Web-Based Tsunami Early Warning System

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Abstract—**Tsunami is a serious threat to the island nation such as Indonesia. The tsunami disasters that were occurred in some parts of Indonesia have immerged the need for tsunami early warning system that is reliable and can be applied to the Indonesian archipelago. North Sulawesi is one of the areas prone to tsunamis since this area lies in the path called the ring of fire's. This article describes a tsunami simulation application for the north coast of North Sulawesi. Web-based applications were built so that they can be monitored online from anywhere and at anytime. This system reads the real-time seismic data that affect the North Sulawesi region from a number of sources. Dynamic and static data that are received are processed using data mining method to predict the chances of a tsunami, while flood flooding algorithm is used to visualize the map of affected areas of North Sulawesi. The resulting information is available in detail in the form of web pages and also through short message to the relevant authorities handling of the tsunami disaster in order for them to act in accordance with applicable standard operating procedures. With this application, the public can obtain information that is more accurate. Relevant authorities can conduct tsunami disaster mitigation measures more effectively.**

Keywords— **Flood Fill Algorithm, Simulation, North Sulawesi, Tsunami**

Abstract—***Tsunami merupakan salah satu ancaman yang serius bagi banyak wilayah kepulauan, khususnya Indonesia. Bencana tsunami yang pernah terjadi di beberapa wilayah di Indonesia telah memunculkan kebutuhan akan suatu system peringatan dini yang handal dan dapat diaplikasikan di wilayah kepulauan seperti Indonesia. Provinsi Sulawesi Utara adalah salah satu wilayah di Indonesia yang rentan mengalami bencana tsunami. Hal ini karena wilayah ini, khususnya pantai utara Sulawesi Utara, terletak di dalam lintasan cincin api dunia. Artikel ini membahas tentang aplikasi simulasi tsunami untuk pantai utara Sulawesi utara. Aplikasi berbasis web yang dibangun mengkonsumsi data dari beberapa sumber agar dapat memonitor secara daring dari mana saja dan kapan saja. Sistem membaca data seismik yang berkaitan atau berdampak pada area yang dituju secara daring. Data dinamis dan statis ditangkap dan diproses menggunakan pendekatan penggalian data untuk memprediksi kejadian, dan algoritma flooding digunakan untuk memvisualisasikan area terdampak dari waktu ke waktu. Informasi terkait hasil simulasi dan visualisasi dapat dilihat.secara rinci melalui halaman web dan juga melalui pesan singkat yang dikirim ke pihak terkait dengan penanganan bencana tsunami. Pihak-pihak ini yang akan memutuskan dan mengambil langkah-langkah mitigasi bencana sesuai dengan prosedur baku tertentu. Dengan aplikasi ini, masyarakat dapat memperoleh informasi dengan lebih akurat. Pihak-pihak terkait juga dapat melakukan tindakan mitigasi yang terkukur dan efektif.***

*Kata Kunci—**Algoritma Flood Fill, Simulasi, Sulawesi Utara, Tsunami***

I. INTRODUCTION

Tsunami comes from the Japanese language. The syllables "tsu" means harbor, while "nami" means wave. It is generally defined as a large tidal harbor. Given this senses, the tsunami can be interpreted as long-period ocean waves generated by an impulsive disturbance of the sea floor [1]. Tectonic earthquakes, volcanic eruptions, or landslides under the sea are the types of sources of the impulsive disturbance. Velocity distribution of the tsunami wave is directly proportional to the depth of the sea. The deeper the sea, the higher the speed of the tsunami. This means, this speed will decrease when the tsunami waves approach the shore (approximately 25-100 km/h). However, with a relatively slower pace of wave, the devastating tsunami still can still cause devastated destruction to everything in its path, particularly around the coast.

Since the Tsunami can be fatal in areas around the coast, then there is a need for an assessment of tsunami risk. Learning from the tsunami disaster in Aceh in 2004, the terrors of the earthquake and tsunami in the province of Nanggroe Aceh Darussalam and North Sumatra raises serious concerns of all people in the world, because it has caused death toll expected to reach more than 200,000 people and damage to infrastructure reaches more than 90 %. Seismic events are events that cannot be predicted when it will happen (unpredictable) and even includes events that ~~there is no chance to escape from~~ the enormity of the earthquake (unpreventable). The tsunami, which caused by the earthquake, has the same properties as the earthquake, since it is unpredictable and there is no chance of escape.

