modelled output shows good agreement with the observed data at Quy Nhon station, Binh Dinh. The values of the Nash–Sutcliffe efficiency coefficient and correlation coefficient are very good, over 0.87. The verified model parameters are important data for the future salinity forecasting projects under climate change.

Keywords Hydrodynamic · Salinity · MIKE 21 · Binh Dinh

5.1 Introduction

Binh Dinh is a coastal province in South Central Vietnam. The province is in a very important strategic position in the socio-economic development of the Central region. It is also an important gateway to the Central Highlands, Southern Laos and Northeastern Cambodia, Thailand, and into the East Sea. The province has a

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134 km long coastline interspersed with many lagoons and bays. There is a wide range of aquatic resources in Binh Dinh. Its waters have biodiversity and are rich in aquatic resources with hundreds of species. For example, there are 500 species of fish. Marine shrimp has 20 species. Therefore, in recent years, Binh Dinh has focused on the ocean economy and fisheries (Development, B.D.D.o.A.a.R.: Binh Dinh Fisheries Development Master Plan To2020 2020).

Binh Dinh has promoted the development of freshwater and brackish-water aquaculture Producers (Producers, V.A.o.S.E.a.: Binh Dinh: the sustainable development of brackish shrimp farming (in Vietnamese) xxxx). The environmental conditions, such as salinity, play a very important role in the growth of brackish-water and salt-water aquaculture (Tibblin et al. 2012). If the salt concentration in the water exceeds the allowable threshold, it will negatively impact on aquaculture. In many fish farms, the change in salinity has killed a large number of aquatic animals (Boamah et al. 2020). In addition, climate change in Vietnam has made salinity spread stronger in recent years. It directly impacts aquatic ecosystems as well as fish farming. Therefore, a hydrodynamic model and a salinity map for the aquaculture environment are necessary for planning for aquaculture development in Binh Dinh.

There are two main kinds of models for hydrodynamic processes, such as physical models and numerical models. In terms of the physical models, they can represent the phenomenon because they use laboratories with precise measuring instruments. Therefore, this method can represent mechanisms and phenomena that are difficult to observe in real conditions. However, it is very expensive to install and maintain the physical model. Numerical models refer to the use of computer codes based on the theoretical foundations and the most reliable conditions and scenarios. In recent decades, computing technologies have been developed significantly, which allows the numerical models to correctly simulate hydrodynamic problems. The numerical models usually use the finite element method, boundary element method, finite difference method, and finite volume method. They can be classified into different spatial dimensions, such as one-dimensional (1D) models and two-dimensional (2D) models.

This study uses a 2D numerical model because the model has been widely popular in simulating the hydrology and water quality processes of rivers, estuaries, and oceans. One example of a 2D numerical model is MIKE21. Danish MIKE 21 is developed and maintained by the Danish Hydraulic Institute. It is a two-dimensional model to simulate the hydrodynamics, transport of pollutants, thermal plumes, and water quality parameters of rivers, estuaries, and oceans (Gao et al. 2018; Zhang et al. 2020; Kim et al. 2017; Remya et al. 2012).

5.2 The Study Area

Binh Dinh province, shown on Fig. 5.1, located in Vietnam South Central Coast, has diverse types of terrain and a dense system of streams and rivers. The province is influenced by the tropical monsoon climate. Climate in Binh Dinh is typified by the humid

