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A prototype of an integrated information system for geographic information produced during the rehabilitation and reconstruction process following the earthquakes and tsunami disasters in Aceh province, Indonesia

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A large amount and variety of geographic information has been produced to support the four years' rehabilitation and reconstruction (RR) process following the earthquake and tsunami disasters in December 2004 in Aceh province, Indonesia. After the RR process, the geographic information has been handed over to the Aceh Geospatial Data Center (AGDC), managing information services and supporting decision making for sustainable development in the Aceh province. However, AGDC has no integrated geographic information system (GIS). Therefore, the authors developed a prototype for an integrated GIS. The system is implemented with ESRI products such as ArcIMS Server, ArcGIS Server, ArcSDE Geodatabase connection for PostgreSQL/PostGIS and ArcGIS Desktop. The system consists of various geographic information produced during the RR process and geographic information related to Aceh province, which has been collected by the first author. Metadata and Metadata catalog service are also provided by the system. The target users of the system are AGDC staff, local government decision-makers or end users, and application developers. Examples of analysis using the system indicate the potential to support the planning of sustainable development. AGDC has evaluated that the system is suitable for implementation. Consequently, the authors concluded that the system will be useful for Aceh province, Indonesia.

Keyword: tsunami disaster, geographic information system, metadata, data management, information service

1. Introduction

The devastating tsunami of December 26th 2004 destroyed or badly impacted every sector in the Aceh province, Indonesia[1]. Another earthquake hit Nias island in North Sumatra province on March 29th 2005. These two disasters are called the Aceh - Nias disasters. On April 15th, 2005, the Indonesian government established the National Bureau for Rehabilitation and Reconstruction (BRR) to

manage 2,200 international or Indonesian special projects for rehabilitation and reconstruction (RR) process following the Aceh - Nias disasters. The formal RR phase was the period between April 2005 and April 2009.

Geographic information has turned out to be necessary and very useful in the RR process. A large amount and variety of geographic information has been produced by many international or Indonesian special and temporary project teams to support the RR process.

Table 1 The geographic information in Aceh province [2] [3][4] [5] [6] [7]

Item No.	Producer	Type of Map	Resolution/Scale	Area	Year
1	BAKOSURTANAL	Topographic line map	Scale 1:50,000, Scale 1:250,000	Entire Area Aceh Nias	1970s
2	NORAD/BLOM[*1] BAKOSURTANAL	Aerial imagery Topographic Line Map	Resolution: 30cm 1:5,000 and 1:10,000	Around 6000 sq km Around 6000 sq km in affected area	2005 2006
3	JICA - study team in Aceh province	Topographic line map ARRIS[*2] thematic map	1:2,000 1:2,000	Banda Aceh area Banda Aceh area	2005 2005
4	World Bank/BPN RALAS[*3] program	Land parcel maps		Tsunami affected area in Aceh – Nias	2005
5	LAPAN[*4] supported by EUROSAT/UN disaster chapter	SPOT5 LANDSAT 7 ASTER IKONOS	2.5m panchromatic 30 meter pre and post tsunami	Tsunami affected area Tsunami affected area Tsunami affected area Banda Aceh & Meulaboh	2005
6	BGR[*5]	Airborne electromagnetic map ground water map		Banda Aceh, Sigli, Meulaboh and Calang district	2005
7	AusAID[*6] and BAKOSURTANAL	IFSAR DEM (Digital Elevation Model)	Resolution: high, Scale 1:2,500	14,832 sq km	2007
8	BRR	Barrack geodatabase	Point feature	Entire Aceh area	2006
9	BRR	Housing geodatabase	Point, line and polygon feature	Entire Aceh and Nias area	2008
10	AusAID-GTZ AMAP[*7]	Asset mapping spatial data	Point, line and polygon feature	Entire Aceh and Nias area	2009
11	UNDP-BRR Technical Team	Asset geodatabase	Point and line feature and other data	Entire Aceh and Nias area	2009

*1 BLOM (Norwegian Geographical Information Company)

*2 ARRIS (Aceh Rehabilitation & Reconstruction Information System) [5]

*3 BPN-RALAS (National Land Agency, Indonesia) - Reconstruction of Aceh Land Administration System, Indonesia)

*4 LAPAN (National Aerospace and Aviation Association, Indonesia)

*5 BGR (The Federal Institute for Geosciences and Natural Resources, Germany)

*6 AusAID (The Australian Agency for International Development)

*7 AusAID funded the Asset Mapping Assistant Project (AMAP), which is managed by GTZ (German Agency for International Cooperation).

However it is difficult to collect such geographic information. The collection and preparation of geographic information are important for use in GIS (geographic information system), because the information is necessary and useful for the future developments of the Aceh province. An integrated GIS is also necessary to manage and use the information. Therefore, the objectives of this study are to collect the information, to

prepare it for use in GIS, and to develop a prototype for an integrated GIS for the Aceh province.

We will explain the geographic information and applications in the RR phase in this section. The problems of existing applications at Aceh Geospatial Data Center (AGDC) are mentioned in section 2.

We will describe the design, architecture and services of our prototype system in section 3, the system functionality for AGDC staff, decision-makers and end users, and application developers in section 4, analysis in section 5, and discussion including evaluation of the prototype in section 6. Section 7 is the conclusion of this paper.

1.1 Geographic information produced during the rehabilitation and reconstruction phase in Aceh province

During the RR phase, many kinds of geographic information were produced in the different RR projects as shown in **Table 1**. Various RR projects used basic geographic information shown in **Table 1** in the RR phase.

In order to provide the geographic information, BRR and international agencies established the Spatial Information and Mapping Centre (SIM-C), which was a special center used in the RR phase only. BRR and the Indonesia National Agency for Survey and Mapping (BAKOSURTANAL) also established the Geospatial Task Force (GTF) to provide geographic information services based on national mapping standards [8].

SIM-C produced in excess of 9,000 maps and other information [9] and distributed around 2,773 hard copy maps, 706 digital copies of spatial data and 90 aerial images requested by users at BRR. Suwandy et al. [10] in 2009 discovered 30,000 ESRI shapefiles, received from many agencies on the SIM-C's data server.

The first author has participated in the RR process for 2 years, and took part in maintaining a large quantity (approximately 12 Terabyte) of geographic information, including around 2,000 ESRI ArcMap Documents [11], available on GTF's and SIM-C's data servers.

