# A WebGIS Solution for Estimation Landuse Affected by Salinity Intrusion: Case Study in Ben Tre Province, Vietnam

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## Abstract

Ben Tre, located in the Mekong Delta, is one of the most places affected by climate change, especially in sea level rise and salinity intrusion. For the seven provinces bordering the East Sea, the need for monitoring water resources is critical. This paper represents an approach to build a web-based GIS to store, manage, analyze and visualize the data of saline intrusion phenomenon. The novelty focuses on automating the workflow for the generation and publication of time series saline intrusion maps on server side. The analysis results are provided on the web browser interface. This helps users access valuable information without having to install professional GIS software. Spatial distribution of saline intrusion and statistical results support government agencies in planning and decision making. This work is funded by Ben Tre Provincial People's Committee and Vietnam Academy of Science and Technology (VAST).

## Keywords

Geographic Information System, WebGIS, Salinity Intrusion, Mekong Delta

## 1. Introduction

Mekong Delta (MKD) is the largest agriculture and aquaculture production region in Vietnam. It contributes about 55% - 60% of nationwide agricultural production and plays an important role in ensuring food security [1]. In the context of climate change, sea-level rise, and dams developed upstream, severe drought and salinity intrusion have been occurring in MKD of Vietnam [2]. As one of seven provinces of the MKD bordering the East Sea of Vietnam, Ben Tre province is one of the regions, where is most affected by environmental changes.

In 2016, Ben Tre Province experienced the most severe drought and saline intrusion in more than 60 years. These are the causes of damage to fruit and paddy production [3]. The provincial government has several policies to improve the irrigation network and water capacity for cultivation. However, they need a monitoring system for the saline intrusion to make quick and reasonable decisions [4].

According to the Research Center in Southeast Asia, the advanced modeling and Geographic Information System (GIS) techniques should be used in developing high spatial and temporal resolution maps of areas at risk for salinity and drought [3]. GIS can be used to improve the storage, retrieval, analysis, and presentation of bulks amounts of data, especially in integrating and sharing spatial data among administration agencies [5]. GIS is currently converging with several other technologies to provide new levels of accessibility and functionality as web [6]. Since web technologies and the GIS advanced considerably and practiced widely, the web-based GIS (WebGIS) has become a popular means of information sharing and visualization in the form of maps [7]. In recent years, studies using WebGIS in water resources management showed the effectiveness of data management and analysis [8] [9].

The mapping of saline intrusion using GIS approach has been conducted in several studies [10] [11]. Nevertheless, this work requires researchers to use sophisticated GIS software. With the time series of input data, creating a series of maps poses challenges for users. Therefore, the automation of the workflow of analyzing and publishing data through WebGIS is necessary. The processing, analysis, and publication of data are performed automatically server-side. This means users do not need to install professional GIS software on personal computers as well as saving time for spatial data processing.

This paper presents the design of a web-based GIS that can integrate an automated tool for the estimation of landuse affected by salinity intrusion. The technical solutions are to collect, store, analyze and visualize data use free and open source software for geospatial (FOSS4G). In particular, this study shows the effectiveness of integrating geoprocessing tools into the web-based GIS system. The interpolation and statistical tools programmed in Python in order to provide an overview of salinity intrusion for the decision-maker.

## 2. Study Area

The vision of this study is to build a water monitoring system for seven provinces along the coastal zone of the MKD which can collect, store, analyze and visualize data related to salinity intrusion. As a first step, the project was implemented in Ben Tre province with funding from Ben Tre Provincial People's Committee and VAST.