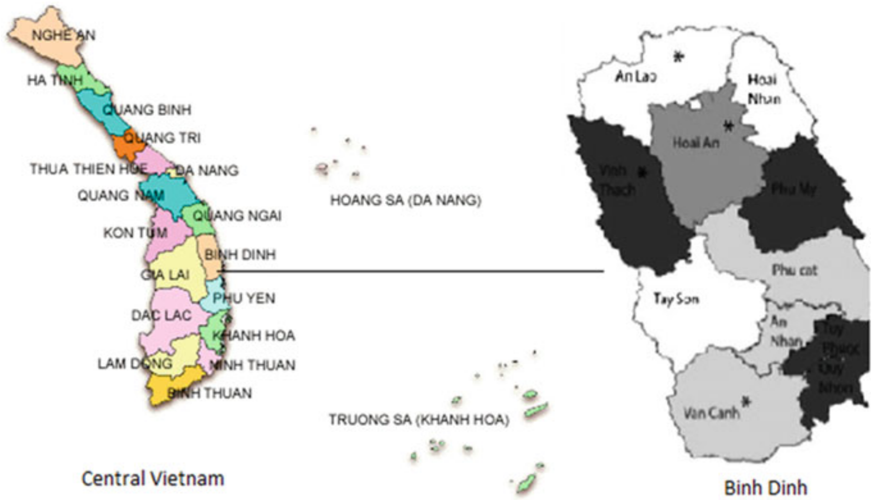

Fig. 5.1 Binh Dinh province

tropical monsoon. Due to the complexity of the terrain, the monsoon winds change direction and intensity when reaching the province. The rainy season runs from September to December. In mountainous regions, there is an additional rainy season lasting from May to August under the influence of the rainy season in the Central Highlands. The dry season in Binh Dinh lasts from January to August. The annual average rainfall in mountainous districts is 2000–2400 mm, and in coastal regions it is 1751 mm. The rainfall tends to decrease gradually from mountainous regions to coastal areas and from the northwest to the southeast. Rivers in the Binh Dinh province are derived from the high mountains of the eastern slope of the Annamite Mountains. Rivers are small and short, having steep slopes and low silt concentration.

Binh Dinh has a 134 km coastline, a 2500 km^2 territorial sea and a 40,000 km^2 exclusive economic zone. Along the coast of Binh Dinh, there are some estuaries, such as Tam Quan, De Gi and Quy Nhon. Moreover, it has many lagoons, such as Tra O lagoon, covering an area of about 1200–1400 ha, Thi Nai lagoon (5060 ha), De Gi lagoon (1600 ha) and the Tam Quan estuary, covering an area of about 300 ha. The Thi Nai lagoon is known as a nursery for endangered aquatic species. The Tam Quan estuary is suitable for brackish water aquaculture such as shrimp and crab farming, fish and oysters. In addition, there are about 2283 ha for brackish water aquaculture, such as white leg shrimp and black tiger shrimp.

In recent years, salinity intrusion has negatively affected aquaculture activities in Binh Dinh province. Salinity intrusion is one of the main reasons for the tons of dead fish in the Tuy Phuoc district, Binh Dinh province.

Salinity intrusion is observed in estuaries, land and sea in Binh Dinh. It is affected by river flows, tidal regimes, river bed slopes and topography. Because tidal dynamics can lead to turbulent mixing based on saltwater transportation, tides are considered one of the most powerful sources of mixed fresh and saltwater. Therefore, it is the main source of saltwater intrusion. The tidal regime is unequal at the study site. At Quy Nhon station, the number of tidal days lasts from 18 to 22 days. The high tides last longer than the low tide. The variation in high and low tidal amplitudes is negligible. During May and June, the tidal regime at Thi Nai lagoon is similar to that in Quy Nhon. The heights of the tidal peaks in both locations do not change significantly.

5.3 Methodology

MIKE 21 is a proven computer program available worldwide to estimate flows, waves, sediments and ecology in rivers oceans, coasts and estuaries in two dimensions. The spectral wave (SW) module, the hydrodynamic (HD) module and the Advection–Dispersion (AC) module of MIKE 21 are adopted in this study. The SW module can be used to simulate wind generated waves (Xiang et al. 2019). The HD module is the foundation part of the MIKE 21 model, and generates the hydrodynamic input for other modules of MIKE 21, such as the AD and Water Quality modules (Warren and Bach 1992). The AD module can simulate suspended substances, including salinity and temperature, in an aquatic environment (Warren and Bach 1992).

5.3.1 The Spectral Wave (SW) Module

The SW module is developed to estimate the growth, decay and transformation of wind based on waves in offshore and coastal areas. The SW module has a wide range of formulations and parameters. Two formulations are available: a directional decoupled parametric formulation (Holthuijsen et al. 1989) and a fully spectral formulation (Young 1999). The first is also suitable for the nearshore zones, while the second one is used for the offshore areas. In this study, the SW module is used to analyse the growth of waves under wind action. The wave boundary condition set includes wave height, wave crest and wave direction.