AGDC [12-14] was established at the Aceh Development Board Office (BAPPEDA) by BRR with support from SIM-C, GTF and other agencies on December 2006. While BRR, SIM-C and GTF are temporary organizations, AGDC is a permanent organization for Aceh province. After the RR phase, a large amount and variety of geographic information about Aceh province in various formats has been handed over to AGDC.

The main tasks of AGDC [12] are (a) to give access to geographic data and information easily and quickly, (b) to encourage the utilization and integration of data and information to support decision-making for sustainable development, and (c) to improve the understanding about the use of geographic information in Aceh province.

1.2 GIS applications implemented or used in rehabilitation and reconstruction phase

Many GIS applications were implemented during the RR phase. They are: 1) GeoNetwork Opensource [15] implemented by SIM-C, 2) GeoSamba [16] developed by NGIS Australia, 3) Huntara Online [16] developed by

BRR and SIM-C, 4) GEOTEC Germany Camtrixx [16], 5) BRR-GTF Web mapping application [17] implemented by BRR-GTF using Autodesk MapGuide Enterprise [18], 6) AGDC Web mapping [19] developed by SIM-C. Most of these applications were developed to suit a particular purpose, and they were not designed as an integrated system.

In April 2009, at the end of the RR process, the applications mentioned above were handed over to AGDC.

ADGC implemented Geoportal (http://gdc.nad.go.id) in October 2007. The Geoportal was equipped with GeoNetwork Opensource, and was developed by AGDC with support from a national consultant [13] and SIM-C.

ESRI ArcGIS Desktop was used in SIM-C in the RR phase, and has been used in AGDC since the RR phase.

2. AGDC's issues to be considered

2.1 The problems of existing applications

Although AGDC received 6 applications mentioned in section 1.2, only AGDC Geoportal has been accessible through the Web since 2011. The possible reasons for inaccessibility of other applications are license agreements, the lack of maintenance staff, and compatibility among operating systems, database servers, and application platforms.

Currently, AGDC does not have an integrated GIS that can be used to efficiently and effectively manage and provide services for AGDC's huge store of geographic information. AGDC has only dealt with two

separate main applications: a metadata catalog service and a Web mapping application [20]. The latter is supported with PostgreSQL/PostGIS and MapServer[21] serving Web Map Service (WMS)[22]. That is an Open Geospatial Consortium (OGC) standard.

The disadvantages of the existing inefficient and ineffective work processes at AGDC are as follows.

a) ESRI ArcCatalog Metadata Editor has been used to create metadata in the ISO 19115[23] format. GeoNetwork Opensource XML metadata tool has been used to publish the XML metadata file. AGDC staff cannot directly publish the created metadata document to the metadata service from the catalog tree in ArcCatalog by dragging and dropping it into the metadata service.

b) AGDC staff can not automatically provide live map services to users when publishing metadata document into the metadata service. Therefore, users cannot directly use the live maps of geographic information services, retrieved from the metadata catalog service, in the client side GIS Desktop software.

c) AGDC staff cannot directly utilize the large amount of ArcMap Documents, received during the RR process, as input to create and publish Map Services. This is due to the fact that MapServer uses a Mapfile to create WMS.

d) The existing work process of using the PostgreSQL/PostGIS does not allow AGDC staff to directly store geospatial data to

geodatabase from ArcCatalog. Therefore, users also cannot directly access the published geodatabase in ArcGIS or other GIS Desktop software.

e) AGDC staff cannot easily create and customize Web mapping applications.

2. 2 GIS software used in Aceh province

SIM-C has trained 796 local government staff on operating ArcGIS Desktop in beginner, intermediate and advanced training programs[16]. A study of the use of GIS software in Aceh reported that a significant number of users know and use ESRI software. The study shows that 33 governmental users and 16 non-governmental users use ESRI software and 8 governmental users and 12 of non-governmental users use non-ESRI software[24].

These studies [16] [24] clearly showed that AGDC staff and Aceh local government staff, who have tasks related to spatial planning, are familiar with operating the ArcGIS Desktop.

3. System design, architecture and published services

3.1 System requirements

We have analyzed issues and conditions mentioned in section 1 and 2. There are three target users of our system. They are AGDC staff, local government decision-makers or ordinary end users, and application developers.

The system requirements for an integrated GIS for the three types of users are as follows:

a) AGDC staff need an integrated GIS that can be used to easily manage and provide services relating to their huge store of geographic information, especially

ArcMap Documents. These include several applications:

- Geodatabase management system, used to manage the geodatabase for the fundamental dataset and other geospatial data,
- Map server, used to manage and publish map services,
- Metadata catalog service, used to manage and publish metadata documents of various types of geographic information,
- Web mapping manager, used to create simple or advanced Web mapping applications,
- Applications, which can easily and directly utilize a lot of ArcMap Documents for providing map services.

b) Local government decision-makers or ordinary end users need the following services:

- Metadata catalog service, used to browse and search content metadata services for geographic information,
- Live data and maps services, found from metadata search results, which can be directly added as layers in the GIS Desktop software,
- Geospatial database service, Image Service and Feature Service, which can be directly accessed in the GIS Desktop software,

c) An application developer needs geospatial database service, ArcMap Image Service, ArcIMS Image Service, ArcIMS Feature Service, ArcGIS Server Map Services, WMS and WFS, used in the developer's custom Web mapping application.

3.2 System architecture

In order to meet the system requirements, we designed an integrated GIS for the three types of users to access geographic information derived from various resources.

The system architecture shown in **Fig. 1** consists of the following three layers:

(1) Data layer:

(a) Geospatial data, (b) ArcSDE [25] Geodatabase, (c) PostgreSQL/ PostGIS spatial database,

(2) Server layer: ArcIMS Server [26][27], ArcGIS Server [28] and their services including ArcMap/ArcIMS Image and ArcIMS Feature Service, ArcGIS Server Map Services, and OGC-WMS/WFS,

(3) Application layer:

(a) GIS Desktop software:

(i) ArcGIS Desktop,

(ii) ArcExplorer [29],

(iii) QuantumGIS (QGIS) [30], etc,

(b) ArcIMS Administrator [31],

(c) Web applications:

(i) ArcGIS Server Manager,

(ii) ArcIMS Metadata Explorer[32] [33],

(iii) ArcGIS Server REST API [34],

(iv) Web mapping applications,

(d) Custom applications.

