BUILDING INTEGRATED TOOLS FOR FLOOD WARNING AND INUNDATION FORECAST OF RIVER BASINS IN KHANH HOA PROVINCE

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Received: 18 August 2023; Accepted: 15 September 2023

Abstract: *In order to strengthen the flood warning and inundation forecasting system in the South Central region, the authors aim to study an integrated tool for flood disaster prevention, pilot application in two main river basins in Khanh Hoa Province. This area often suffers great damage due to the influence of storms and tropical depressions, which can be mentioned as floods in 1980, 1986, 1993, 1998, 1999, 2003, 2009, 2013, and 2016. The tool is the connection of scientific and technical products in automatic monitoring equipment and transmits real-time rainfall, water level data; as input for forecasting and warning models of flood and inundation risks; provides forecast data to users through the WebGIS online platform. The article details how to build an integrated tool for flood warning, inundation forecasting and verifying in a historical flood in 2016. The study has great significance in improving the effectiveness of natural disaster prevention, storm and flood monitoring; optimal and timely support in case of emergency. At the same time, it contributes to the forecasting of Viet Nam's Hydrometeorological Sector.*

Keywords: *Flood warning, inundation forecasting, integrated tools, model, WebGIS, Khanh Hoa.*

1. Introduction

Research into flood forecasting is still an urgent issue today, especially science and technology are increasingly developing, storm and flood forecasting and warning systems are a combination of hydro-hydraulic models, numerical forecasting model, rain forecast radar, satellite, remote sensing, GIS; support to improve the quality of forecast more and more accurately. Among the above methods, the model is considered a very popular tool and has been applied since a long time ago [5], [6], [8], it is a typical method in the forecasting profession, supporting forecasters to issue hydrometeorological warning bulletins. However, the application of simulation models to warn of floods currently has shortcomings, such as it often takes a long time to operate the models and when the results are available, in many cases the flood situation has already occurred, so the warning information is of little or no value.

Today, approaching the explosion of information technology, and technical sciences with the development of IoT monitoring systems and artificial intelligence algorithms, the monitoring and warning of drought, flood and inundation have made significant progress. However, in order to transmit disaster information more timely and effectively, it is necessary to have an intuitive and easy-to-understand system on the Web-based platform so that it can be accessed by all audiences, in line with the trend of digital transformation consistent with the trend of digital transformation [9].

Experimental research on building a real-time integrated flood and drought monitoring and warning system on the WebGIS platform by Tran Anh Phuong et al., provided a system consisting of 3 main components: 1) Observation and monitoring system, 2) Information storage, processing and forecasting system, 3) Information provision and emergency response support

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system. The input of the system is rain data, real-time observed water level and forecast rain data from the global weather forecast model. The drought monitoring system also provides drought indices such as SPI, SWDI,... [9]. The Central Center for Hydrometeorological Forecasting coordinates with the Japan Aerospace Exploration Agency (JAXA) to improve the monitoring and warning systems in managing risks caused by floods at a reasonable cost and practical experience through the application of space-based technology (SBT), information and communication technology (ICT) for the Thao River basin with an area of 48,000 km² in the Hong River system. The activities carried out in the project include correcting rainfall data in river basins via satellite, building an interface system between satellite rain data and flood forecasting, building a flood warning GSWeb; building pilot models, strengthening technology capacity and developing policy guidelines, monitoring and evaluating remote sensing management methods [1]. Another study by the National Center for Hydrometeorology, calculated on 2 main river basins: Gianh river and Kien Giang river (Quang Binh province), Thach Han river and Ben Hai river, Quang Tri Province. Determine thresholds to monitor changes in hydrometeorological phenomena (rainfall data, water level); build rain-water level correlation equations to warn water levels at key locations (main stations) on the river system; apply numerical rain forecasting products of 2 models WRFARW, WRFNM with input being the analysis and forecast fields of 5 global models GEM, GFS, GME, GSM, NOGAPS, evaluate and provide solutions to calibrate quantitative rain forecast data as input for the NAM model to simulate runoff forecasts from rain [7].