Figure 1. The 2007 Tsunami Disasster in Pangandaran Coast.

Around the world, tectonic earthquake was recorded as the primary cause of the tsunami. From the last 400 years, there have been 107 times the incident in Indonesia. Of that amount, more than 91% due to earthquakes, 8% due to volcanic eruptions, and 1% due to landslides on the seafloor [2]. Examples of the impact of the 2007 tsunami in Pangandaran is one example of the impact of a tsunami can be observed and can be used as the basis for tsunami hazard mapping (Figure 1).

There are a number of researches and developments have been done in the field of supervision and control of environmental degradation and natural disasters system [2,3]. All of them focus on human effort to be able to

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predict the possibility of disaster and further reduce the adverse effects caused by such disasters on life and environment. Such systems are often referred to as the Early Warning System or Early Warning Systems (EWSs). Most of such systems and technology approaches involve the use of sensors for data collection, data transmission, evaluation and analysis, dissemination of early warning information in a timely manner, and efficient response to such information [4].

Implementation of an emergency response to a tsunami early warning information before the actual impact of the disaster occurred is a difficult task and requires a concerted effort by all parties. All parties here especially at the level of government, such as the National Agency for Disaster Measures (BNPB), the Regional Disaster Management Agency (BPBD), the Center for Volcanology and Geological Hazard Mitigation (PVMBG), the National SAR Agency (Basarnas), as well as relevant agencies. All of them plays a role not only when a disaster occurs, but also when pre-disaster planning and disaster response training.

Researches and developments of early warning systems have been widely introduced. Vordzorgbe (2003) noted that in the Americas, focusing on the development of EWS many landslides, earthquakes, climate change and El Nino [5]. In Europe, a more accurate EWS is built to predict hazards and food scarcity, climate change, water quality, and pollution. EWS is integrated with Internet technology and remote sensing. Meanwhile in Asia more towards EWS development related to the tsunami disaster.

In Indonesia, the development of EWS, specifically for the tsunami disaster, has also been carried out. One of the EWS developed after the tsunami in Aceh in 2004 was the German-Indonesian Tsunami Early Warning System (GITEWS). This system is an initiative of the German government is done by GeoForschungsZentrum Potsdam [5,6]. GITEWS architecture was built from a number of components with the main component gauging station is located on the Warning Center. Gauging station continuously collects relevant data, such as seismic information, position, water level, absolute pressure and pressure difference, as well as other technical variables. OBU is deployed at some point on the seabed will perform preprocess all the data related to the pressure at the sea floor and transfer them to the GPS Buoys on the surface using acoustic data transmission. This data along with the data (high water) collected by GPS Buoy sent via satellite to the gauging station. Seismometers located at monitoring stations also transmit data to the gauging station in Warning Center located in Jakarta via satellite. All of data and information are processed using simulation methods and models that have been built to detect the possibility of a tsunami. This system is only tested on a small scale in the Sunda Strait. This is because the cost of infrastructure is very expensive.Other that, until now, the system is still the intellectual property of the GFZ.

Aside from these systems, there are also other similar systems, such as the Early Warning Center Pacific (http://ptwc.weather.gov) and EWS owned by the Japan Meteorological Agency (http://www.jma.go.jp/ en / quake). However, although the system can provide early warning of the tsunami disaster in almost all parts of the world, such systems do not provide relatively fast access to stakeholders and the community in Indonesia. For example, in the event of an earthquake on the southern coast of the island of Java in July 2006, the early warning has been sent to the Indonesian government, but not enough time to disseminated to local governments and communities.

This article describes an information system that supports the process of tsunami early warning called North Sulawesi Tsunami Early Warning System (NSTWS). The system is built to take advantage of existing seismic data provider on the internet by collecting real-time seismic data. The real-time and historical data of seismic activity were used to create a prediction model of tsunami even in North Sulawesi north coast. The model was developed using several data mining classification method according to the characteristics of the data obtained. The geological data was used to model the dynamic spread of flood on the affected area. A software was developed to visualized the model.