5.3.2 The Hydrodynamic (HD) Module

The HD module can calculate flows and distributions of temperature and salt, which are influenced by different functions and boundary conditions. The module is a 2-dimensional model and based on the numerical solution of the two-dimensional incompressible Reynolds averaged Navier–Stokes equations with the assumptions of Boussinesq and hydrostatic pressure. It uses a cell-centred finite volume method to model the spatial discretisation of the primitive equations.

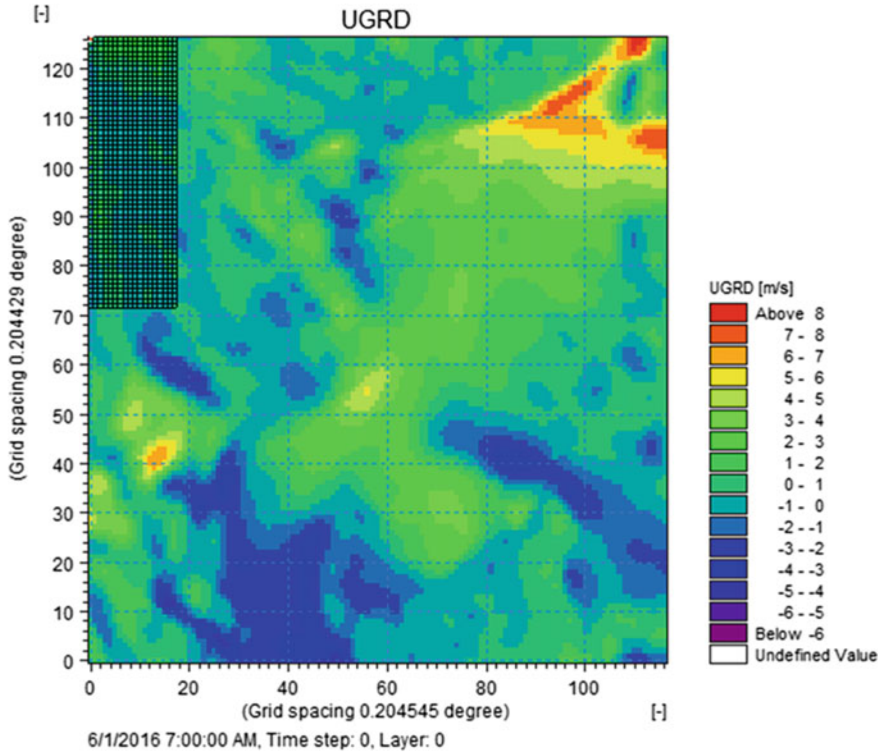

Fig. 5.2 Wind data

5.3.3 The Advection–Dispersion (AD) Module

The AD module can simulates suspended substances, including salinity and temperature based on a two-dimensional form of the QUICKEST finite difference scheme (Warren and Bach 1992). The module uses points of the grid covering the study site to estimate the concentration of the substance. Currents and water depths at the points are generated by the HD module. Other input data are substance concentrations at outfalls and boundaries as well as discharge quantities at outfalls.

5.3.4 The Detailed Bathymetry

Bathymetry plays an important role in hydrodynamic estimation based on Mike 21. Bathymetric data is obtained and processed in an XYZ format from old bathymetric maps before it is added to the Mesh Generator tool in MIKE Zero. The unstructured finite-element model domain has 29,607 elements and 17,397 nodes. The study