AGDC staff can manage and access the server layer and the data layer through the application layer (3). Decision-makers or ordinary end users access services in the server layer and the data layer through the application layer (3)(a), (3)(c)(ii), (3)(c)(iii) and (3)(c)(iv). Application developers consume services in the server layer and the data layer through a custom application (3)(d).

3.3 Published services

ArcIMS Server provides geographic information through ArcMap Image Service, ArcIMS Image Service and ArcIMS Feature Service, which are created from geographic information in the data layer, and are published. A source of ArcMap Image Service is the ArcMap Document (MXD file). The AXL[35] file (ArcXML based map configuration file) is a source of ArcIMS Image Service and ArcIMS Feature Service (See **Table 2**).
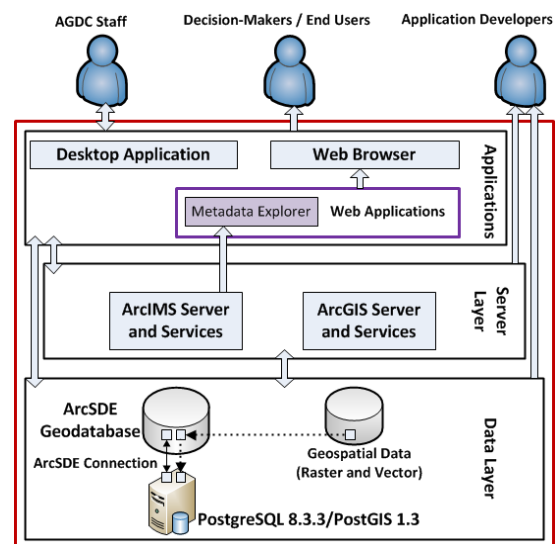

Fig. 1 The architecture of our integrated GIS and its users

ArcGIS Server provides geographic information through ArcGIS Server Map Service, which is created from geographic information in the data layer, and is published. Either MSD (Map Service Definition) file or ArcMap Document is a source of ArcGIS Server Map Service.

The first author collected the geographic information in Aceh province from the various projects and centers in the RR phase in order to utilize them for our system as shown in **Table**

2. The collected geographic information consists of various formats including shapefiles, ArcMap Documents, ESRI Personal Geodatabases (Microsoft Access data files), PostgreSQL/PostGIS database backup files, non-georeferenced images and maps in reports, georeferenced raster images, e.g. aerial orthophotos, satellite images, scanned maps, etc.

We further emphasized using all geospatial data from the "Thematic atlas of Aceh province project [36]" (see item No. 4 of Table 2), in which the first author has taken part as a cartography editor. The thematic atlas covers almost all thematic data in the entire Aceh province, because information from many Indonesian national departments has been compiled into the atlas.

The collected geographic information is stored in ArcSDE geodatabase and geospatial data in data layer as shown in Fig.1.

How to create and publish services will be described in section 4.1.

Table 2 Selected list of collected geographic information and published services in our system

Item No	Name of geospatial data or project	Total No. of the Published Services (using AXL/MXD /MSD)	Total No. of ArcMap Documents	Total No. of Imagery	Total No. of ESRI Shapefile and Feature Class	Total No. of ESRI / PostgreSQL Geodatabase	Correspondent to item No. of Table 1
1	Topographic line maps (1978) 50,000	20	11	-	340	-	1
2	Topographic line maps (1978) 250,000	10	10	-	72	-	1
3	Topographic maps 1978 50k (scanned maps)	10	0	98	-	-	1
4	Thematic atlas of Aceh province [36] project	52	50	29	160	-	
5	NORAD orthophoto Aceh area imagery	39	36	1480	-	-	2
	- Banda Aceh city area imagery	25	26	104	-	-	
	- Aceh Barat district area imagery	14	10	566	-	-	
	- Sigli district area imagery	-	-	810	-	-	
6	NORAD TLMs compiled by SIM-C	23	31	-	2069	-	2
7	AusAID IFSAR imagery	10	14	90	4	-	7
8	Aceh spatial planning project by SIM-C	20	40	37	376	5	
9	Prospect area of natural resources in Aceh	4	4	-	4	-	
10	Spatial data exchange in Aceh project[37, 38]	20	22	337	136	1	
11	BRR housing geospatial data	5	63	-	26	1	9
12	Asset mapping geospatial data	6	6	-	63	1	10
13	JICA –ARRIS geospatial data	10	76	69	192	18	3
14	ADB-ETESP-SPEM* in Aceh project	5	26		414	4	
15	ADB-MCRMP** for Aceh disaster response	2	3	20	87	2	
16	BRR-GFT infrastructure map of Banda Aceh	10	20	-	109	-	
17	Leuser forest ecosystem geospatial data	6	10	-	183	-	
18	Barracks IDP geospatial data	6	24	-	39	1	
19	UN-HIC 2005- geodatabase	3	5	-	105	3	
20	Sea defense consultants coastline spatial data	6	6	4	20	-	

* ETESP-SPEM: Earthquakes and Tsunami Emergency Support Project – Spatial Planning and Environmental Management

** MCRMP: Marine & Coastal Resources Management Project

3. 4 Published metadata services

Our system provides ArcIMS Metadata Service and Metadata Explorer for users to search and access published services managed by ArcIMS Server and ArcGIS Server.

Metadata from ArcMap Image Service, ArcIMS Image Service and ArcIMS Feature Service are compiled as metadata documents, and are published into ArcIMS Metadata Service. Metadata document of the items of ArcGIS Server Map Service have also been compiled as metadata documents, and are published into ArcIMS Metadata Service. Accessing the items of ArcGIS Map Service is performed through ArcGIS Server REST API.

Metadata of published services are described according to ISO standard: ISO 19115:2003 [23] and FGDC (Federal Geographic Data Committee) [39].

4. System functionalities

4.1 System functionalities for AGDC staff
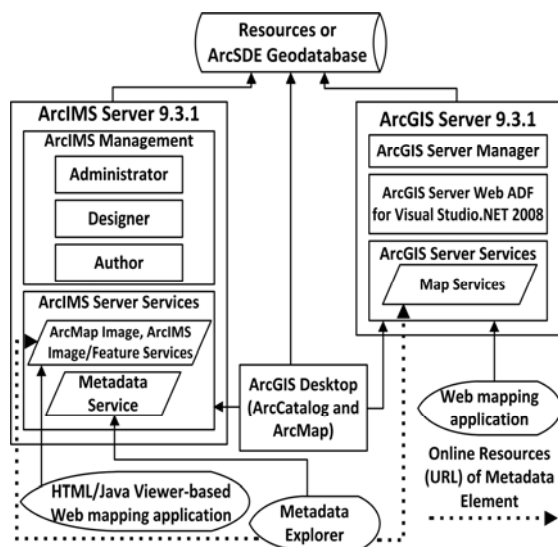
Fig. 2 Software components, service and data access in the integrated system

Our integrated GIS consists of software components as shown in **Fig 2.** The system allows AGDC staff to perform the following process:

1) To easily manage and serve ArcSDE Geodatabase

   This task is performed using ArcCatalog.