II. MATERIAL AND METHODS

A. Materials

Judging from descriptions of specific data from different data providers, a minimum data requirements and standards for NSTWS need to be specified. It is necessary to create a system that is not dependent on only one data provider and can be replaced with other data provider. To be able to predict tsunamis, NSTWS using three types of data, namely:

- Bathymetry data, this data represents the land and seabed topology, the time comes, direction, and speed of tsunami waves. The bathymetric data collected in this study is only for the North Sulawesi region. This data will also be displayed as a digital map.
- Seismic data, this data represents the time, location, depth, and magnitude of seismic activity. Furthermore, the data is used to simulate the epicenter and high sea waves in accordance with the basic topology sea and land as well as the strength of the earthquake.
- Sea wave conditions, this data along with information point location and magnitude is used to predict the height of sea waves accurately. Rather than make predictions of sea level to detect a tsunami, it would be more accurate to use the data from the sensor buoys that have been available. So the sea wave height data that could be obtained. The data needed is the sea wave height, wind speed, wind direction, and wind gusts.

To define the data requirements for seismic sea waves, the description of the data from each data provider needs to be explored further. Description of this data will be used to examine the data availability characteristics, such as the type of data provided, the data generation mechanism, and data formats. Each data provider has different data format. Therefore, NSTWS has to make a global data definition for multiple data providers. A format specifically designed for NSTWS need to be built to ensure that NSTWS is independent to any data providers. This strategy avoids the problem with respect to the case when data provider stop the service in the future. When it happens, NSTWS can easily retrieve data from other data providers. Program 1 shows some descriptions of data from the USGS, PTWC, and NDBC.

To get the data from the USGS (http://www.usgs.gov) can be used web service APIs that have been provided. Web service is an implementation of FSDN (of Digital Seismograph Networks Federal) Event Web Service, and provides search services specific to earthquake information using a variety of parameters. Applications that utilize this web service should use the Real-time GeoJSON feeds to display the earthquake information whenever possible, because it will produce the best performance. A GeoJSON object represents geometry, feature, or a collection of features. GeoJSON is transferred using a JSON response (lightweight data exchange format / simple), but the response GeoJSON packed in the function call, eqfeed_callback. The use GeoJSON protocol is intended as interface for the application.

```
{  type: "FeatureCollection",
   metadata:
     { generated: Long Integer,
       url: String,
       title: String,
       api: String,
      count: Integer,
       status: Integer
     },
   bbox:
     [ minimum longitude, minimum latitude, minimum depth,
       maximum longitude, maximum latitude, maximum depth
     ],
   features:
     [
       {
       type: "Feature",
       properties:
         {
           mag: Desimal,
           place: String,
           time: Long Integer,
           updated: Long Integer,
           tz: Integer,
           url: String,
           detail: String,
           felt:Integer,
           cdi: Desimal,
           mmi: Desimal,
           alert: String,
           status: String,
           tsunami: Integer,
           sig:Integer,
           net: String,
           code: String,
           ids: String,
           sources: String,
           types: String,
           nst: Integer,
           dmin: Desimal,
           rms: Desimal,
           gap: Desimal,
           magType: String,
           type: String
         },
       geometry:
         {
           type: "Point",
           coordinates: [ longitude, latitude, depth ]
         },
         id: String
       }, ...
   ]
}
```

Program 1. JSON Format for Geographical Data.

Potential Data Source from the PTWC Tsunami

PTWC (Pacific Tsunami Warning Center) is an agency under NOAA (National Oceanic and Atmospheric Administration) United States who provide service delivery potential tsunami event notification messages. Users can obtain the message in real time by subscribing through the medium of email, SMS (text message), RSS, or social networking. In general, the PTWC serves Pacific basin area. As for the other areas, there are other data providers. NOAA provides services in WCATWC (West Coast and Alaska Tsunami Warning Center). Pacific Tsunami Warning System, PTWC provides warnings for Pacific basin tele-tsunami (tsunamis that can be destructive regions far outside the center of the event) to all countries in the Pacific rim and all the islands in the Pacific. This service was held under the supervision of the UNESCO/IOC (International Coordination Group). One of the access options that can be used to get a tsunami early warning is to subscribe to the RSS (Really Simple Syndication). This service is the easiest service to get an alert when the an event occurred. Nothing like a visit to the site to find the latest news, RSS automatically notifies when there is new news is posted, which can be read through the user's choice of news reader application. PTWC RSS feeds provide three services: a) PTWC Pacific Ocean RSS Feed, b) PTWC Hawaii RSS Feeds, and c) the PTWC Caribbean Sea RSS Feed.