A flood warning project in Cao Bang city has achieved the following results: - Developed flooded risk maps of critical areas with an occurrence frequency of 1%, 5%, 10% and Alert levels II and III; - Built 10 flood warning towers at a number of critical locations in Cao Bang city as a basis to warn the flooded depth situation when a flood occurs so that the community can recognize the flooded situation and assist in the direction and prevention of inundation in the city [3]. The project also applies forecast data of the European Center for Medium-Term Weather Forecasting to develop 5-day flood forecasting plans for major rivers in Central Viet Nam under the Science and Technology Program to improve the capacity of meteorological and marine warnings and forecasts and serve the state management of hydrometeorological and climate change in the 2016 - 2020 period. The study proposes to build a set of MIKE software tools in which for the first time MIKE SHE is used in forecasting research in combination with MIKE 11 and MIKE 11-GIS in simulation and calculation, extending the forecast period up to 5 days on some major rivers in the Central Central region (Thach Han, Vu Gia - Thu Bon and Tra Khuc - Ve river) [4].

Realizing that the central coastal area is always the focus of mention in the annual stormy period in our country. The cause of inundation comes from the relationship between "heavy rain - topography". The common characteristics of river basins all originate from high mountains, the upper part of the river is narrow and steep when there is a flood, and the water gathers quickly, rises quickly, and descends quickly. [2] However, the South Central Coast region with lower disaster prevention capacity than others has not yet been invested in disaster warning forecasting systems, especially for floods and inundation. Research for this area is still limited and not really of interest. Meanwhile, the continuous floods from 1980 to 2020 have left serious consequences on life, property and the ecological environment. Typically, Khanh Hoa is a province in the South Central Coast that suffers heavy damage every year due to storms and floods. On average there are 4 storms and 4 - 5 floods per year and dangerous hydrological phenomena [2], which can be mentioned as floods in 1980, 1986, 1993, 1998, 1999, 2003, 2009, 2013, and 2016 [2], [5], [10]. In there, Dinh River and Cai River are the two main rivers of the province, with an area of more than 2,500 km^2, and are the economic center of the South Central region and the

Central Highlands.

Nowadays, unstructured approaches especially early flood warning systems have attracted more attention, due to saving time for development and operation, increasing cost efficiency and no additional space or facilities are required for new construction or physical modifications. This shows that strengthening the flood warning system, real-time flood forecasting and flood risk level is necessary. Scientific research products will provide forecasting units with comprehensive, usable, durable, complete and reliable information that can meet the nation's flood forecasting and warning needs in the long term.

Therefore, the article "Building integrated tools for flood warning and inundation forecast of river basins in Khanh Hoa Province" details the method of system construction, how to operate and transmit information forecast data and warnings to users on the WebGIS online platform.

2. Method of building flood warning and inundation forecasting systems in the river basin of Khanh Hoa Province

The flood warning and inundation forecasting systems in Khanh Hoa Province's river basin are built on the basis of 22 automatic measurement stations (water level stations and rainfall stations), operating with a frequency of transmitting 1 actual measurement value every 5 minutes. Next, the automatic information encoding department will process this raw data to form the input database for the prediction model. The output results are presented on the WebGIS system and convey danger warning information. This real-time data will provide forecast maps and newsletters warning of flood risks and inundation to affected subjects on the two main river basins (Dinh River and Cai River) of Khanh Hoa Province.

The significance of this research for science and practical effectiveness is:

- Create a foundation for developing flood warning and forecasting systems for areas frequently affected by storms and floods;

- Upgrade and innovate technology and monitoring equipment according to automatic models for existing meteorological, hydrological and rain measuring stations in the basin;

- New establishment and addition of measuring stations, automatic hydrometeorological data transmission equipment;

- Invest in facilities, equipment and technology for the Khanh Hoa Provincial Hydro-meteorological Station and the South Central Region Radio Station to manage the operation and collect monitoring information of the station network;

- Provide forecasting models to enhance flood forecasting and warning capacity;

- Training staff through training programs and technology transfer;

- Ensure that after handover, the system can operate independently and immediately become effective.

