A study of integrated environment for heterogeneous geographic information generated in tsunami recovery processes

April 2013

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概要

本研究の目的は、多様な地理情報のための統合環境を考案すること、そしてインドネシアのアチェ州の将来の開発を支援するための地理データセンターの統合環境を例として統合環境を実現することである。その統合環境では、デシジョン・メーカーすなわち将来の開発の計画者、ソフトウェア開発者、そしてその環境の管理者である３種類のユーザがその環境から提供される機能を使うことができる。

統合環境が必要な理由はつぎのとおりである。

(a)　地理データセンターにおいて多用な地理情報が入手可能なこと

地理情報は、製作者と GIS ソフトウェアの多様性のために、様々な種類のデータ型とフォーマットにおいて多様になりがちである。たとえば、大量で様々で多様な地理情報がアチェ州の津波被害後の復興過程の間に作成されたが、それは多くの異なる一時的なプロジェクトチームが多くの GIS ソフトウェアを使用して作成された。これらの大量で様々で多様な地理情報は殆ど全ての意思決定支援で使用された。

(b)　情報管理者、デシジョン・メーカー、そしてソフトウェア開発者が必要な機能は異なる。

(i)　情報管理者のニーズは、簡単で信頼できるツールを使って多様な地理情報、地理データベースサービス、メタデータサービスを含む様々な種類の地理情報サービス、マッピングのための Web サービス、そして Web マッピング・アプリケーションを操作できることである。これらのツールは、情報管理者が様々な種類の地理情報サービスを公開する時にベクター型、ラスター型、地理データベース型と多様な地理情報を扱う能力を持たなければならない。

(ii)　デシジョン・メーカーのニーズは、メタデータ・サービスで地理情報を検索する機能、検索した地理情報のマップサービスを直接使用する機能、地理データベース・サービスにアクセスする機能である。

(iii)　ソフトウェア開発者のニーズは、彼らが開発しているアプリケーションまたは情報システムで使用する地理データベース・サービスと様々な種類のマップ・サービスである。

(c)　アチェ州には地理情報のための使用可能な統合環境は無い。

2006 年に設立されたアチェ地理データセンター(AGDC)はインドネシア政府によって州立の特定機関として承認された。AGDC は、国家機関や復興工程プロジェクト等から受け取った大量

で様々で多様なアチェ州に関する地理情報を管理し、アチェ州内のユーザに配布するための機関である。AGDC の任務には、地理データ・情報を統合化し、アチェ州の中の持続可能な開発のための意思決定を支援することがある。しかし、AGDC は未だ多様な地理情報のための統合環境を持っていない。

(d)　新規の地理情報資源と新規ユーザの可能性

(i)　統合環境は新規の地理情報資源については典型的な 22 種類のデータフォーマットをサポートする能力を持つ。

(ii)　統合環境は新しいタイプのユーザへの拡張も可能である。新しいユーザの要求に基づいてソフトウェア機能を割り当てる。

　これらの理由のため、私は本研究の目的を実現するため次に示す調査・研究を行った。

(1)　様々な種類の多様な地理情報の調査・収集

　一時的なプロジェクトチームが復興工程期間に作成した地理情報を収集することは難しい。私は 2007 年 6 月から 2010 年 10 月まで定期的に現地に行って、地理情報センターとユーザを調査し、地理情報と復興に関連する他の情報を収集した。

　私は 2 年間、復興工程に参加し、約 12 TB の大量地理情報を保守する仕事で働いた。私は大量かつ様々な地理情報を収集した。それには 2000 の ESRI ArcMap Document が含まれる。私は関連する調査報告も調査した。

(2)　関連研究の調査・分析

　私は復興工程を支援するために開発されたアプリケーションとシステムを調査し、AGDC 内のアプリケーションを含めて現存しているアプリケーションも調査した。復興工程が終わった時に多くのシステムは廃棄されたが、それらは復興工程を支援するために作られたためである。復興工程終了後も必要な GIS やアプリケーションもある。なお、関連して SDI (Spatial Data Infrastructure)についても文献調査した。

(3)　収集した地理情報のための Web マッピング・アプリケーションの製作

　Web マッピング・アプリケーションは地理情報をマップ形式で提供または配布する Web アプリケーションである。私は収集した地理情報のために次の２つの Web マッピング・アプリケー