National Data Buoy Center (NDBC) is part of the National Oceanic and Administration's (NOAA) National Weather Service (NWS) whose job is to design, mengoprasikan and manage network data collection buoys and providing meteorological observations ocean, oceanography, and geophysics accurate and in real time to help warning centers, marine forecasts, military, marine platform operators, and the general public.

In addition to using the data from the USGS seismicity, tsunami early warning systems also utilize data from multiple sensor buoys in the waters of North Sulawesi to improve the prediction of a possible tsunami. Buoy data is data obtained from sensors mounted buoys at sea. Buoys generally have multiple functions, including to measure the depth of sea water, air temperature, wind speed, and others. These data are typically used to predict storms, tidal waves or tsunami the sea water.

To use the data buoys, may be used data that has been provided by NDBC (National Data Buoy Center) under NOAA (National Oceanic and Atmospheric Administration) the United States government. The nature of the data is the same as the data from the USGS, which can be used freely by the general public. Each buoy mounted sensors have their IDs as a marker. Users who want to utilize the data buoy buoy ID simply states that the data will be retrieved. Around the world, the distribution is uneven buoy sensors. Buoy sensors are found in coastal regions of America and the Pacific. Whereas in other areas, particularly Indonesia, buoy sensor is not commonly found. Sensor buoys in the located in the sea of north Sulawesi can be used to predict the potential tsunami that may occur in the waters of the Philippines and North Sulawesi.

```
public function get_earthquake_data()
{
   Set starttime and endtime of data;
   Initialize json object;
   Initialize array for data holder;

   for each features in json object do {
        copy to data holder
   }
   return $data;
}
```

Program 2. Pseudocode for Extracting Real-Time Seismic Datafrom USGS Web Service

Data shown on NDBC server using a simple text file format that can be downloaded using the HTTP protocol, wget, or Perl / LWP. It is recommended to use the HTTP protocol in the process of downloading data. Realtime folder (data/ realtime2) contains data within the last 45 days. In general, real-time data is data that has been through an automatic quality control being released in the global telecommunications system. Station_id.datatype named file.

In addition to using the HTTP protocol, the data from NDBC can be obtained from the RSS, e-mail, and telephone. NDBC data format used among others:

- txt, for standard meteorological data
- drift, for meteorological data from drifting buoys
- cwind, for continuous wind data
- spec, for a summary of spectral wave data
- data_spec, to raw spectral wave data
- swdir, for data spectral wave (alpha1)
- swdir2, for data spectral wave (alpha2)
- swr1, for data spectral wave (r1)
- swr2, for spectral wave data (r2)
- ADCP for acoustic doppler current profiler
- ocean, to the data oceanographic
- tide, for a tidal wave of data

NSTWS utilizing data provided by the USGS Earthquake to show information about the earthquake that occurred in the region of North Sulawesi within the last 24 hours. Program 2 is a pseudocode to retrieve location information of the earthquake, the depth of the epicenter, the quake strength, latitude and longitude, time and potential tsunami.

The bathymetry data represents the basic topology sea and land. NSTWS need bathymetric data for the North Sulawesi region. Bathymetry data is used to perform simulations of the tsunami affected areas. The system models the tsunami wave velocity of water and then combined it with bathymetric data to predict the impact of the tsunami and height of tsunami in various areas in North Sulawesi.

The bathymetry data can be retrieved by observing the North Sulawesi region using sonar and utilize the help of satellites (GPS) to determine the position. Some institutions have a worldwide bathymetric data that can be utilized by the NSTWS. Bathymetry data sources used in this study comes from the General Bathymetric Chart of the Oceans (GEBCO). the data consists of latitude and longitude coordinate data along with height / depth of a location on the earth's surface. GEBCO bathymetry dataset provides two types of the GEBCO One Minute Grid and GEBCO 30 Second Grid. GEBCO One Minute Grid is a global bathymetric data are represented in arc-minute grid. The second type of bathymetric data is GEBCO_08 Grid, the global bathymetric data were represented in the 30 arc-second. This data is processed from the data with the interpolation ships depth gauge gravity data obtained from satellites. GEBCO_08 Grid is still actively developed until now.