Investment items: (1) Equipment and technology for monitoring and forecasting; (2) Information technology and communication equipment; (3) Hydrometeorological forecasting technology.

This warning system belongs to the project program to enhance flood forecasting capacity in the central provinces of Viet Nam, including 5 provinces: Khanh Hoa, Binh Dinh, Phu Yen, Ninh Thuan and Binh Thuan (Figure 1).

2.1. Flood warning and inundation forecasting systems

The monitoring, warning and forecasting system for flood and inundation in the Khanh Hoa river basin consists of 5 parts (Figure 2):

(1) Monitoring station system: Including automatic measuring devices for meteorology, rain, and water level, continuously updated 5 minutes/data value. Principles in installing automatic measuring stations:

+ The place where the station is installed needs to ensure consistent and reliable data;

+ For each station location, the correct selection of the appropriate station configuration ensures reliability, accuracy, cost-effectiveness, maintainability and stable monitoring;

+ Rain-measuring station: The ground used for station installation is soil, or soil mixed with

gravel, ensuring the stability of the footing of the rain gauge column, as well as the rain gauge column and the equipment installed on the column;

+ Hydrological station: The location is installed on the traffic bridge, ensuring the measurement of Hmin and Hmax positions;

+ Meteorological station: The installation location is necessary on a large, well-ventilated area to ensure that the measurement elements are not affected by the surrounding environment such as trees, tall buildings, etc.

(2) Data management center system: Monitoring data is transmitted and aggregated at this system in real-time via GPRS, 3G, and 4G transmission lines. The necessary hardware and software devices are equipped as follows:

- Server: Automatic station data management for data collection and system configuration;

- Auxiliary system: Including workstations and dedicated computers to display data in remote places.

- And some essential tools for data transmission.

To exchange data with the regional center; Using forecast data from regional centers; Network management at Regional Centers; Alerts to Provincial Centers.

(3) Data encryption software: This software supports encoding monitoring data, and converting data files into input boundaries for forecasting models.

(4) Forecasting and warning modelling software: Includes the MIKE FLOOD model suite, supporting the integration of rain-flow model, 1D-2D hydraulic model (MIKE11-MIKE 21), simulation of overflow on open channel system. Model results are values of water level and depth of flooding. Then check with the measured data if the reliability is good, and update data on the system (flooded forecast map, flood warning level).

(5) Information management and display tool - WebGIS: Is a place to store, access, and provide functions that administrators want to share with users, such as information about rain situations, and flood level changes. , flood risk, inundation, and download real-time measurements and forecasts. When the water level reaches alarm level I, II, or III, the measuring station location will display the corresponding alarm flags.