Geographically, Ben Tre province locates between the two main branches of the Mekong River (Figure 1). The land area of the province is 2394 km² which is divided by the Tien River to the north and the Co Chien River to the south. The
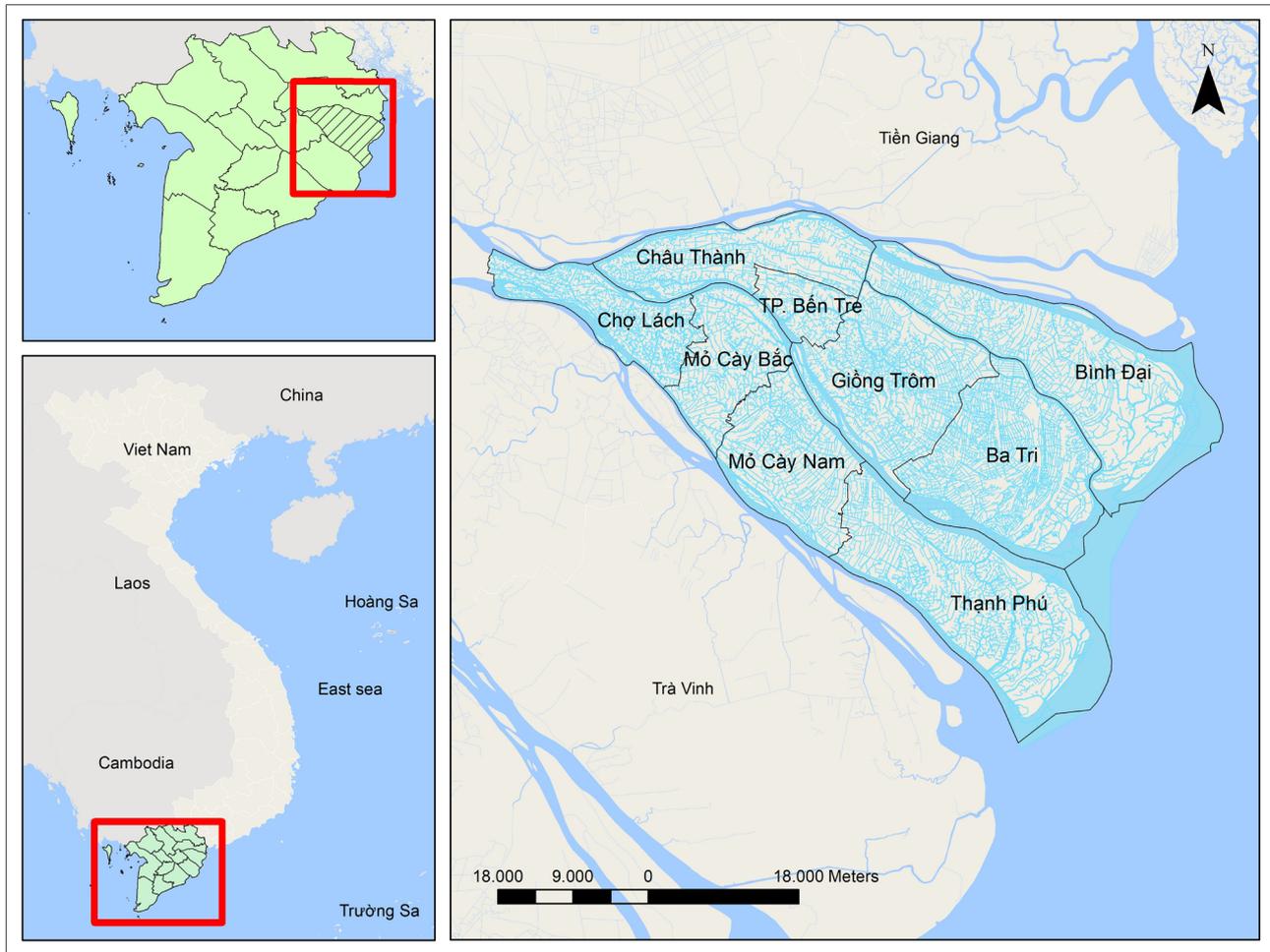
**Figure 1.** Case study Area, Ben Tre Province.

entire province is criss-crossed with a network of smaller rivers and canals with a total length of 6000 km. The river system in Ben Tre is convenient for waterway transportation. On the other hand, it also causes significant obstacles to water supply in the dry season, when the East Sea tides bring salinity deep into the canals. Normally, salinity in the estuaries varies 0 ppt - 12 ppt in the wet season and 12 ppt - 30 ppt in the dry season [12].