In this study, NSTWS system using bathymetric data in the form of GEBCO One Minute Grid. General data is provided by GEBCO global data (the whole world). This data is then processed to obtain the data from North Sulawesi are located at 5.7°N - 0.3°S and 120°-130°E (latitude 5.7° north up to -0.3° south and longitude 120° -130° east). This data is then stored into the database system to be used further.

B. Experimental Method

Data Mapping Bathymetry from GEBCO to Google Maps

To obtain elevation data points entered by the user, the system will select the closest point that has been stored in the database. Then the system will use the elevation data at the closest point. In general, the algorithm for determining the height of a point elaborated in the following steps.

1. Calculate the difference in latitude is requested with latitude all points.
2. Calculate the difference in longitude longitude requested with all the points.
3. Sort the data difference between latitude and longitude ranging from the smallest difference.
4. Take the first point resulting from the third step. Thus obtained the closest point on the system with the desired point.
5. Find the height of a point that has been obtained in the fourth step.

Visualization of Tsunami Affected Areas

To show the area affected by the tsunami, the system takes a digital map for the region of North Sulawesi. This digital map should be coated (overlay) into several layers in order to display the information of the area affected by the tsunami. Each layer displays different information. This layer is used to visualize the wave height sea water and the estimated time of arrival.

NSTWS utilizes digital maps provided by GoogleMaps. GoogleMaps provides functions are summarized in the Google Static Maps API that allows for the coating of digital maps with any information. GoogleMaps provides several modes appear on a digital map, namely: mode terrain map mode.

Flood Fill Algorithm

NSTWS uses Flood Fill algorithm for modeling dispersion of flood due to potentially cause a tsunami. This algorithm determines the areas that are connected to the point (node) in a particular multi-dimensional arrays [7]. In the case of simulation, the epicenter of the earthquake is entered by user. In the case of life event, the epicenter of the earthquake is input from the data provider. From the epicenter, the algorithm detects the affected areas around the point from different directions and within a certain distance or radius corresponding to the height of sea waves.

In NSTWS system, flood fill algorithm is processed by calculating the elevation or contour of the land. The land contours affects the water wave height up to the shoreline. Program 3 displays pseudocode flood fill algorithm that is used for modeling the flood dispersion. The input of this function is the epicenter coordinates (latitude and longitude)

```
Public function run ()
{
   Initialize latitude epicenter;
   Initialize epicenter longitude;
   Initialize wave height;
Initialize overlaid grid size to 1 minute,
and bathymetric to 6 minutes;
   Initialize data holder to NULL;
   Initialize pointCount to 0;


   From epicenter, start flood fill algorithm
(point (x,y), fill, old)  {
if ((x < 0) || (x >= width)) return;

   if ((y < 0) || (y >= height)) return;
   if (getPixel(x, y) == old) {
   setPixel(fill, x, y);
   floodFill(x+1, y, fill, old);
   floodFill(x, y+1, fill, old);
floodFill(x-1, y, fill, old);
floodFill(x, y-1, fill, old);
}
}
Visualize data ;
}
```

Program 3. The Pseudocode of Flood Fill Algorithm for NSTWS Applications.

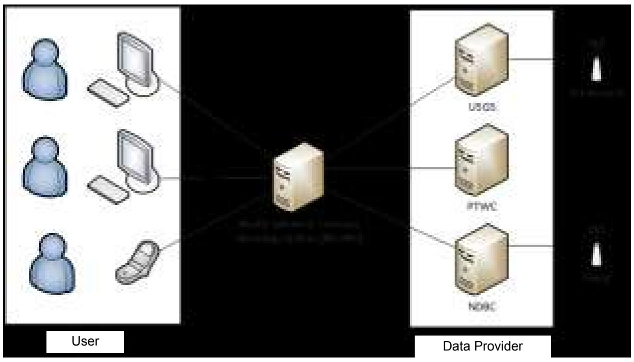

Figure 2. NSTWS Interconnection Architecture.

and high sea waves. This function provides outputs in the form of location, time and high waves in the tsunami affected areas.