2) To easily provide geographic information services, which consist of two sub-tasks:

   2.1) Creating and publishing ArcMap or ArcIMS Image Service or ArcIMS Feature Service. This task is performed using ArcIMS Administrator.

   2.2) Creating and publishing an ArcGIS Server Map Service. This task is performed using ArcCatalog, ArcMap or ArcGIS Server Manager.

3) To create a metadata document and publish it onto an ArcIMS Metadata Service.

   This task is performed using only ArcCatalog.

4) To develop Web mapping applications, we used:

   4.1) ArcIMS HTM/Java viewer based web mapping application. This sub-task is performed using ArcIMS Designer.

   4.2) Microsoft ASP.NET based Web mapping application. This sub-task is performed using either ArcGIS Server Manager or Web ADF for Visual Studio.NET 2008.

The implementations of the integrated GIS service supporting the work of AGDC are described in detail below.

4.1.1 Storing and accessing geographic data in ArcSDE Geodatabase

Our system allows AGDC staff to easily store geospatial data into ArcSDE Geodatabase and access and manage it using ArcCatalog. The system also allows users, who use non-ESRI

GIS Desktop software such as QGIS and uDig [40], to directly access, query and visualize the geodatabase from PostgreSQL with PostGIS geometry storage type.

4.1.2 Providing geographic information services

4.1.2.1 Creating and publishing ArcMap Image Service, ArcIMS Image Service and Feature Service

Our system allows AGDC staff to create and publish ArcMap Image Service, ArcIMS Image Service and ArcIMS Feature Service.

AGDC staff can select which service is most convenient depending on the availability of geographic information types at AGDC. The huge MXD file can be directly used as an input to ArcIMS Administrator for creating an ArcMap Image Service. Georeferenced raster images, such as scanned maps and maps product, can also be published as ArcMap/ArcIMS Image Service.

ArcIMS Feature Service is generated by utilizing a AXL file as an input to ArcIMS Administrator. An AXL file can also be created using MXD to AXL converter [41]

4.1.2.2 Creating and publishing ArcGIS Server Map Service

ArcGIS Desktop 9.3.1 or ArcGIS Server Manager 9.3.1 is used to publish ArcGIS Server Map Service and manage the published ArcGIS Server Map Services.

ArcGIS Server Map Service is utilized here to provide additional external links (online resource or URLs) in the metadata element. We only provided online resources or URLs in the metadata document when we directly published a metadata document of geospatial data into ArcIMS Metadata Service without creating any prior ArcMap Image Service, ArcIMS Image or Feature Service for this geospatial data.

4.1.3 Creating and publishing metadata documents

In order to allow a user to directly bring geographic information retrieved from Metadata Explorer, our integrated system provides two ways of creating and publishing metadata of various geographic information.

The first way (way I) has 3 steps: I(a), I(b), and I(c) as shown in **Fig. 3**. As the result of way I, users can directly bring the published ArcMap/ArcIMS Image and ArcIMS Feature Service found in Metadata Explorer to their ArcMap. When publishing the ArcMap/ArcIMS Image Service's metadata, both a "Map Preview" and a "Special Links Add to ArcMap" will be available in the Details Tab in the Metadata Explorer, but when publishing the ArcIMS Feature Service's metadata, only the "Special Links Add to ArcMap" will be available.

The second way (way II) has 4 steps: II(a), II(b), II(c) and II(d) as shown in **Fig. 3**. Way II is only used when publishing any item's metadata (except the metadata from ArcMap/ArcIMS Image Service, ArcIMS Feature Service), because neither a "Map Preview" nor a "Special Links Add to ArcMap" will be available in the Details Tab in the Metadata Explorer.

As the result of way II, users can view a metadata document found in the Metadata Explorer in full HTML or XML mode and access the URLs of ArcGIS Server services

(REST-API) to preview geographic information with ArcGIS JavaScript on the Web browser and to directly bring ArcGIS Server Map Services to

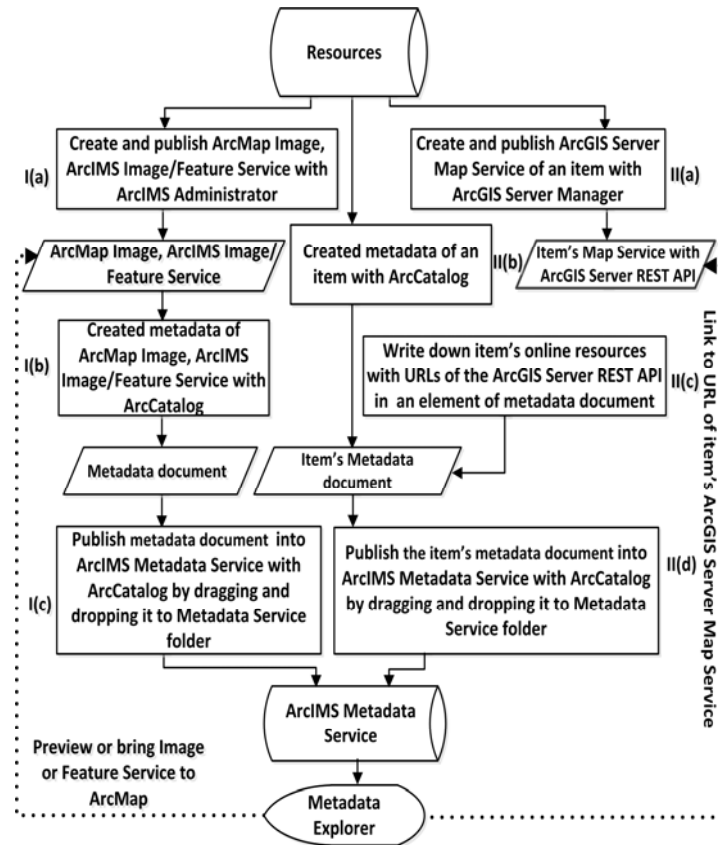their ArcMap, ArcGIS Explorer and Google Earth application.