Ben Tre is one of the most provinces affected by drought and saline intrusion. In the context of increasing frequency of extreme climate event and dam development in upstream countries, small upstream flow volume compared to recent years and annual average. The saline intrusion occurred in a complicated manner. According to the Viet Nam Disaster Management Authority (VNDMA), saline intrusion in 2020 has entered from 55 km to 110 km (**Figure 2**), directly affecting 2000 hectares of winter-spring rice and more than 200,000 people in Ben Tre [13]. These conditions have resulted in a water shortage and significant damage to crops, threatening agricultural production, livelihoods, and access to fresh water. Therefore, the monitoring and analysis system for saline intrusion is important. The first phase of the project
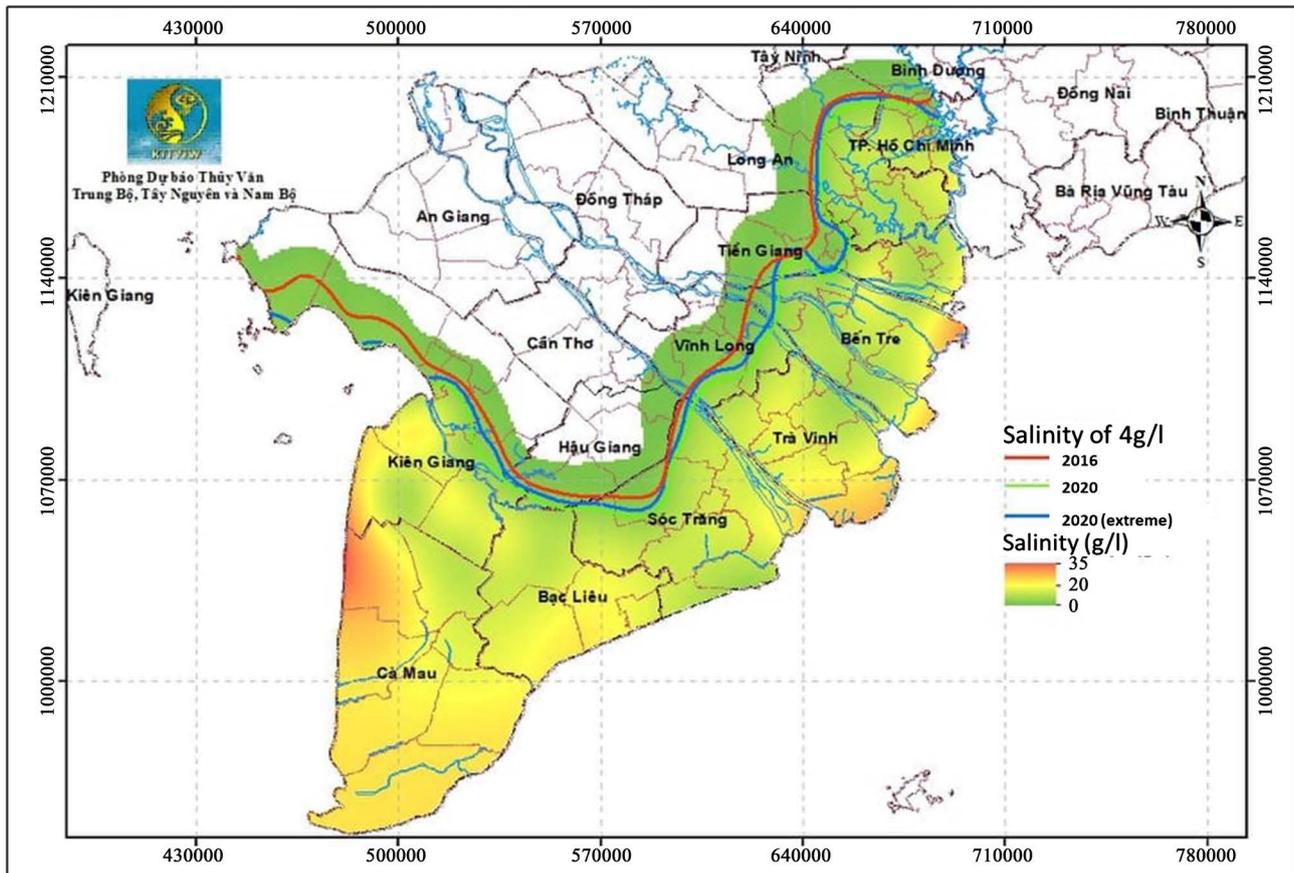
**Figure 2.** Saline map of Mekong Delta (Source: VNDMA).

in Ben Tre is a framework to expand to all coastal provinces of MDK.

## 3. Methodology

### 3.1. Data Collection

In order to analyze the effects of saline intrusion on landuse, input data is aggregated from water salinity and landuse data. For detail, data includes:

- Water salinity is collected from 2 resources: (1) Ben Tre Irrigation Works Exploitation One-Member Limited Liability Company (IWEC), (2) Ben Tre Hydro-Meteorological Station (BTHMS). IWEC observes salinity at the 20 existing sluices. BTHMS provides data from 5 water observation stations. IWEC and BTHMS publish data daily at fixed monitoring locations in spreadsheet format.
- Landuse data is collected from Department of Natural Resources and Environment of Ben Tre Province (DONRE).

### 3.2. System Architecture

WebGIS is an effective approach to provide geographic information to a wide range of users. The basic architecture of a web-based GIS application usually includes a web server in server-side that can handle incoming re-

quests and generate corresponding responses. Another main component of the server side is a map server that can provide geospatial data [6]. Besides, a database management system (DBMS) is used to manage spatial and attribute data. On the client-side, different mapping frameworks can be used such as OpenLayer, Leaflet, Mapbox. They allow users to interact map on the web browser.

This study intends to develop a WebGIS framework with open source tools to estimate the effects of salinity intrusion on landuse. Spatial analysis results are provided to the users without installing GIS software on the client-side. Therefore, the design of WebGIS framework needs to integrate GIS functionality on the server-side. Figure 3 shows the system architecture of the WebGIS framework used in this study. The three main components of this framework include data, WebGIS back-end, and WebGIS front-end.

WebGIS back-end:

The back-end is a combination of applications and databases on the server environment. A back-end GIS server is used for publishing spatial data and functionalities as web services consumed by the front-end application. However, complex task requires the application to use complex GIS functionality [8]. GIS analysis functions needed by processing on the server side and providing results to the client. As shown in Figure 3, input data such are collected in different data structures. To provide the analysis results, these data need to perform in processing steps.