ションを製作した。私はサーバ GIS で OGC (Open GIS Consortium)の WMS (Web Map Service) と WFS (Web Feature Service)を使って地理情報を提供した。

(3a)　地理情報を配布する Web マッピング・アプリケーション

私が Autodesk MapGuide Enterprise (MGE)サーバを用いて開発したアプリケーションは復興時に使用された。

(3b)　アチェ州の geo-hazard map と geo-risk map を提供する Web マップ・アプリケーション

私が開発したアプリケーションの特徴は、アプリケーション内で得たレイアーに Add WMS 機能を用いて WMS レイアーをオーバーレイできることである。このアプリケーションでは MapFish framework とミネソタ大学が開発した MapServer を用いた。

(4)　収集した地理情報をインターアクティブに表示する機能の研究と実現

私は収集した地理情報をインターアクティブに表示する Web ベースのアプリケーションを開発した。そのアプリケーションは復興工程の進展を年ごと、寄付者ごとなどに地図やチャートで示すことができる。インターアクティブ表示のためにズーム・イン／アウト、視点の移動の機能と地域、寄付者などから検索する機能などを GIS 機能として用意した。このアプリケーションは天然資源、ハザード、地勢の地図の俯瞰も提供する。

私はこのアプリケーションを開発するために MapFish framework を使用した。この技術により地理データベースまたは WFS/WMS からのマップのレイアーをバインドすることができる。私はクライアント側では HTML, CSS, JavaScript を、サーバ側では PHP スクリプト言語、MapServer, ExtJS, OpenLayers, PostgreSQL/PostGIS データベース、WFS/WMS を使用した。

この結果、私は、地理データを視覚化する Web ベースのオンライン GIS アプリケーションによって、従来の地理データを配布する方法を簡単にすることができた。

(5)　アチェ州のための統合環境の設計、製作と評価

統合環境を設計する前に、私は、復興工程で作られた地理情報、AGDC で地理情報のために使っているアプリケーションとシステム、３種類のユーザのニーズ、アチェ州の GIS ユーザを分析した。私は、地理情報は様々な種類のフォーマットがあって多様なこと、多くの ESRI ArcMap documents があること、統合環境が AGDC に無いこと、３種類のユーザは異なる機能と手段を必要とすること、アチェ州の多くの GIS ユーザは ArcGIS desktop を使用することを見つ

けた。そこで私は、私の統合環境の概念に基づく統合システムを AGDC のために開発した。私は ESRI の製品：ArcIMS Server、ArcGIS Server、PostgreSQL/PostGIS 接続機能付き ArcSDE、ArcGIS Desktop そして Open source の desktop GIS を使った。

開発した統合環境は、私が収集した復興工程の時に作られた多様な地理情報とアチェ州に関する地理情報を持つ。そのシステムは、マップ・サービス、地理データベース・サービス、メタデータとメタデータ・カタログ・サービスを含む地理情報サービスも提供する。

このシステムを使った地理情報の分析例は持続可能な開発の計画を支援する可能性があることを示した。分析例には、バンダ・アチェで再建設された家の分析、集落と農業地域の再構築の分析、保護林・プランテーション・鉱業許可地域の分析がある。AGDC はこのシステムを実行に適したシステムであると評価した。従って、私はこのシステムはインドネシアのアチェ州に役立つと結論する。

この統合環境のアプローチは、Spatial Data Infrastructure (SDI)のいくつかの実行上の難しい点、たとえば、多くの数の機関と個人、十分な資金、多くの分野の専門家、そして時間の問題を乗り越えることができる。SDI は GIS の拡張であって、通常は国または州の政府によって始められる。ハードウェア、ソフトウェア、機関、人、政策を含むインフラストラクチャであり、それらを用いて地理情報を作り、管理し、配布する。

私は統合環境または多様な地理情報のための統合情報システムの開発方法についても議論した。システム開発、保守、コストの観点から geoFOSS (free open source software)を用いた SDI の開発についても議論した。