Fig. 3 Two ways to create and publish metadata documents

4.1.4 Web mapping application

4.1.4.1 Creating the Web mapping application using ArcIMS Designer

ArcIMS Designer [42] is used to generate and customize a Web mapping application in the HTML Viewer or Java Viewer. It provides several kinds of map functionality in the Web mapping application, such as legend, scale bar, map extents, layer visibility, overview map and toolbar functions including zoom and pan, query, etc.

AGDC staff can easily utilize the ArcIMS Designer, choose ArcMap/ArcIMS Image Service or ArcIMS Feature Service, and customize several options for map

functionalities as shown in the ESRI ArcIMS manual [27].

4.1.4.2 Developing a Web mapping application using ArcGIS Server Manager

We implemented both ArcGIS Server Web Application Manager 9.3.1 and Web ADF 9.3.1 for the Microsoft .NET Framework for developing an ASP.NET Web mapping application. This system allows AGDC staff to develop a Web mapping application using either ArcGIS Server Manager or Visual Studio.NET 2008 integrated with ArcGIS Server Web Control.

AGDC staff can easily utilize the ArcGIS Server Manager, choose their ArcGIS Server

Map Services or ArcMap Image Service or ArcIMS Image/Feature Service as map service resources, and customize several options of map functionality in the Web mapping application. The process of developing an ASP.NET based ESRI Web mapping application [43] can be done without writing any code. However, when utilizing Visual Studio.NET 2008, AGDC staff need to have some .NET coding ability.

4.2　System facilities for decision makers and end users

The system allows local government decision-makers and end users to find geographic information by searching and browsing through the contents of ArcIMS Metadata Service using either ArcCatalog or Metadata Explorer. Users can bring the geographic information services found in the Metadata Service into their ArcMap.

1) Finding geographic information through Metadata Service with ArcCatalog

ArcCatalog can be used to search and browse the contents of a Metadata Service. ArcCatalog offers several search methods *i.e.* Name and Location Search, Geographic Search based on specific area, Date Search and Advanced Search [33]. After adding and establishing a connection to ArcIMS Server in ArcCatalog, a user can first search for geographic information and then directly utilize ArcMap/ArcIMS Image Service or ArcIMS Feature Services by dragging and dropping from the catalog tree in ArcCatalog to ArcMap.

2) Finding geographic information in Metadata Explorer

Metadata Explorer is used to search and browse content of ArcIMS Metadata Service through a Web browser [33]. After finding the geographic information in Metadata Explorer, users can utilize an ArcMap/ArcIMS Image Service, ArcIMS Feature Service or ArcGIS Map Service.

The main page of Metadata Explorer is divided into two areas: a left panel, containing (1) two search methods: Geographic Extent Search and keyword search, and (2) three category selections: content types, folders name and themes, and a right panel containing four Tab Menus: overview, catalog, place and detail as shown in **Fig**. **4**. In **Fig. 4**, Metadata Explorer displays several of the 52 items of the published metadata documents generated as the result of a search, where the keyword is "Bakosurtanal atlas".

4.3　System facilities for application developers

The system allows an application developer who wants to develop custom Web mapping applications to utilize geographic information services available at the AGDC. If the developers utilize ESRI technology, including ArcGIS Web ADF [43] or ArcGIS API for JavaScript [44], Silverlight.NET [45] and Flex [46], they can easily and directly consume ArcSDE Geodatabase and ArcIMS or ArcGIS Server Map Services.

If the developers utilize other technologies which have the ability to interact with an OGC standard WMS(Web map service)/WFS(Web feature service) for example OpenLayers[47], Autodesk MapGuide, they can consume OGC standard WMS/WFS of all ArcMap/ArcIMS Image Service and ArcIMS Feature Service

served through ArcIMS's WMS/WFS Connector[48][49]. Web mapping developers, who utilize OpenLayers and MapServer[21], can also visualize the geodatabase directly from the PostgreSQL/PostGIS using MapServer

connection for PostgreSQL in Mapfile. We used this method when visualizing the assets and the housing geospatial database in our previous study [50].

Fig. 4 The Metadata Explorer Catalog tab shows the list of metadata document

5. Analysis using our system

Our published geographic information (GI) services corresponding to the items in Table 2 can be used in analysis to support Aceh geographic planning, assessment and asset management. Typical examples of GI services are listed as follows.

(a) Thematic atlas GI service (corresponding to item no. 4 in Table 2) for hazard potential analysis, land-use analysis including conservation and natural resource analysis,

(b) GI service about NORAD/BLOM high resolution images (item no. 5) and TLMs

(item no. 6) for analysis to support decision making about tsunami affected areas.

(c) Asset mapping GI service (item no. 12) for analysis to support assets management,

(d) JICA-ARRIS GI service (item no. 13) for analysis to support disaster assessment and management, hazard and risk management, and city planning in Banda Aceh,

(e) ADB-ETESP-SPEM GI service (item no. 14) for analysis to support sub-district level geospatial planning and environmental management,

(f) ADB-MCRMP GI service (item no. 15) for

analysis of marine and coastal resources,

(g) Housing GI service (item no. 16) for analysis of reconstructed houses,

(h) Coastline GI service about Sea Defense Consultants' data (item no. 20) for analysis of coastline,

A simple example of analysis using queries is shown in section 5.1. Typical examples of analysis using plural GI services are shown in section 5.2, 5.3 and 5.4.
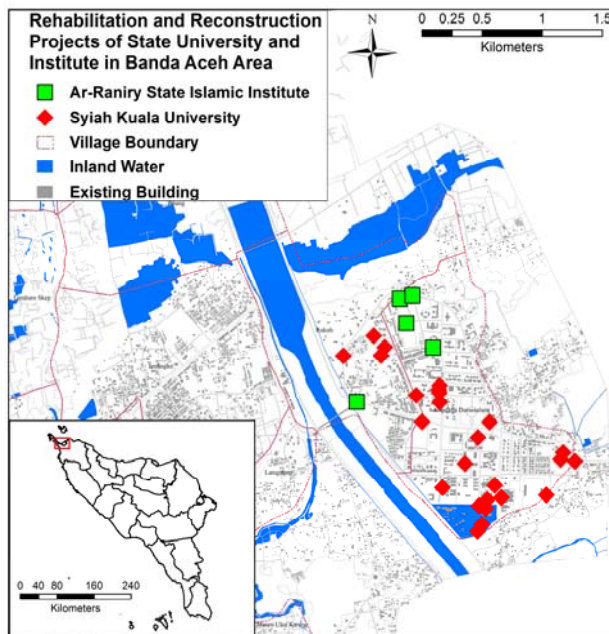