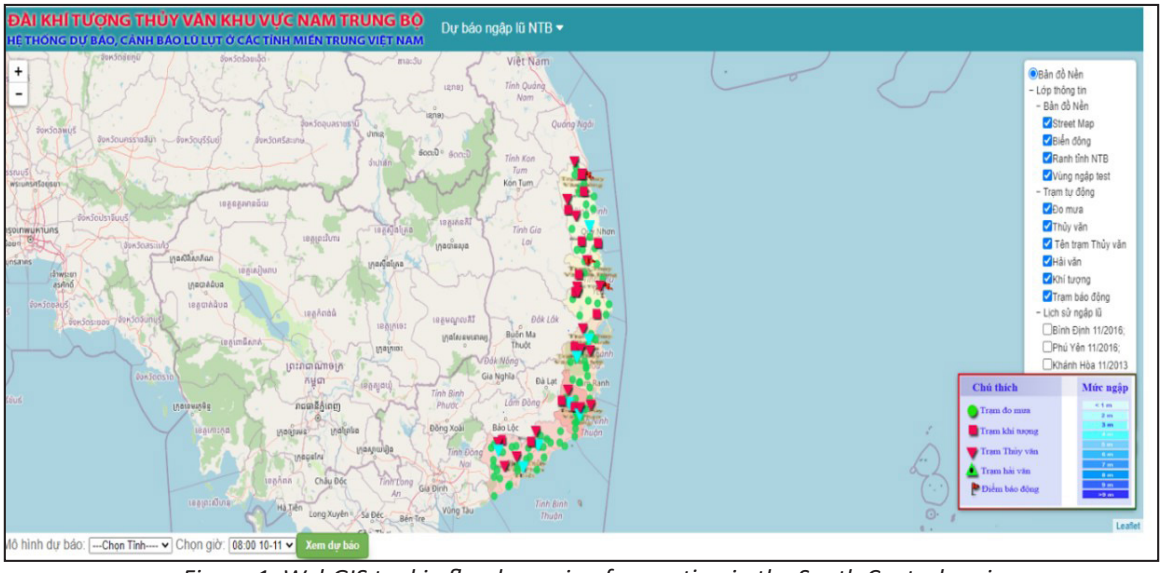

Figure 1. WebGIS tool in flood warning forecasting in the South Central region

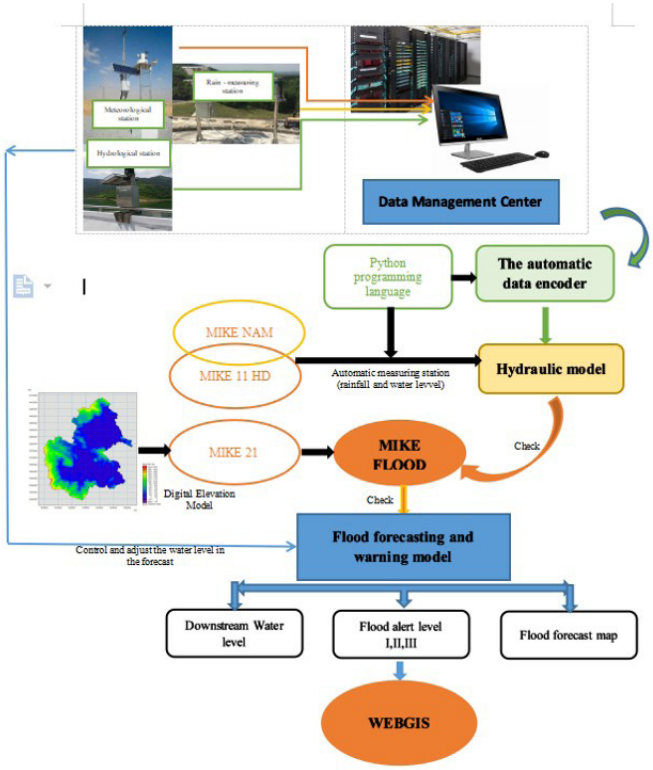

Figure 2. Overview diagram of the flood warning and inundation forecasting systems in Khanh Hoa Province

2.2. Setting up real-time flood forecasting models

a) Model of rain-flow MIKE NAM

In the process of basin delineation, the NAM model uses a DEM topographic map to register the UTM WGS coordinate system 84 zones 48 corresponding to the location of the river, with a resolution of 30 × 30 m.

The entire Dinh river (Ninh Hoa) and Cai (Nha Trang) basins are divided into 10 sub-basins with a total area of about 905 km^2 and 1,600 km^2 respectively to serve calculations in the model. The sub-basins in the NAM model are subdivided based on the river network, topography and rain gauge stations (Figure 3, 4, 5).

From the basin division diagram, continue to calculate the rain weight for the sub-basins according to the Thiessen polygon method. The sub-basins corresponding to each area are shown in Table 1.