最後に、私は本研究が成功したと結論することができる。私は多様な地理情報のための統合環境のモデルを考案し、そのモデルを AGDC のための統合情報システムのプロトタイプとして実現した。このシステムは地理情報資源の多様性：様々なデータ型とフォーマットと 3 種類のユーザのための機能と手段が可能であり、管理者のためのマップサービス、地理データベース、メタデータの管理、作成、公開が可能であり、デシジョン・メーカーのための Web マッピング・アプリケーション、メタデータサービスの検索機能が可能であり、そしてアプリケーション開発者のための様々な種類の地理情報サービス（マップサービスと地理データベースサービスを含む）へのアクセス機能が可能である。

私の博士論文の寄与は次のとおりである。

- 私の研究は、私が考案したモデルが、様々な型の地理情報データフォーマットを含むマップサービスを提供し、異なる種類のユーザにサービスする統合情報システムの設計に役立つことを示した。このモデルはシステムの汎用性の維持にも効果がある。
- 私の研究は、同モデルを使うことによって SDI の実行上の６つの困難の中の第６番目を解決できることを示した。その理由は、地理情報コンテンツを作成する際のボトムアップモデルとは独立に、統合情報システムの設計が同モデルを用いると可能だからである。
- SDI の６つの困難の大部分は AGDC のための統合情報システムには見つからない。
- 希な情報資源は地理情報学では重要である。私は、津波からの復興工程で一時的なプロジェクトチームによって生成された地理情報を網羅的に収集した。その理由は、その情報が貴重で高い品質を持つためであり、そのプロジェクトチームが解散するときに消える可能性があったためである。収集した様々なデータ型またはデータフォーマットの型は多様な地理情報のための統合環境のアイデアを私に示した。

私は、将来、AGDC で発生する要求に対応するため、統合環境のモデルに基づく多様な地理情報のための統合環境の拡張を考案するつもりである。また、同モデルの拡張を将来、シア・クアラ大学で学生とともに研究するつもりである。

ABSTRACT

The aims of this study are to devise an integrated environment for heterogeneous geographic information (GI), and to realize an integrated environment to support future development for Aceh Province in Indonesia, as an example of an integrated environment with a centralized geographic data center. In the integrated environment, three types of user can use functions provided by the environment. The three types of users are decision makers or planners for future development, software developers, and administrators of the environment.

The reasons why an integrated environment is necessary are as follows:

(a) The availability of heterogeneous geographic information at a centralized geographic data center

Geographic information tends to be heterogeneous in various kinds of data types and formats due to the diversity of producers and GIS software used. For example, huge volumes of diverse geographic information were produced by many different temporal project teams using many different kind of GIS software during the rehabilitation and reconstruction (RR) process following the tsunami disasters in Aceh province. This geographic information was used to support all decision-making processes.

(b) The functionality needed by information administrators, decision makers, and software developers is different.

(i) Information administrators need simple and reliable tools to handle heterogeneous GI, various kinds of GI services, including geodatabase services, Web services for mapping (map services) and metadata service, and Web mapping applications. These tools must have the ability to utilize heterogeneous GI including three data types (vector, raster, and geodatabases) and different kinds of data formats of GI resources while the information administrators publish various kinds of GI services.

(ii) Decision makers need facilities to search GI in a metadata service, to directly consume the GI found in the metadata service through its map services and to access geodatabase services for analysis purposes.

(iii) Software developers need geodatabase services and various kinds of map services to be used in the application or information system they are developing.

(c) No integrated environment for geographic information was available in Aceh province.

Aceh Geospatial Data Centre (AGDC), established in 2006, is a special provincial geographic data center authorized by the Indonesian government. AGDC manages huge volumes of diverse provincial geographic information in different kinds of data formats, received from RR process projects, provincial and national departments, etc. One of the tasks of AGDC is the integration of geographic data and information to support decision-making for sustainable development in Aceh province. However, AGDC does not yet have an integrated environment for heterogeneous geographic information.

(d) The possibility of new GI resources and new users

(i) The integrated environment has ability to support around 22 kinds of typical data formats for potential new GI resources that can be used in the integrated environment.

(ii) It also has ability to extend new user types. When new types of users are necessary in the environment, the available software functions will be assigned based on new users' requirements.