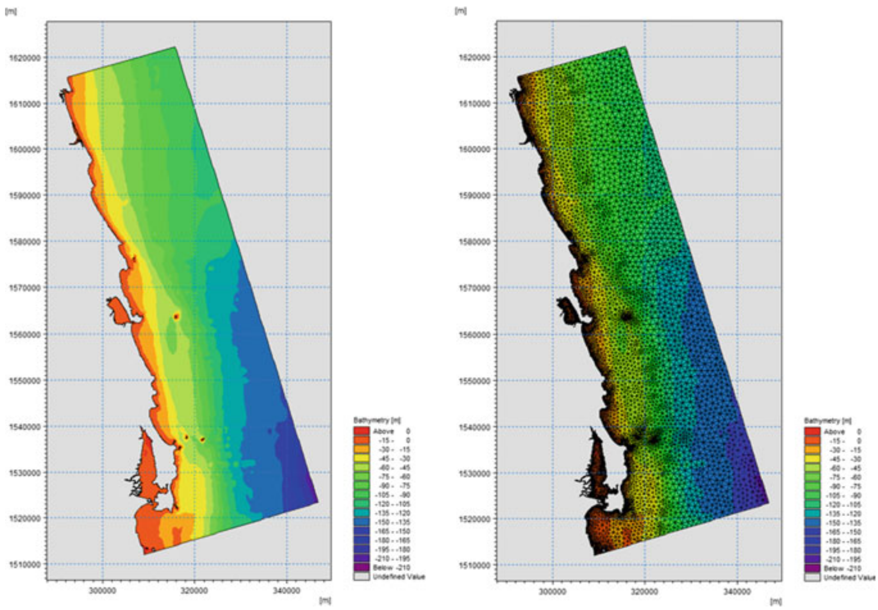

Fig. 5.3 The bathymetry (left) and computational mesh scheme (right) of the study area

carefully considers the trade-off between computational time and numerical stability. When the number of elements increases, the model reduces the simulation time step but requires more numerical effort. The bathymetry and grid resolution are shown on Fig. 5.3.

5.3.5 Input Data

The input data for the SW module has wind data and boundary conditions provided by the Southern Institute of Water Resources Research, Vietnam. The boundary conditions include average wave height, wave period and wave direction.

For the AD module, the input data includes the salinity value and temperature. The salinity value is 0 PSU for flows from rivers in the area. Salinity in the coastal waters is divided into 3 regions with different salinities: offshore (35 PSU); inshore (32 PSU) and near shore, lagoon, bay (30 PSU). The temperature over the study site is settled at 30 °C.

In terms of the HD module, the input data consists of wind speed, wave height, boundary condition, viscosity coefficient and roughness coefficient. Wind data is observed in the coastal area and the offshore areas in Binh Dinh. The wind data is shown on Fig. 5.2. Wave data is calculated by the SW module. Boundary conditions include sea-level conditions and river discharges. Sea-level conditions are