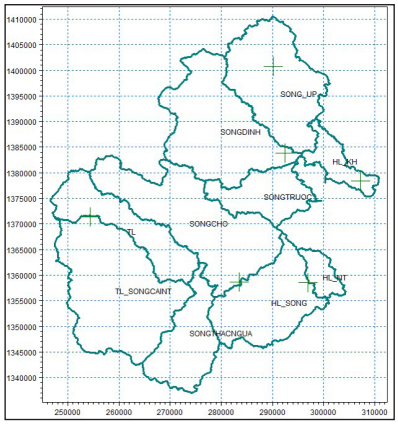

Figure 3. Sub-basin division diagram and rain distribution

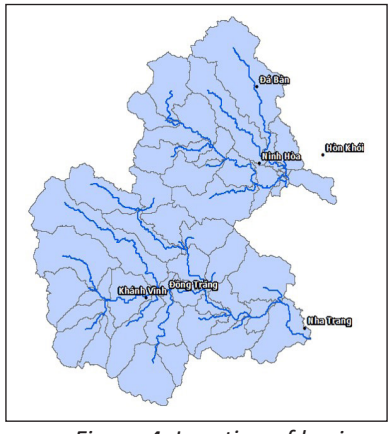

Figure 4. Location of basin calculation stations

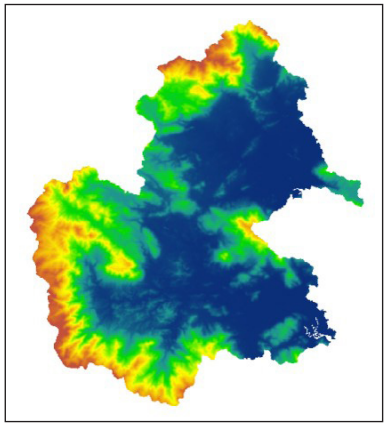

Figure 5. DEM topographic elevation map of river basin

Table 1. Distribution of sub-basins of rivers in Khanh Hoa Province

TT	River basin	Parts basin		
		Name of the basin	Control area	Area (km^2)
1	Dinh river basin (Ninh Hoa)	SONG_UP	Control area at Da Ban lake	327.010
2		SONGDINH	Dinh river main basin area	383.022
3		SONGTRUOC	Truoc River Basin	147,319
4		HL_NT	Hon Khoi station area	48.152
5	Cai River Basin (Nha Trang City)	SONGCHO	Dien Xuan station area	416.034
6		TL_SONGCAINT	Cai River main basin area	468,683
7		TL	Upstream area of Cai river	202.464
8		SONGTHACNGUA	Control area at Suoi Dau lake	188.450
9		HL_SONG	Control area from Dong Trang to Nha Trang	265.319
10		HL_NT	Lower Cai River	48.152

b) MIKE 11 HD Hydraulic Model

Calculation range of the 1-D model in 2 river basins: Dinh river (Ninh Hoa) and Cai river (Nha Trang city) are as follows:

- Cai river basin in Ninh Hoa with a calculated margin upstream from EA Krong Rou lake in a main tributary (Cai river), tributaries from post-dam position at irrigation reservoirs; river tributaries in the calculation domain include: Dinh river, Da river, Da Ban river, and Truoc river.

- Cai River basin (Nha Trang city) upstream from Khanh Vinh station, tributaries from the position after the dam at irrigation reservoirs; river tributaries in the calculation domain include Cai river, Thac Ngua river, Cho river, Suoi Dau river, Am Chua river, Cau river.

- The midzone basins enter laterally from MIKE NAM results.

The tidal ranges in the estuary area are taken from the observation data of the Cau Da hydrographic station (Nha Trang) for both river basins, the data has been converted to the national elevation.

The river basin calculation network, starting from the upstream of the river to the mouth of the sea, has a total of 155 cross-sectional values, including the Dinh river basin (Ninh Hoa) with Dinh river (38), Da river (9), Da Ban river (30), Truoc river (7); Cai river basin (Nha Trang city) has Cai river (28), Thac Ngua river (8), Cho river (7), Suoi Dau river (7), Am Chua river (14), Cau river (15).