NSTWS Interconnection Arthicture with Data Provider

In accordance with the global architecture in Figure 2, NSTWS requires interconnection of data with the data provider. It extracts the description of data with minimal variation in the availability and format of the data available from various data providers, and then takes a special mechanism that can facilitate the addition and replacement of data sources.

The interconnection architecture is modularly designed, so that anyone can create a data provider module that can be accessed uniformly by NSTWS. When a connection of a module is not available, then NSTWS can automatically turn to other available module. To be able to do, an interface class is created for each module based on the description of the minimum data requirements. Figure 3 describes the class diagram that contains a class interface standard used to establish a connection with any data provider that is

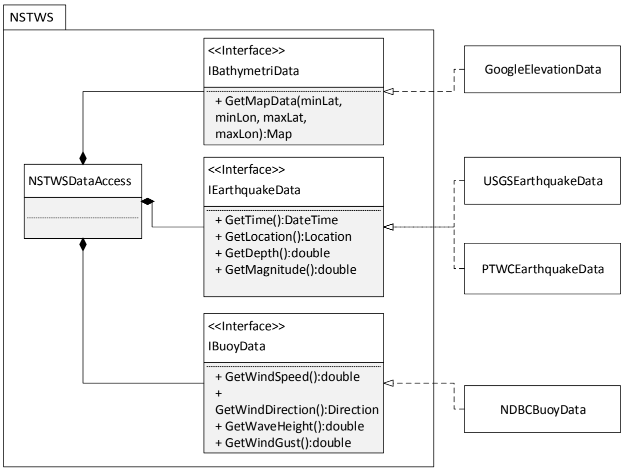

Figure 3. NSTWS Class Diagram.

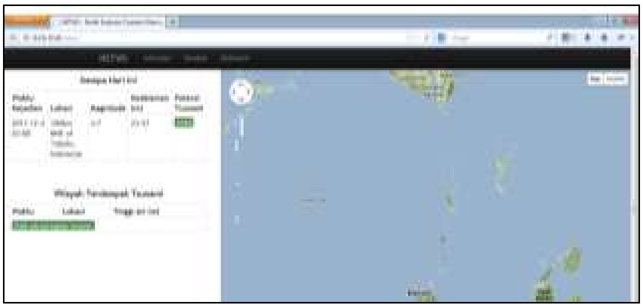

Figure 4. NSTWS Information Page.

wrapped into a module. For example, seismic data module defined on IEarthquakeData. There are two modules that implement these interfaces is USGSEarthquakeData and PTWCEarthquakeData. NSTWS data providers can use both interchangeably if one does not work.

III. Results and Discussion

NSTWS applications can be accessed through the main web page that has three pages, i.e. information, simulation, and bathymetry pages. To test the system, this study uses two scenarios. First scenario aims to validate the model implementation against the referred algorithms. The second scenario aims to verify the functionalities of the features implemented in the system. For testing the model, a data associated with the North Sulawesi region was used. As for testing the functionality of the system, a set of use cases is used. These use cases were captured during the developed process which is conducted in the early phase.

Information Page

This page shows information with regard to the event of earthquake that occurred within the day. It displays the earthquake occurrence time, location and depth of the epicenter, the earthquake scale, and the status of a potential tsunami. If it has high probability of producing a tsunami, then the system displays the information about tsunami affected areas. It includes the approximate time of the tsunami reach the shores, the location affected, and sea levels. In addition, the area affected by the tsunami will be visualized on a digital map as shown in Figure 4.

Bathymetry on the web page NSTWS provide services to determine the level of land relative to sea level by entering latitude and longitude coordinates of a location. Bathymetry page views can be seen in Figure 5.