This study builds a "GIS processing module" to perform processing tasks in an automated way. Daily salinity data are sent to the server in the form of spreadsheets (xls, csv). This data is analyzed with the Python programming language and libraries working with geospatial data. The Pandas library in Python is used to manipulate spreadsheets. SAGA-GIS library is also
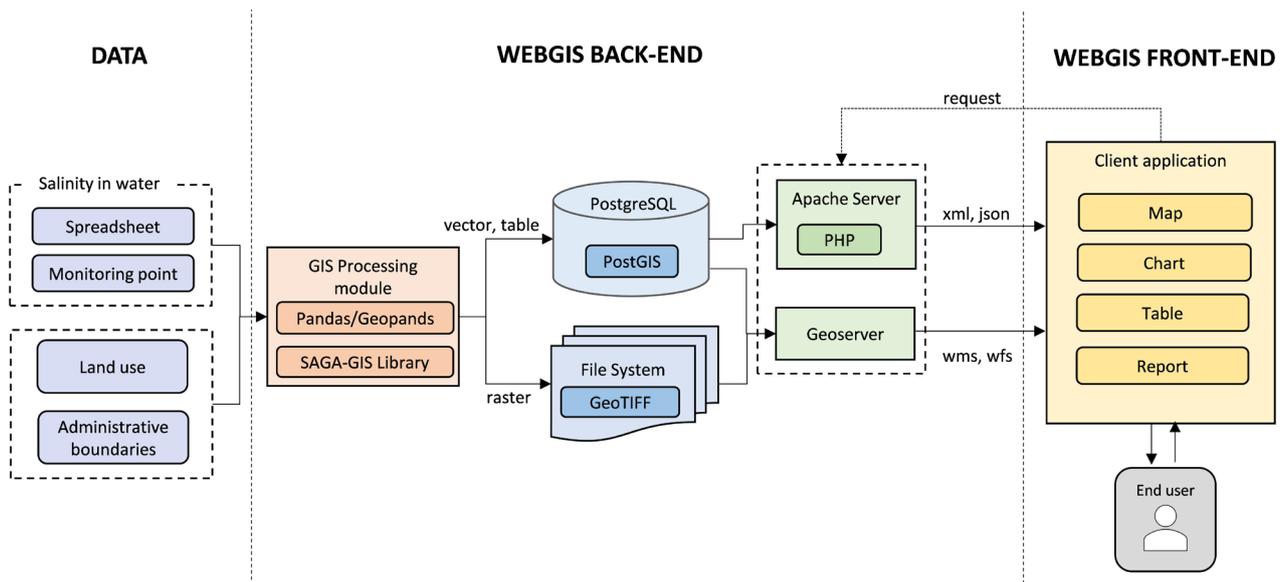


**Figure 3.** System architecture of WebGIS.

integrated to perform interpolation and generate saline intrusion maps. The results of the interpolation map (raster) are stored as system file. Besides, contour of saline intrusion (vector) and statistical results (table) are stored in the DBMS.

DBMS for a WebGIS framework must be established so that can store spatial data. The WebGIS application in this study uses PostgreSQL and PostGIS extension. PostgreSQL is an open source object-relational database system that provides the full functionality for working with spatial data [15]. Salinity value over time series at monitoring stations, salinity contour, and statistical analysis results are stored in PostgreSQL. Although PostgreSQL has support for Raster data, the speed of connecting and responding to the map server (GeoServer) through testing is not high. Therefore, a solution for storing Raster data using a file system as GeoTIFF was selected.

Web Server as Apache Server used to handle incoming requests and generate corresponding responses through the Hyper Text Transfer Protocol (HTTP) and the Hyper Text Markup Language (HTML). In Apache HTTP Server, the PHP language is used to process the request and respond with the web browser (Binh *et al.* 2019). In this study, Apache HTTP Server transfers data between client and server in the XML or JavaScript Object Notation (JSON) format.

The map server is an important component of a WebGIS application. Functionalities of map servers usually rely on OGC's (Open Geospatial Consortium) standards such as Web Map Service (WMS), Web Feature Service (WFS). Geoserver is a popular open-source platform to generate and publish maps from spatial data (Trung and Tam 2018). In this study, Geoserver is used to publish map layers from PostgreSQL and GeoTIFF files. Accordingly, saline intrusion maps are provided through the WMS-T (WMS with a Time Dimension) standard.

WebGIS front-end:

The front-end consists of a graphical user interface (GUI) that allows users to visualize and interact with tables, charts, maps [14]. To handle and control the components of the GUI in this study, JavaScript framework libraries are integrated such as jQuery, Bootstrap, AngularJS.

In order to display and control the map on the client application, the Leaflet library is used to build an interactive map application. By using GUI the user can interact with the map by the navigation tools such as zoom in, zoom out, pan, and identify the feature. In addition, the AmChart library is integrated to visualize information through charts.

In WebGIS front-end, when the user sends a request through their interaction with the GUI, the WebGIS back-end will return the necessary component (spatial data, non-spatial data). From there, it will be assembled on the Document Object Model (DOM) and rendered properly on the user's browser using HTML5, JavaScript, and CSS.