Fig. 5 A map from ArcIMS Feature Services showing the rehabilitated or reconstructed buildings and facilities in universities and institutes in Banda Aceh

5.1 Analysis of education sector using Asset mapping GI

In **Fig. 5**, the location of reconstructed buildings and facilities belonging to Syiah Kuala University and Ar-Raniry State Islamic Institute are shown with red diamond and green square symbols, respectively. Our system gets the location coordinates as the results of the query phrases to the ArcIMS Feature Service of the assets mapping GI as follows; One is

"ASSETNAME LIKE '%UNSYIAH%'" for Syiah Kuala University, whose asset name is UNSYIAH, and the other is "ASSETNAME LIKE '%IAIN%'" for Ar-Raniry State Islamic Institute, whose asset name is IAIN.

5.2 Analysis of reconstructed houses in Banda Aceh

An output of our system that overlays the layers of GI services relative to reconstructed houses is shown in **Fig. 6**. The following facts are listed based on **Fig. 6** and other relative outputs of our system.

(1) After the tsunami, the coastline has shifted inland by about 1.5 km. Data relating to coastlines before and after the tsunami provided by the coastline GI service in our system are used. Tsunami inundated areas and lines of tsunami water level contours are displayed using the JICA-ARRIS GI service of our system.

(2) Houses have been reconstructed not only in new relocation areas but also in areas affected by the tsunami. The areas marked with "A" were highly damaged by the tsunami. NORAD/BLOM high resolution images in our GI service show that almost all houses in the A areas are completely destroyed, however the images are not displayed in **Fig. 6**, because they overlap and eclipse the other layers. Our JICA-ARRIS GI service shows that a fishpond exists near to the A area. The existence of a fishpond indicates that it is necessary for persons farming fishes to inhabit near the fishpond. In the A area, houses have been reconstructed, and escape buildings have been constructed. The distribution of reconstructed houses and the location of roads are displayed using the housing GI service and asset mapping GI service.

Location data for escape buildings are received

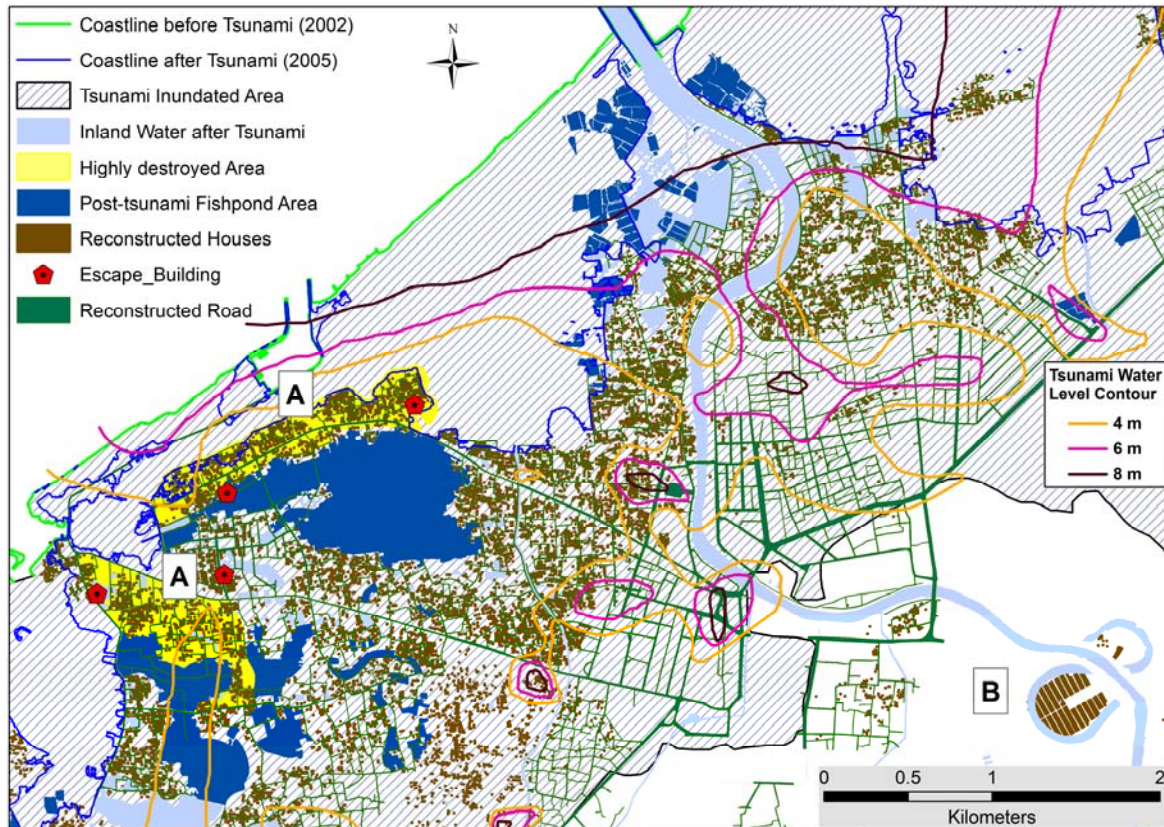from the GIS Center of Syiah Kuala University.

Fig.6 Distribution of reconstructed houses and relating issues in Banda Aceh

A: Highly destroyed area,　B: New domiciles

(3) The housing GI service displays that houses have been constructed in the relocated areas unaffected by the tsunami, such as the area marked with "B".

　The planning mentioned above keeps jobs of persons farming fish. The planning is reasonable, and indicates a kind of sustainable development. It indicates that our system has a potential to support the planning of a sustainable development.

5.3 Analysis of reconstruction in settlement and agricultural areas

　The width of the tsunami inundated area is around 7 km from the coast line as shown **Fig.**

7. The tsunami caused extensive damage to the region including settlement area "I" and the area of estate crop plantation "J" in south west coast of Aceh province. The following facts about the reconstruction are provided by our system.

(1) Many health sector facilities, such as sewers, community health centers, hospitals, etc., were provided or constructed by Japan, USA, Germany and other countries during the RR phase. The distribution of health sector facilities is displayed using the asset mapping GI service in **Fig. 7**.