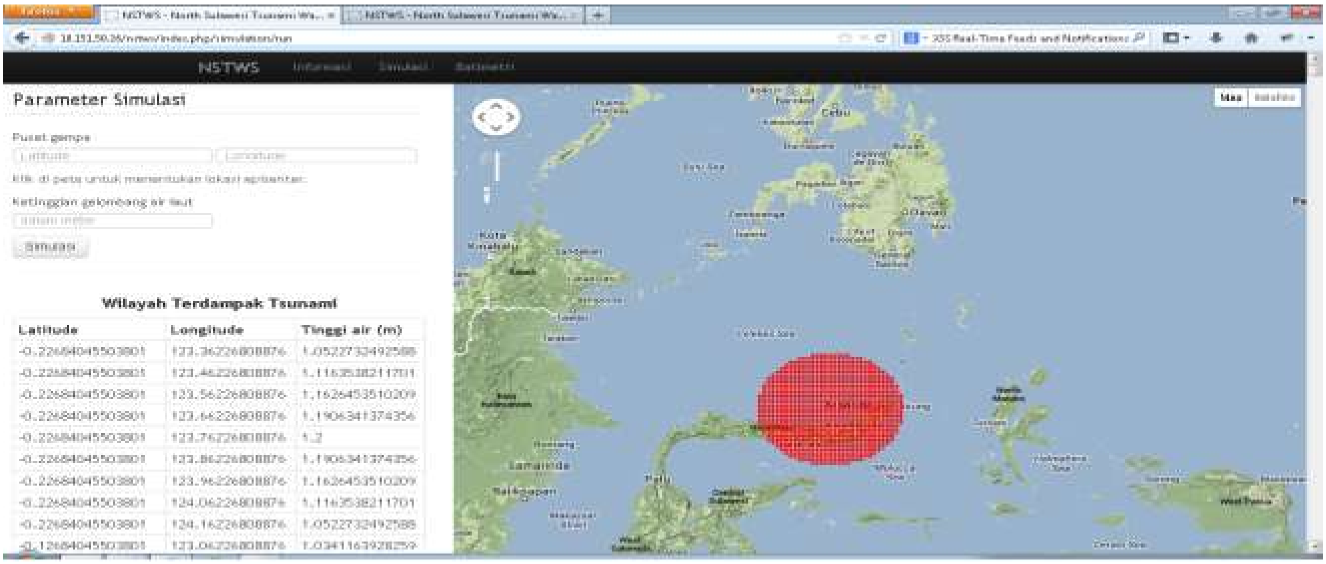

Figure 5. NSTWS Simuation Page.