The distance between the cross-sections is relatively uniform. Depending on the topography, the cross-sectional locations are selected to represent a small area of the river. The roughness of the river bed and riverbanks of each representative cross-sectional position is determined during model calibration and verification.

c) MIKE FLOOD inundation Model

Calculating the flooded area of Khanh Hoa province's river basin, researching and applying the MIKE FLOOD 1-2-way connected flood model, with both concentrated flow in rivers and streams and an overflow flow on the surface when the water level in the river is higher than the bank elevation. The model set uses river network, river cross-section data, boundary conditions from MIKE 11 and topographic grid from MIKE 21 FM (2-way horizontal flow simulation). Topographic data is essential to simulate the flow process as well as the hydraulic regime in the river system.

The two-dimensional hydrodynamic domain is defined as the entire study area, the terrain has elevations from below 0m to 1,994 m. The calculation area is limited to coordinates from 12°00' N to 12°45' N and from 108°30'E to 109°15'E. After setting up the general information about the calculation domain as above, proceed to divide the grid. The grid used here is a triangular grid with 91,285 elements and 61,690 grid nodes set up (Figure 6).

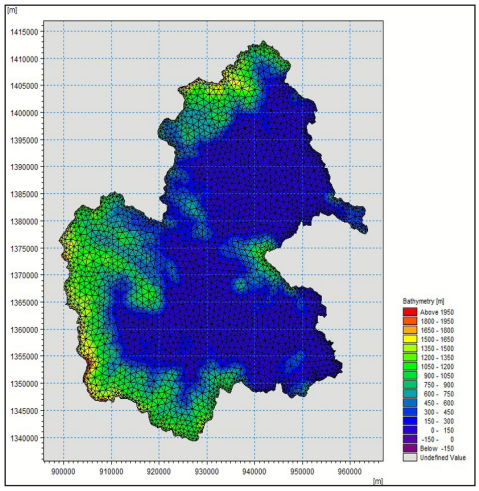

Figure 6. Setting up river basin network in flood calculation

2.3. Operation process of flood forecasting model

Process 1: The module automatically updates the data at the automatic measurement stations, then encodes and displays it into product files and is managed by the WebGIS tool (Figure 7).

Process 2: Statistics, automatic data normalization and forecasting from the Web to dfs0 file data format for flood model input.

Process 3: Make a design table to identify the forecasted rain results of the weather model and put these forecast results into a product file similar to automatic measurement data.

Process 4: Simulate real-time flood and inundation forecasting: The time series of warning, forecasting from 1 - 3 days, to ensure a stable level for the forecasting model, the input margin uses 72 h from the monitoring data combined with the next 12 h forecast results from the WRF weather forecast model to provide products (water level, flood map) forecasting and warning in real-time (Figure 8).

Figure 7. The installation location of the automatic measuring stations in Khanh Hoa Province

**Note: Meteorological Station ; Rain Gauge Station ; Water Level Station*

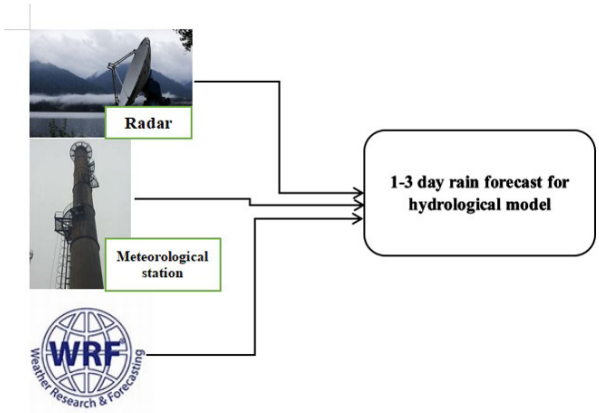

Figure 8. Rainfall forecast chart for 1 - 3 days for river basin in Khanh Hoa Province

- Build the calculation domain and set up a forecasting model with 2 options including option 1: 2 forecast grids 9 - 3 km with input GFS 0.25 degrees and option 2: 3 regions 27-9-3 km with input GFS 0.5/1.0 degrees.