(2) The location of reconstructed houses is near

location of health sector facilities. The distribution of reconstructed houses is not displayed in **Fig. 7**, because the overlap of the distribution of houses and health sector makes the distribution unclear. In our system, the distribution of reconstructed houses and the distribution of health sector facilities are displayed using housing GI service and asset

mapping GI service, respectively. The locations of reconstructed houses are divided into same areas and relocated areas. Examples of the former are the area "I" and area "J". Examples of the latter exist in dry land agriculture areas where the tsunami did not reach, as shown in **Fig. 7**. Land-use data is displayed using thematic atlas GI service.
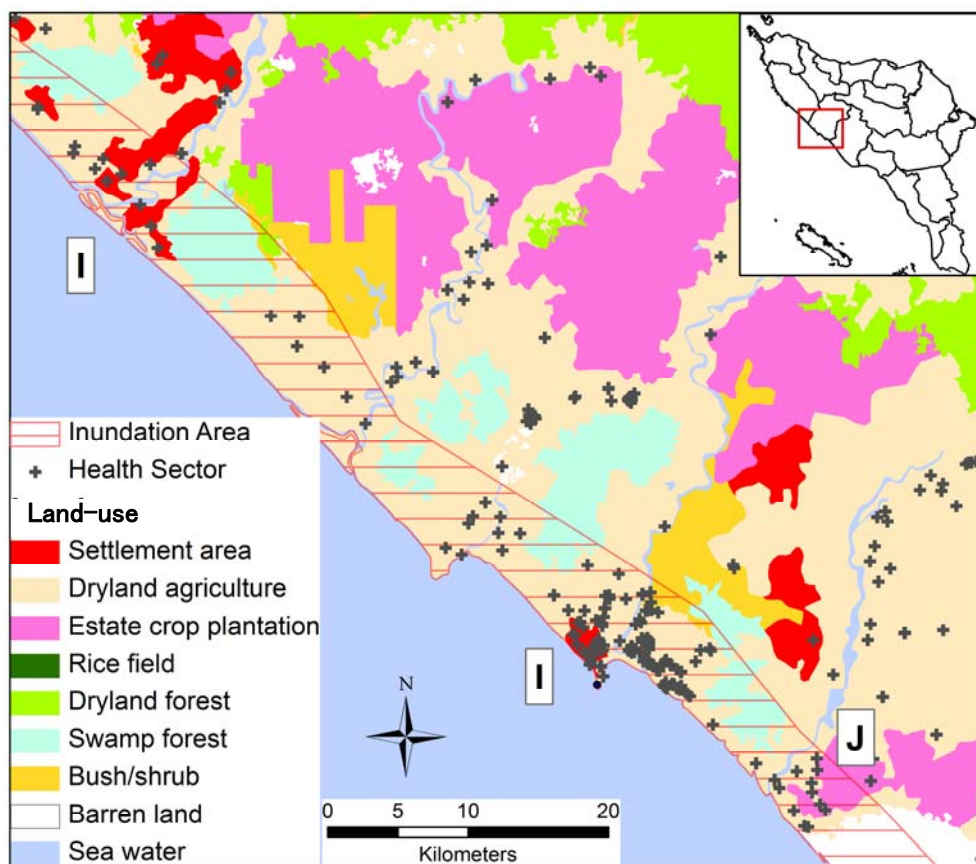

Fig. 7 Reconstruction and relating issues in agricultural regions on the south west coast
I: Settlement area damaged by the tsunami;   J: Area of estate crop plantation near coast

(3) Oil palms, coconut palms and rubber trees are planted in areas of estate crop plantation in Aceh province, and furthermore a coconut palm, a native plant, has been planted in areas near housing, and grows in Asian tropical coast. Thematic atlas GI

services can display the areas of the plantation as shown in **Fig.7**, but they do not contain information relating to the species of the plants. The area "J" near the coast was partially inundated by the tsunami. The GI service of NORAD/BLOM with aerial

high-resolution images have not been displayed in **Fig. 7**. They show that palm trees are planted in "J" area, but it is difficult for the authors to identify the species of palm, because the trunk of a coconut palm is different from that of an oil palm [51],[52], and because the trunk of the fallen palm is not found in the images in "J" area. The images from the plantation area, *i.e.*, the beach 2 km west of "J" area, shows that all trunks of fallen palms are trunks of coconut palms, and several destroyed houses.

The planning of relocation mentioned above keeps farmers' jobs in dry-land agriculture area. Our system indicates a potential to support the planning of sustainable development, since our system consists of land-use data.

5.4 Analysis of protected forest areas, plantation and mining concession areas

Aceh province is covered by around 3,469,450 hectares forest, which is classified into four categories [36]: production, protection, conservation and other. Conservation forest is strictly protected forest, and includes strict nature reserves, national parks, wildlife sanctuaries and natural tourist objects. Distributions of production forest, protection forest and conservation forest are shown in **Fig. 8**. Distributions of conservation forests in our system are generated with a definition query where Forest_Code LIKE 'CF' (CF = Conservation Forest) from ArcIMS Feature Service of forest area. The aggregated total of conservation forests is around 838,355

hectares, whose value is calculated with the ArcMap function for the statistical data in our system. The biggest area is Mount Leuser National Park with around 624,000 hectares.
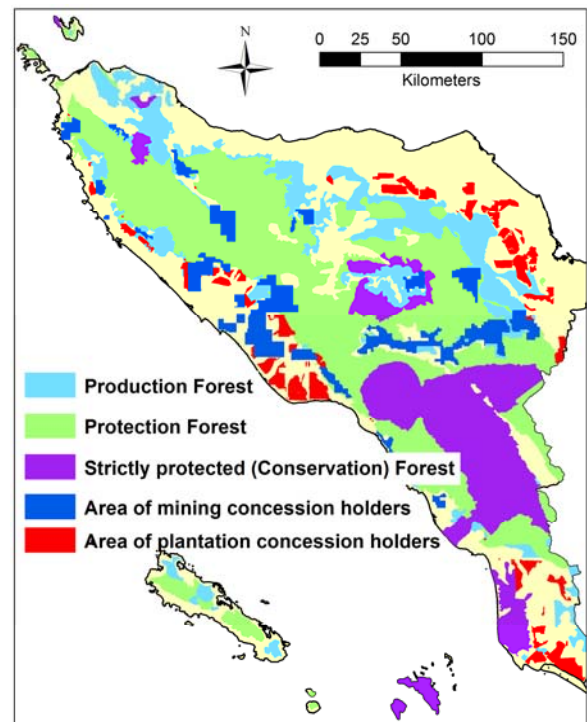

Fig. 8 Distributions of production, protection and conservation forests and areas of mining and plantation concession holders in Aceh province

Areas of mining concession holders in 2006 and 2007 and areas of plantation concession holders are shown in **Fig. 8**. There are 50 areas of mining concession holders and 93 areas of plantation concession holders in Aceh province. Mining and plantation are prohibited in a conservation forest. In a protection forest, only a mining concession-licensed holder can perform mining in the holders' area [53].