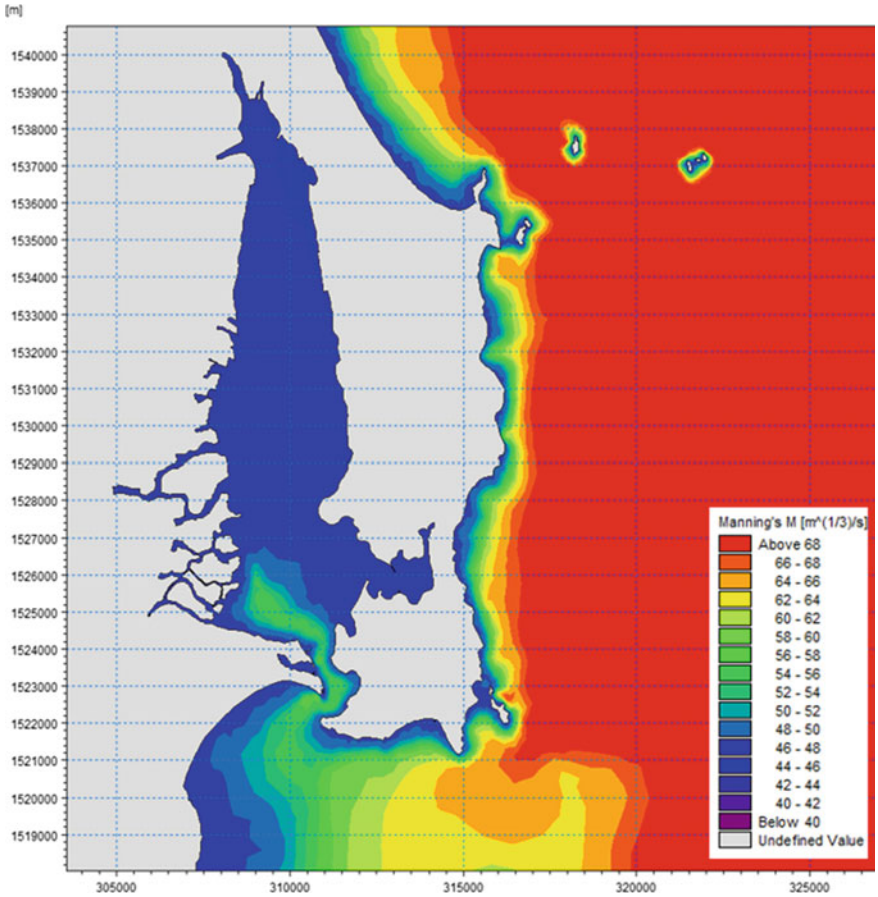

Fig. 5.4 The Manning's roughness coefficients at the study site

provided by the Southern Institute of Water Resources Research, Vietnam and hourly discharge, shown on Fig. 5.5, is recorded at the Con River, Ha Thanh River, Lai Giang River and La Tinh River. The Manning's roughness coefficients built into the whole grid domain represent each seabed topography and region (Fig. 5.4).

5.4 Model Evaluation Criteria

The model parameters are determined by the trial–error method. The selected parameters allow the model calculated results being close to the observed data. The simulation results will be evaluated through the Nash–Sutcliffe efficiency coefficient (E) and correlation coefficient (R).

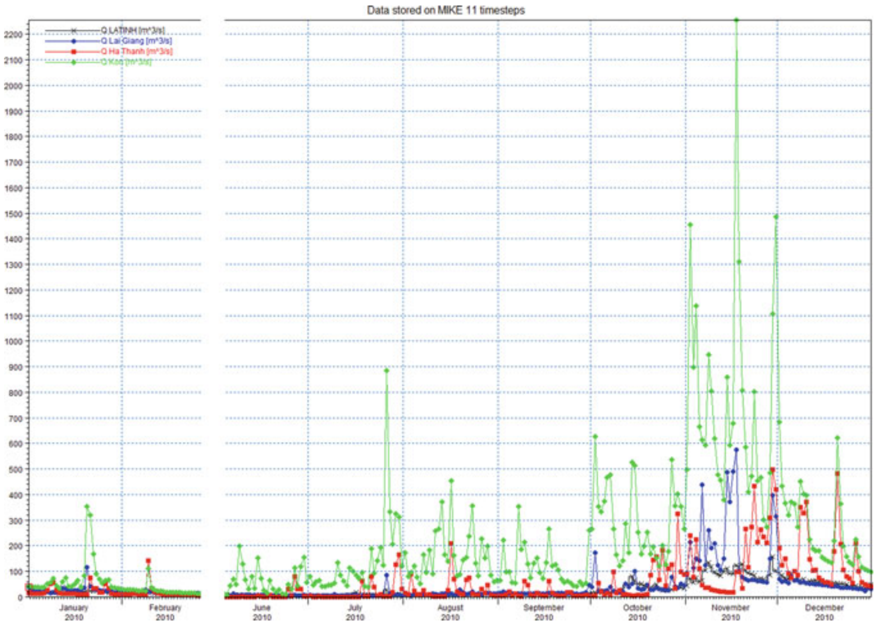

Fig. 5.5 Hourly discharge recorded at Con River, Ha Thanh River, Lai Giang River and La Tinh River

$$E = 1 - \frac{\sum_{i=1}^{n} \left(X_{obs,i} - X_{model,i}\right)^2}{\sum_{i=1}^{n} \left(X_{obs,i} - \overline{X}_{obs}\right)^2} \tag{5.1}$$

$$R = \frac{\sum_{i=1}^{n} \left(X_{obs,i} - \overline{X}_{obs}\right) \cdot \left(X_{model,i} - \overline{X}_{model}\right)}{\sqrt{\sum_{i=1}^{n} \left(X_{obs,i} - \overline{X}_{obs}\right)^2 \cdot \left(X_{model,i} - \overline{X}_{model}\right)^2}} \tag{5.2}$$

5.5 Model Calibration and Validation

5.5.1 Model Calibration

The HD and AD modules are calibrated against the observed tide levels and salinity concentration at Quy Nhon station. The calibration period was from 1st June 2010 to 11th June 2010. The calibration process aims to adjust and select parameters of the HD and AD modules (Table 5.1).