- Build a module that automatically collects, decodes, filters and encodes traditional and non-traditional sources of monitoring data and global boundary condition data (USA, Japan) for the problem of data assimilation and business forecasting (regional forecasting system (WRF) for Viet Nam region.

- Synchronization of local and project monitoring data into the common data assimilation system.

Process 5: Encrypt, transform data, and put information on the WebGIS system.

3. Flood warning and inundation forecast systems in Khanh Hoa Province's river basin

Input data for the flood forecasting and warning model in the river basin of Khanh Hoa Province is taken from rain forecast data according to the WRF numerical forecast model in process 4 (Figure 9) at 3 rain gauge stations: Dong Trang, Khanh Vinh, Nha Trang.

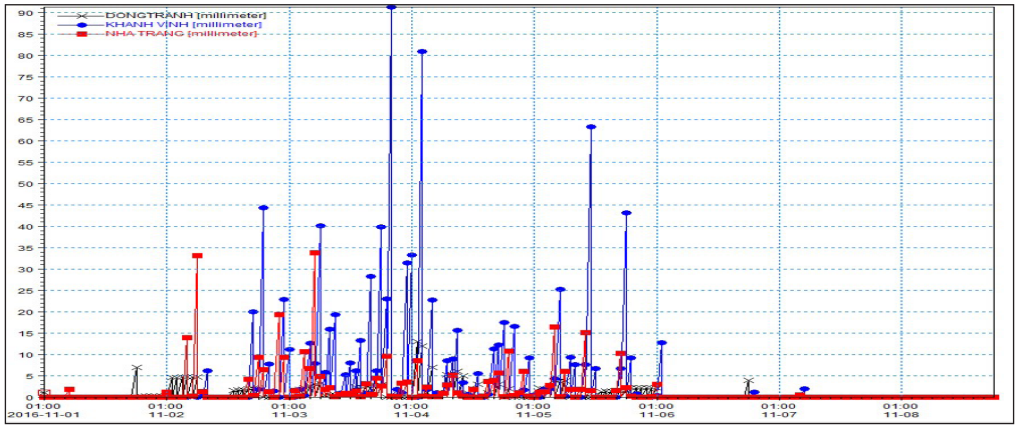

Figure 9. Forecast rain distribution chart in two main river basins in Khanh Hoa Province

Test the results forecast the water level of the historic flood from November 1, 2016, to November 8, 2016. In Cai river basin: Dong Trang hydrological station. In Dinh river basin: Ninh Hoa hydrological station.

The values of flow Q and water level H from the forecast model were compared with actual measured data (Figure 10) of the above two hydrological stations, achieving quite good results. The data provided on rainfall and flood values in two main river basins are consistent with reality and can be applied to future storm events.