### 3.3. Data Interpolation

The spatial interpolation in the "GIS processing module" uses the Ordinary Kriging method. In the GIS approach, the Kriging interpolation method has been widely applied for surface analysis of water quality parameters such as temperature, salinity, pH, chlorophyll-a [10] [16]. Interpolation techniques serve to estimate a value at a point of a region for which a variogram is known, using data in the neighborhood of the estimation location [16]. Kriging is a family of estimators used to interpolate spatial data. This family includes ordinary kriging, universal kriging, indicator kriging, and others. The choice of which kriging to use depends on the characteristics of the data and the type of spatial model desired. In water quality evaluation, the Kriging method generally outperforms Inverse Distance Weighting for all parameters and depth [17].

To generate an interpolation surface from points containing salinity parameters, SAGA-GIS Module Library is used with Python programming language. This library provides powerful spatial data analysis functions such as Kriging interpolation algorithm. The result of the interpolation is used to generate contour lines for salinity.

### 3.4. Estimation of Landuse Area Affected by Saline Intrusion

Salinity interpolation result (raster) is overlayed with the landuse data (vector). SAGA-GIS Library provides "Module Grid Statistics for polygons". For each polygon statistics about the values of all contained grid nodes will be generated. Based on the SAGA-GIS Library functions, a calculation tool was built with the Python programming language. This tool is integrated in the "GIS processing module" of WebGIS back-end which is used to estimate the area affected by saline intrusion. The statistical results will be stored in PostgreSQL. This information is visualized using charts on the client application.

## 4. Results

### 4.1. Portal for Sharing Information

Once the WebGIS was completely developed it was hosted on a web server in order to post it on the internet environment. In this project, the WebGIS application is integrated into Ben Tre Irrigation Management System Portal (available at https://thuyloibentre.com). Sharing of information allows multiple users to access valuable data or analysis results at the same time (Figure 4). In addition to data on saline intrusion, the portal of this project also provides other data sources such as water level, the status of irrigation works, land use/land cover, and meteorology. In adapting to saline intrusion, the combination of useful information helps the local government publish policies reasonably and quickly.

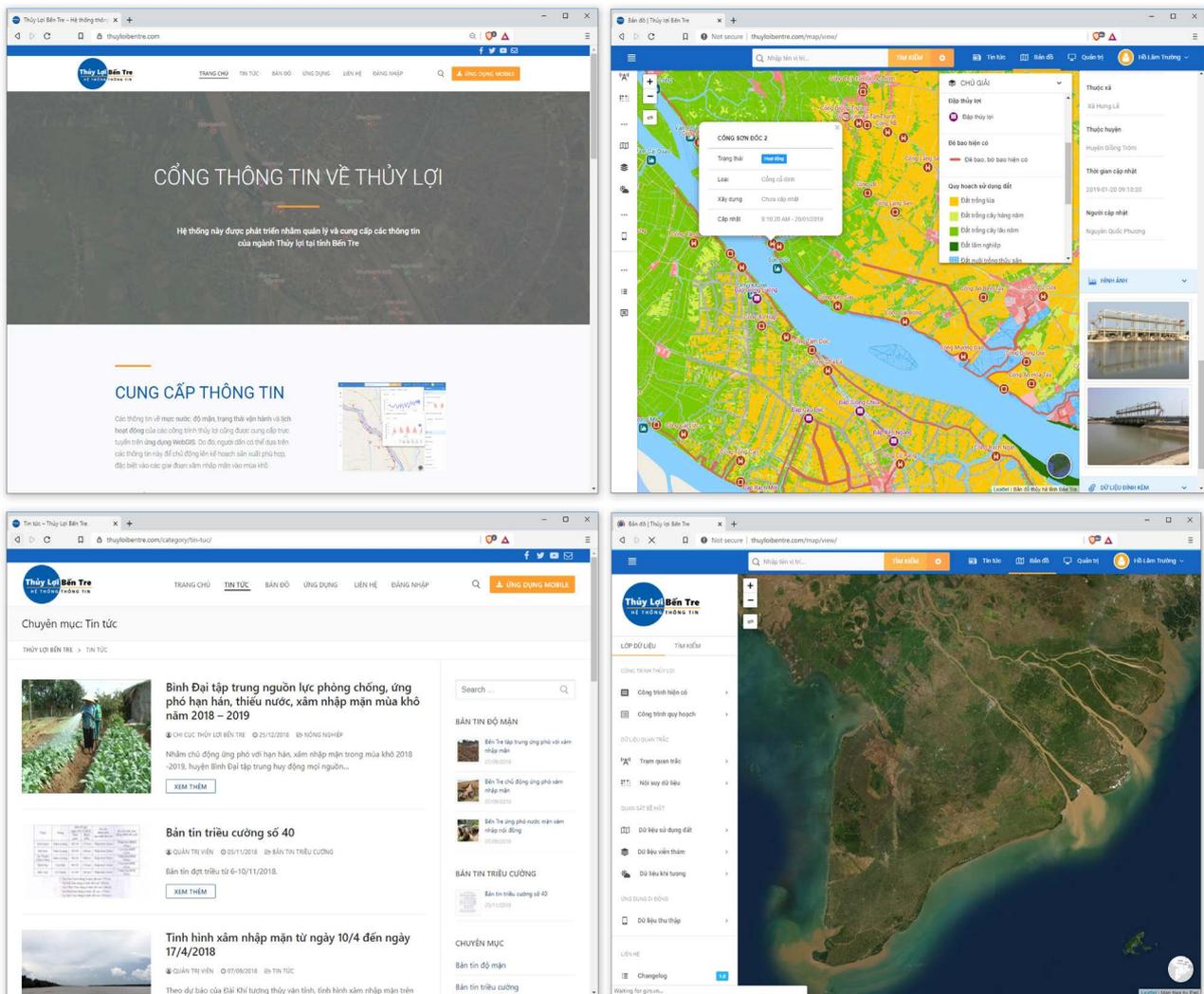The first phase of the project is implemented in Ben Tre province, which is