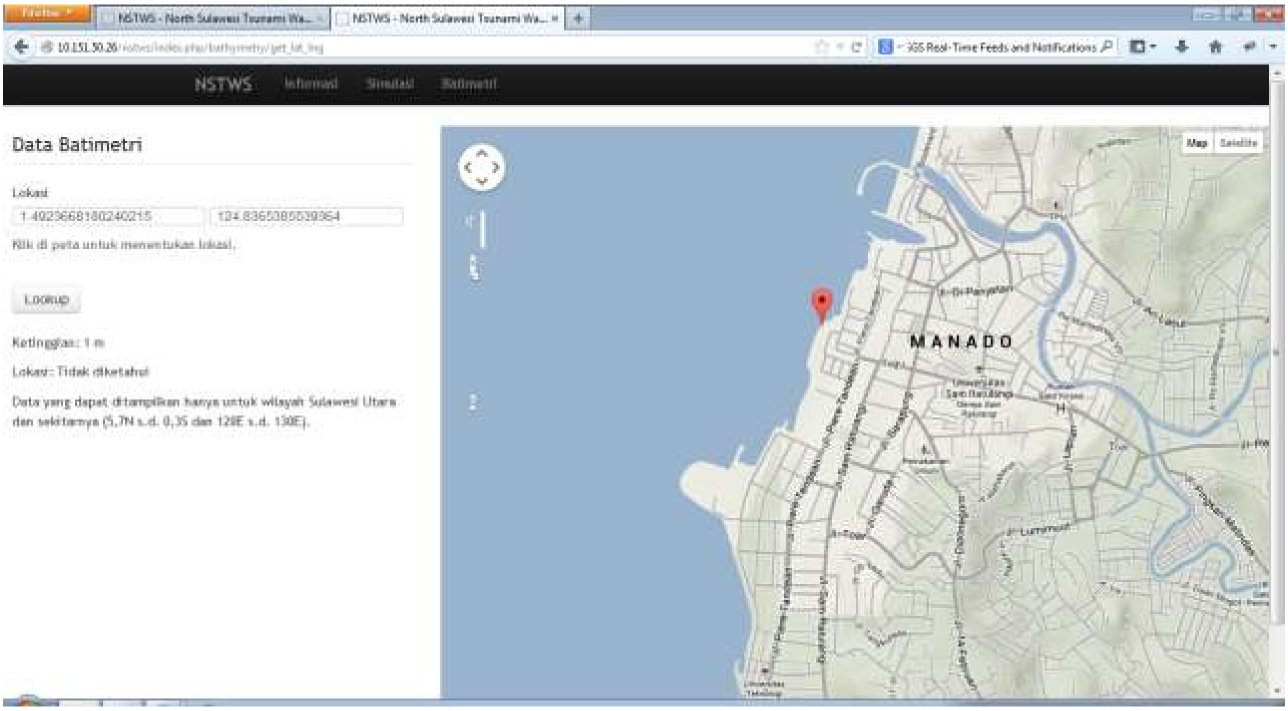

Figure 6. NSTWS Bathymetric Page.

Simulation Page

The simulation page of NSTWS provides a means of simulating the tsunami affected areas on a digital map. To display the region affected by the tsunami simulation, users need to enter data applications NSTWS epicenter location (latitude and longitude) and height of sea waves. In addition to displaying a visualization of the tsunami on the digital map, the system will display a list of locations NSTWS affected by the tsunami as shown in Figure 4.

Bathymetry Page

IV. CONCLUSIONS

Based on the results NTSW development, it can be concluded that the development of systems based NSTWS seismic data can be implemented with multiple needs. Minimum requirement that must be met by the data provider is obtaining (1) bathymetric data and seafloor topography, which is used for modeling the tsunami waves, (2) seismic data in the form of time, location, depth, and magnitude of the earthquake, and (3) sea wave conditions such as wind speed, wind direction, wave height of sea water, and wind.

The system provide a graphical means of modelling and visualizing the tsunami and its effect using digital map. The digital map overlaid with a grid size of 6 minutes. While the bathymetric data used is 1 minute. It is intended that the processing time becomes shorter. On the other hand, it causes loss of precision in predicting the tsunami affected areas.

To facilitate the change and change the data provider, NSTWS provide several classes of standard interfaces that can be implemented into several independent modules for each data provider. Thus, when the module is not functioning, then the system can use the module NSTWS other data providers.

Due to the lack of sensor buoys in North Sulawesi, then use a data buoy synthetic NSTWS to perform simulations.

The use of flood fill algorithm can not handle the amount of data that a lot of the 216,000 bathymetric data for North Sulawesi and the surrounding region. So, we need another algorithm that is more efficient, but it can also use parallel programming. In addition, the size of the grid on the maps that are supposed to be equal to the size of the overlay grid of bathymetric data so that predictions of the location of the tsunami affected more detail.

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REFERENCES

[1] M. Webster, "Tsunami defintion," Merriam-Websters. Merriam-Webster. Access on 23 March 2013.

[2] S. Diposaptono, Tsunami Mitigation Technology. In 2005.

[3] S. Kumar, Shailesh N., P. Kumar, RBS Yadav, BA Kumar, MV Sunanda, EU Devi, NK Kumar, SA Kishore, and SSC Shenoi, "Successful monitoring of the 11 April 2012 tsunami off the coast of Sumatra by the Indian Tsunami Early Warning Centre, "Current Science, vol. 102, no. 11, pp. 1519-1526, June In 2012.

[4] SD VORDZORGBE, "Synthesis of the findings of the regional early warning Consultations in Africa, Asia, the american hemisphere and Europe," in Report For The Second International Early Warning Conference (EWC ii), Bonn, Germany, 2003.

[5] J. Wächter, A. Babeyko, J. Fleischer, R. Haner, M. Hammitzsch, Kloth A., and M. Lendholt, "Development of a tsunami early warning systems and future challenges," Nat. Hazards Earth Syst. Sci., Vol. 12, no. 6, pp. 1923-1935, June In 2012.

[6] W. Hanka, J. Saul, and T. Hoffmann, "GEOFON, GITEWS and the Indian Ocean Tsunami Warning System," in EOS, Transactions, American Geophysical Union, San Fransisco, 2008, vol. 89.

[7] T. J. Lujan, S. M. Madey, D. C. Fitzpatrick, G. D. Byrd, J. M. Sanderson, and M. Bottlang, "A computational technique to measure fracture callus in radiographs," Journal of Biomechanics, vol.43, no. 4, pp.792–795, Mar. In 2010.