Since our system contains information about the distribution of production, protection and conservation forests and areas

of mining and plantation concession holders', a decision maker may make a plan for sustainable development.

6. Discussion

6.1 System evaluation by AGDC

The head and technical staff of AGDC evaluated our system as follows.

(a) The issues raised are problems that have been regularly faced by AGDC when they manage geospatial data.

1) The existing framework and applications in AGDC were developed based on different platforms and products. Consequently, some obstacles arise when AGDC staff try to integrate existing applications.

2) Much of the collected data including maps, metadata, and HTML do not follow the data standards defined by AGDC. This is because this collected data is created by various systems and applications during the RR process.

3) Many classifications of spatial data are not suitable with the standards theme adopted by AGDC. This condition makes it difficult to provide a good spatial data search services.

4) The different field names in the attribute table of the spatial data also cause a problem in sharing geospatial data.

5) Not all geospatial data has a spatial coordinate system.

6) There are many copies of base maps with different versions available in AGDC. This situation sometimes led AGDC to a problem, where AGDC needed to publish many version of the base map.

(b) The Advantages of the prototype system:

1) All geographic information published in this system has a spatial coordinate system;

2) The published geographic information can be directly consumed and used throughout ArcGIS software;

3) This system can be easily used to search and find geographic information because all published geographic information services in the system have metadata;

4) The geographic data shared in this system can be obtained through the web and directly used with ArcGIS Software because all the published geographic information has map services;

5) The designed work process and the developed integrated GIS are based on the ArcGIS software that is familiar and widely used in Aceh, therefore it should be a user-friendly system and easy to integrate;

6) ArcMap Documents (ArcGIS Project Files) can be directly used as an input to create a map service. This process can simplify the process of standardization of the map layout.

(c) The conclusions by AGDC:

This system is very suitable for implementation in Aceh, but the main obstacle is the high cost of buying an ESRI Server product.

AGDC described that this prototype has the six advantages, and concluded that it is

suitable for implementation in Aceh province. This shows that our integrated system can efficiently and effectively support and solve AGDC's task.

The issues that AGDC raised were analyzed by us before we designed our system. The No. 1 issue will be resolved with the adoption of our integration system. The No. 2, 3, 4, 5, and 6 issues are related to spatial data standardization. Therefore AGDC's data administration principle and data management including data clearance, data classification, and image georeferencing are expected.

Following this, our system should be even better at supporting the tasks of AGDC staff, and the keeping of many copies of geospatial data in other local departments in Aceh province will be unnecessary.

6.2 ESRI Geoportal Server

ESRI released the Geoportal Server version 1.2 in December 2011. ESRI Geoportal Server is a free and open source product used to discover geospatial resources [54].

"Register a network service feature"[55] supports GIS resources to register to Geoportal. The GIS resources include ESRI Metadata Server Service (ArcIMS Metadata Service), ArcGIS Server Services, etc. However, ArcIMS Image Services and ArcIMS Feature Services are not supported by the "Register a network service feature" [55]. Therefore we did not adopt ESRI Geoportal in our system.

6.3 System development using geoFOSS (free open source software) and maintenance of the system

GIS can be also developed using various

GeoFOSS (free open source software) components combined with each other. Stefanakis and Prastacos[56] have developed a spatial data infrastructure, *i.e.* a kind of GIS, using various GeoFOSS components. Their developments uses QuantumGIS and GoogleEarth as desktop client, OpenLayers as Web client, WMS for PNG and KML, WFS for GML and SHP, WCS(Web catalog service) for GeoTIFF, CSW(Catalog services for the Web) for ISO19115/19139 as interfaces between clients and servers, MapServer[21] as Map Server, GeoNetwork as Catalog Server, PostreSQL/PostGIS as GeoDatabases, shapefiles as vector data and satellite image files as Raster data. Their method for system development is inexpensive, but sophisticated. GeoFOSS components and their combination have been updated often. For example, the Web client OpenLayers has been used in GeoNetwork since version 2.6[57] instead of InterMap that was used until version 2.4[58]. The design of GeoNetwork version 2.8[59] has also begun.

It is possible for professionals of software development to develop integrated GIS by combining the various GeoFOSS components. However, a GeoFOSS based system is not suitable for AGDC at the present for the following reasons.

(a) Software maintenance of integrated GIS developed with various GeoFOSSs is difficult for the IT staff of AGDC, because none of them have experience in GIS programming. There are only three temporary staff working in IT. Their jobs

are the management of servers, including Web servers and database servers, and management of the network. As mentioned in section 2.1, almost all application software handed over to AGDC is inaccessible now. This fact indicates the current difficulties in software maintenance in AGDC now.

(b) Huge MXD files in AGDC must be converted into the files which can be used by the GeoFOSS based system. ArcMap MXD to MapServer converter is freely available from the ESRI's website[41]. The converter works with ArcMap 9.2, and converts the selected layers (up to 500) into the Mapfile format used in MapServer. Additional editing and testing processes are necessary. The editing process includes writing passwords and correcting unused characters. This conversion and additional processing is a troublesome task for the data processing staff, because there are only 6 of them, and they are fully occupied in their routine work.

In addition, there are 13 other staff members; 7 persons for survey and mapping including 2 temporary staff, 4 persons for administrative staff including 2 temporary staff, and 1 director and 1 manager. The total number of AGDC members is 22.

7. Conclusion

The purpose of this study is to develop an integrated GIS solution for three types of user: AGDC staff, local government decision-maker or ordinary users, and application developers. Our integrated system has been successfully developed. Examples of analysis using our system indicate the potential to support the planning of sustainable development. AGCD has evaluated that our system is suitable for implementation and that it meets their requirements. Consequently we conclude that the system will be useful for Aceh province, Indonesia.

Acknowledgments

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