**Figure 4.** The portal for sharing information.

the foundation and technical framework to expand to all coastal provinces of the MDK. A saline intrusion monitoring system for the MDK provides an overview at a regional level for planners and policy-makers. On the other hand, this system also provides useful information for farmers to have flexible cropping plans.

## 4.2. User Interface of WebGIS Saline Intrusion Map

The GUI of WebGIS is designed to focus on user interaction and information visualization. The basic components for working with the map provided in the GUI include controlling the data layers (in left sidebar), legend control, map view, scale control, detailed information of the feature (in right sidebar). To display and visualize information, tables and charts are displayed in the web dialog. Users can easily interact with the graph in time series by time scrollbar. The example in **Figure 5** shows the salinity chart at the monitoring station.
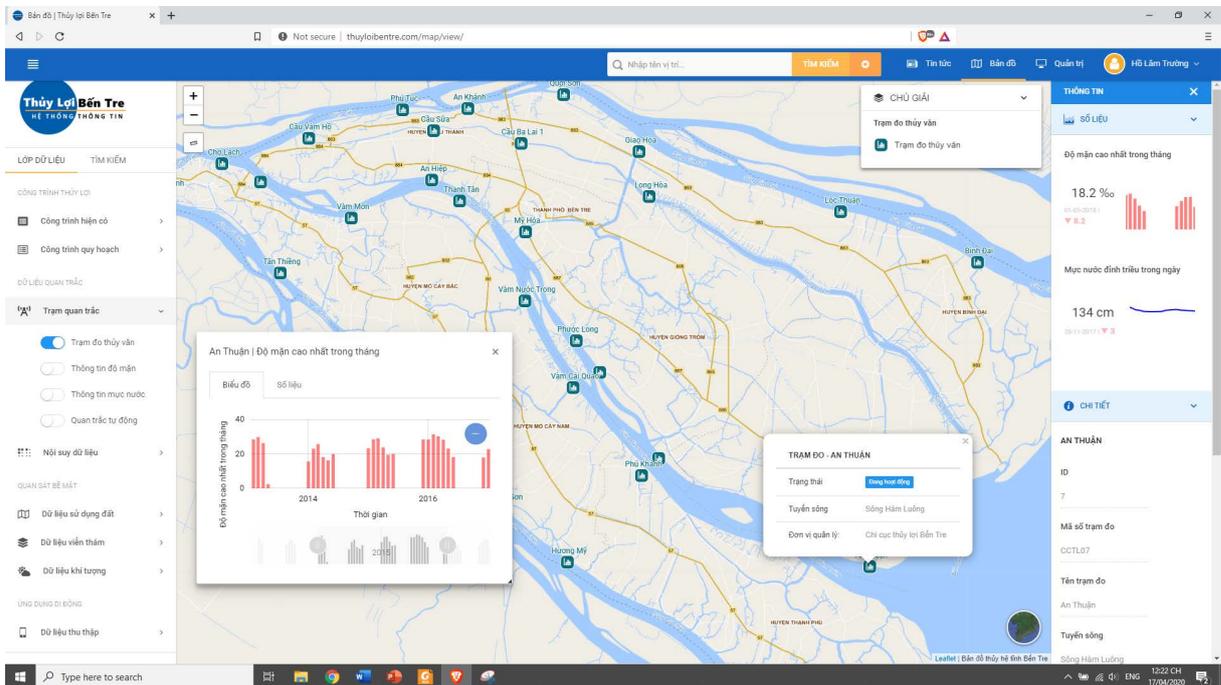
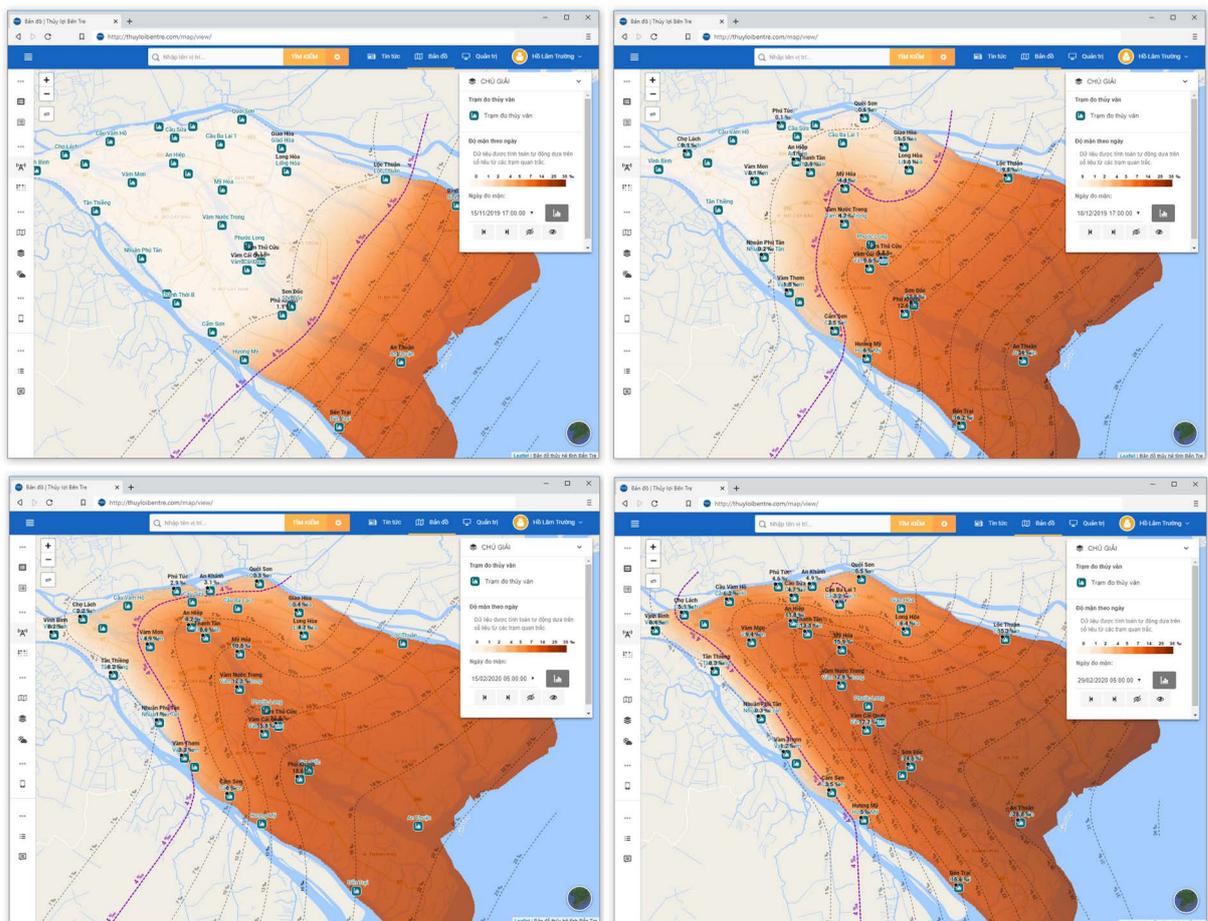**Figure 5.** Information of water observation station.