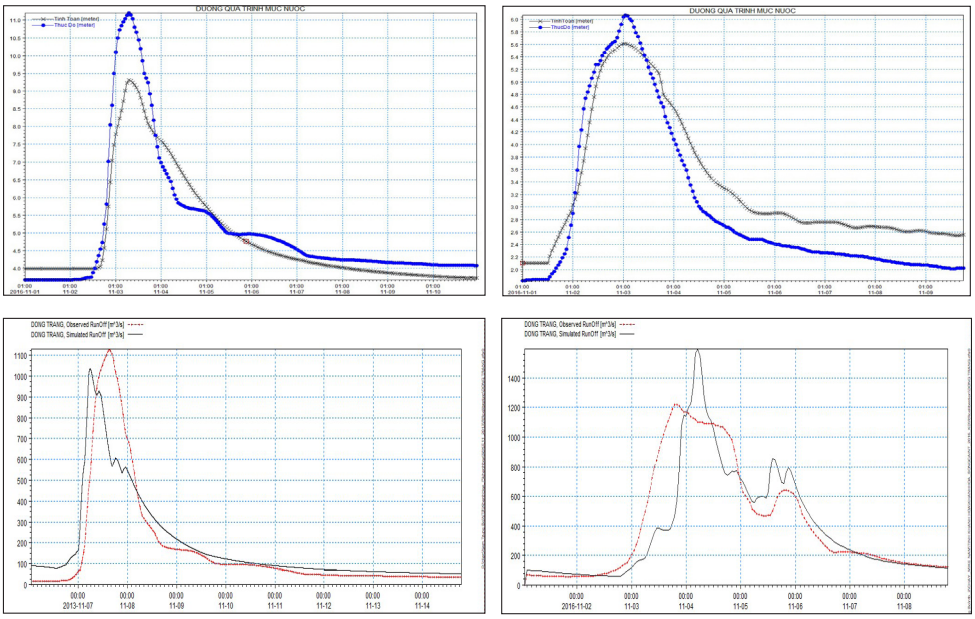

Figure 10. Test results of water level and discharge forecasting for river basin in Khanh Hoa Province

For flood warnings, the system sets up warning codes based on water level regulations corresponding to flood alarm levels at hydrological stations on the river to serve flood prevention, control and response, flooding and socio-economic development. When the water level reaches alarm levels I, II, III, the measuring station location will display the corresponding number of alarm flags on the WebGIS platform. Table 2 below presents the flood alarm level values at two hydrological stations: Dong Trang (Cai river) and Ninh Hoa (Dinh river):

Table 2. Water level values correspond to each flood alert level in the river basin of Khanh Hoa Province

River basin	Hydrological station	The flood alarm level		
		I	II	III
Cai	***Dong Trang***	8.0	9.5	11.0
Dinh	***Ninh Hoa***	4.2	5.0	5.7

Based on the statistical damage of Khanh Hoa Provincial People's Committee, test results were checked with the flood situation report. The total flooded area is 3,438 ha, accounting for 0.67% of the total area of Khanh Hoa Province, most of the flooded area is downstream of Dinh river (Ninh Hoa town). The extent of flooding during the annual flood of 2016 was distributed over 1 town, and 1 city, including Ninh Hoa town (3,257 ha, accounting for 2.72%). Nha Trang city has a flooded area in this flood with an inundated area of 181 hectares, accounting for 0.72% of the city's area. In which the flood level from 1.0 - 2.0 m occupies an area of 84 ha, equivalent to 0.33% of the whole area of the city.

4. Conclusions and Recommendations

This study presents the basis for building a system of measurement, warning and forecasting of floods and inundations for river basins of Khanh Hoa Province on the basis of WebGIS. The system allows the use of real-time rainfall, water level, and meteorological data in combination with the MIKE DHI mathematical model set to complete and improve flood warning and flooded forecasting in river basins of Khanh Hoa Province. At the same time, WebGIS is also a tool that supports storing a large amount of information, has the function of providing, sharing and transmitting data to visitors. The test results simulate past historical floods and

the real-time forecasts and warnings have been verified with actual data at a fairly good level, with a high level of forecast assurance. This will be a product capable of effectively supporting the transfer of scientific and technological advances into practice.

The application of forecasting technology to river systems in Khanh Hoa Province has only been tested in the past and for practical application, it is necessary to make additional forecasts in the coming time, improve the accuracy in management and professional forecasting at beneficiary units.

Acknowledgements: *This paper was researched and completed with the support of the project "Strengthening flood forecasting and warning in Viet Nam - phase II" with the task of "Establishment of flood forecasting model in the South Central region", completed in the period of 2019 - 2021. Contract No. 01/ CAE-SIHYMECC). The authors would like to express their sincere thanks.*

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