Table 5.1 Model evaluation criteria

Evaluation criteria	Very good	Good	Satisfactory	Unsatisfactory
Nash	> 0.85	0.65–0.85	0.5–0.65	< 0.5
R	> 0.95	0.85–0.95	0.75–0.85	< 0.75

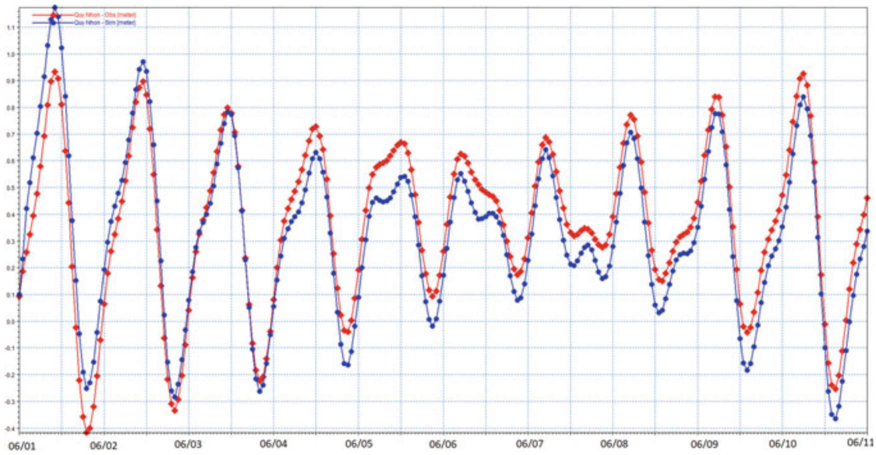

Fig. 5.6 Calibration results for tide levels from 1st June 2010 to 11th June 2010

The results show a good agreement between the modelled data and the observations shown on Figs. 5.6 and 5.7 and Table 5.2. The highest amplitude difference between the modelled and observed tidal levels is about 0.25 m. The highest observed tide level is 1.16 m, while its counterpart is 0.92 m. Similarly, the modelled and observed salinity concentration values share the same trend in this station, as shown on Fig. 5.7. In addition, the evaluation criteria shown in Table 5.2 indicate that the model performance is very good. These indicate that the calibrated parameters are reasonable. However, the model usually underestimates the tide levels.

5.5.2 Model Validation

The model is validated by another set of data on the tide levels and salinity concentration collected in June 2016 for Quy Nhon station.

Figures 5.8 and 5.9 and Table 5.3 compare the modelled values and observations from 1st June 2016 to 11th June 2016. The modelled tide levels and the observed data show a very good fit. The comparison demonstrates the model has the ability to estimate the tide levels on this study side. Therefore, the selected model parameters are useful for future research. In terms of salinity concentration, there are just a few

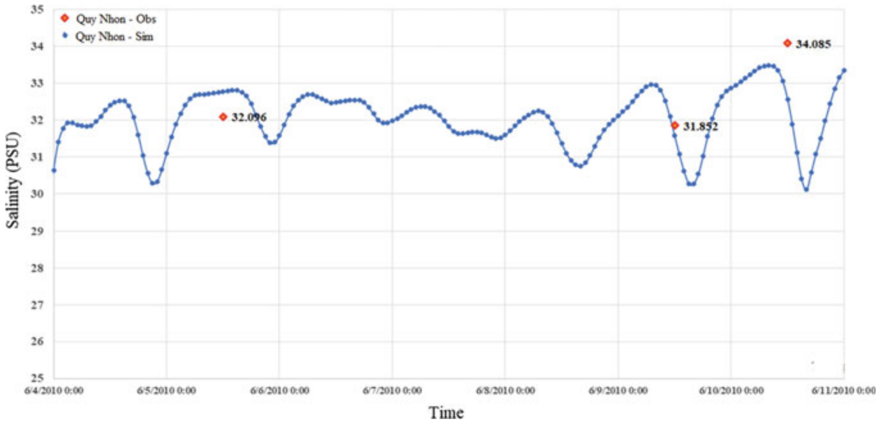

Fig. 5.7 Calibration results for salinity concentration from 1st June 2010 to 11th June 2010

Table 5.2 The calibration performances

Evaluation criteria	Nash	R
Results	0.875	0.950
	Very good	Very good

measured data points, but it is clear that the model can predict the trend in changes of salinity concentration in this station.