**Figure 6.** Trend of saline intrusion in dry season.

## 4.3. Saline Intrusion Map

Based on interpolation results from salinity value points, saline intrusion maps are generated in WebGIS back-end. They are connected to the client application as a web map service with time support (WMS-T). Through daily updated salinity data, the maps with series-time data show spatial, temporal and value dimensions of saline intrusion phenomenon. Figure 6 shows the trend of saline intrusion from December 2019 to February 2020. The boundary of salt concentration 4 ppt enter inland 30 - 40 km deeper than the annual average.

Kriging interpolation method is used as a spatial analysis function of the WebGIS application. However, it has some limitations when the density of the measuring station is not optimal. Compared to complex modeling methods, the Kriging interpolation method is easily applied to a WebGIS system because of the simple input data. This means it is easy to apply for large-scale regions. The interpolation results focus on describing the trend of saline intrusion. If a saline intrusion map can be provided to the Mekong Delta region, it will be of great benefit.

## 4.4. Landuse Area Affected by Saline Intrusion

In order to support decision-making, statistics of landuse areas affected by saline intrusion were calculated. The analysis result is stored in PostgreSQL and transferred to the client application in JSON format. Chart tool in the GUI allows the visualization of statistics. Besides, users can also download this data to make
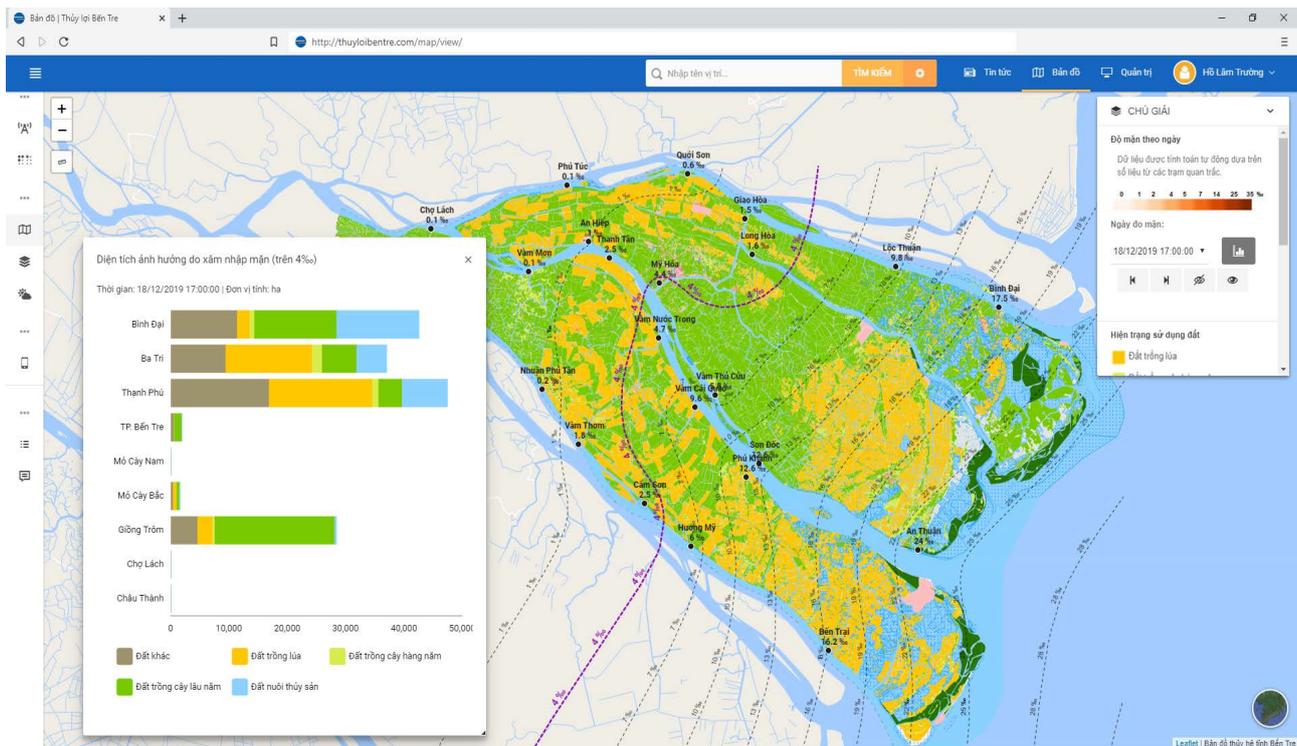


**Figure 7.** Landuse area affected by saline intrusion.

their reports. Analysis results for 5 landuse types include rice crop, vegetables, fruit orchards, aquaculture, and others. Figure 7 shows the statistics of the landuse area that intersects the area with salinity above 4 ppt. Land use areas are grouped according to administrative units. This helps local governments have good policies to adapt to saline intrusion.

## 4.5. Data Management Tool

WebGIS application in this project also provides a Dashboard interface for users to manage the database. Through the Dashboard tool, users can update daily data from spreadsheet files (Figure 8). The daily import files help data have a good temporal resolution.

However, this is a manual way to insert new data. In the next step of this project, the WebGIS system will connect to automatic monitoring stations for collecting data. Besides, the database will also be received data from applications on mobile devices. This helps to establish a complete data collection system for the Mekong Delta.

## 5. Conclusions

This study has built a WebGIS application to monitor and analyze saline intrusion in Ben Tre province, which is the most affected place among coastal provinces in the Mekong Delta. The WebGIS framework of this study is a technological demonstration of integrating available software components. It clearly shows that FOSS4G is capable to provide full GIS functionality and to



**Figure 8.** Data management dashboard.

generate valuable geographic information via the internet environment. The choice of FOSS4G helps to save costs when expanding and implementing this system for the coastal provinces of the Mekong Delta. Furthermore, through Open Source geospatial communities, programmers can reuse, modify, or develop the software's source code. This demonstrates the role of FOSS4G in mission monitoring the environment for government agencies.

To generate saline intrusion maps, spatial interpolation in an automated way helps to publish information quickly. However, this study also has some limitations.

The analysis results do not have a specific step of assessing accuracy. The method of Kriging interpolation depends on the location of the sample point. However, the distribution of monitoring stations depends on human factors as well as not optimal for the interpolation algorithm. With increasing concern of water resources in the Mekong Delta, real-time and autonomous water quality monitoring systems will be implemented in the future. This poses challenges as well as opportunities for further research.

In the context of drought and saline intrusion in the Mekong Delta, the proposed solution with standards of technology concerned with the actual development of the WebGIS framework that can apply efficiently for the Water Monitoring System of coastal provinces in the Mekong Delta. The database of the system can be shared and presented within a web browser, without the need for any additional software, to provide information quickly that supports decision making to adapt to saline intrusion. This solution can bring more value to understand the regional level situation and analyze the trend of salinity intrusion of each province. The system also contributes to creating good information for restructuring agricultural plans in this region.

## Acknowledgements

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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