In the following, the validated model has the ability to model the impacts of future climatic changes on the hydrodynamic and salinity characteristics of Binh

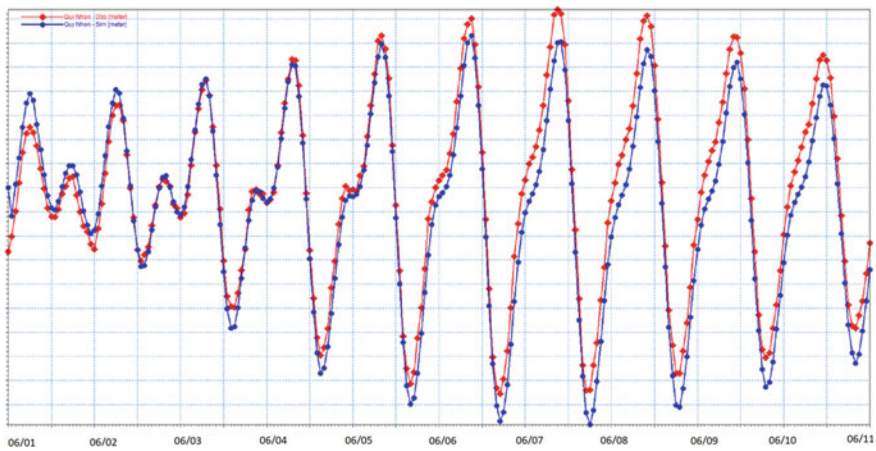

Fig. 5.8 Validation results for tide levels from 1st June 2016 to 11th June 2016

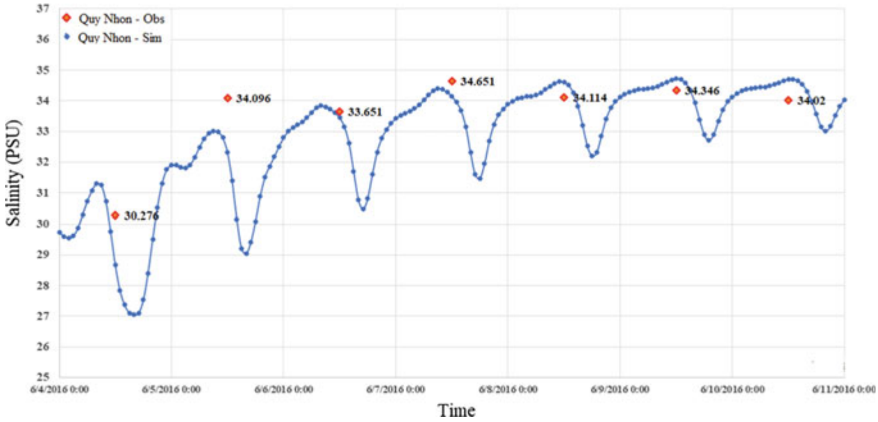

Fig. 5.9 Validation results for salinity concentration from 1st June 2016 to 11th June 2016

Table 5.3 The validation performances

Evaluation criteria	Nash	R
Results	0.931	0.980
	Very good	Very good

Dinh. Moreover, this proposed model can be adopted to estimate different quality prediction scenarios for Binh Dinh.

5.6 Conclusion

Changes in hydrodynamics and salinization caused by climate change have led to significant damage to freshwater aquaculture brackish, threatening the lives of people in the periphery. It is crucial to develop an accurate model to predict the disaster and allow the Government to give necessary response solutions. The study very well evaluates the hydrodynamic regime and the salt propagation based on the Mike 21 model in Binh Dinh province. The model is calibrated and tested in 2010 and 2016. The verified model parameters are important information in developing saline zoning maps, forecasting warnings under the impacts of natural disasters and climate change.

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