For these reasons, I undertook the following research that forms the aims of the study in this thesis.

(1) Researching and collecting various kinds of heterogeneous geographic information

It was a difficult task to research and collect the necessary geographic information produced by the temporary project team during the RR phase. I carried on field surveys and studies by regularly visiting the Aceh province since January 2007 until October 2010 to collect geographic information and any other information related to the RR-process, including applications, geographic information centers and users.

I participated in the RR process for 2 years, and took part in maintaining a large quantity (approximately 12 Terabytes) of geographic information. I collected a large amount of diverse geographic information including around 2,000 ESRI ArcMap Documents. I also studied reports related to the geographic information produced by projects during RR process.

(2) Researching and analyzing related works

I examined the applications and systems developed for support purposes during the RR phase and investigated existing applications including the applications in AGDC. Most of the systems became obsolete when the RR phase ended, because they were built to support the RR process. There is, however, still a need for GIS and other applications after the RR phase.

(3) Examination and implementation of Web mapping applications for the collected geographic information

A Web mapping application is a Web application that provides or disseminates geographic information in a map form. I developed the following two Web mapping applications for the collected geographic information. I used WMS (Web Map Service) and WFS (Web Feature Service) of OGC (Open GIS Consortium) as geographic information provided by server GIS.

(3a) A Web mapping application for disseminating geographic information

This application was used in the RR phase. I developed it using a proprietary server called Autodesk MapGuide Enterprise (MGE) Server.

(3b) A Web mapping application for providing geo-hazard maps and geo-risk maps of Aceh province

I developed a Web mapping application, including a function called “Add WMS” to add a WMS layer to be overlaid with other layers available in the application. I used MapFish framework and UMN MapServer developed by the University of Minnesota.

(4) Studying and realizing a Web mapping application with interactive display functions for the collected geographic information

I developed an interactive Web-based application for the visualization of the collected geographic information. The application can show the progress of the rehabilitation and reconstruction process, based on year, donors, and other classifications, in conjunction with maps and charts. In order to provide interactivity, the application is equipped with some GIS functions such as zoom-in, zoom-out, pan, a search function that query asset data and selections that query locations, type of asset data, donors, etc. The application also provides an overview of natural resources, hazards and topographic maps.

I utilized the MapFish framework to develop the GIS application. This technology allows me to bind layers of maps from geographic databases or WFS/WMS. It employs HTML, CSS and JavaScript on the client-side and a combination of PHP scripting language, MapServer, ExtJS, OpenLayers, PostreSQL/PostGIS database and WFS/WMS on the server-side.

As a result, I was able to simplify the conventional method of disseminating geographic data with an online Web-based GIS application that visualizes the collected geographic data.

(5) Design, implementation and evaluation of the integrated environment for Aceh province

Before designing an integrated environment, I analyzed GI produced during the RR process, existing applications and system for geographic information in AGDC, the needs of the three types of users, and software used by GIS users in Aceh province. I found that (a) the GI contains several kinds of formats (heterogeneity) and also many ESRI ArcMap documents, (b) there is no integrated environment at AGDC, (c) the three types of users need different types of functionality, and (d) most of GIS users in Aceh province use ESRI ArcGIS desktop.

Then I developed an integrated information system to AGDC based on my integrated environment concept. I implemented ESRI products such as ArcIMS Server, ArcGIS Server, ArcSDE Geodatabase with connection for PostgreSQL/PostGIS and ArcGIS Desktop as well as open source desktop GIS. The integrated information system contains huge volumes of diverse GI in different kinds of format produced during the RR process and other GI related to Aceh province, collected by me.

Examples of spatial analysis using the system indicate the potential to support the planning of sustainable development. Examples include analysis of reconstructed houses in Banda Aceh, analysis of reconstruction in settlement and agricultural areas, and analysis of protected forest areas, plantation and mining concession areas. Finally, AGDC has evaluated that the system is suitable for implementation. Consequently, I have concluded that the system would be useful for Aceh province, Indonesia.

The integrated environment approach can be implemented to overcome several difficulties in the implementation of Spatial Data Infrastructure (SDI), such as SDI requiring huge numbers of different organizations and individuals, an adequate budget, experts for many fields, and time. The SDI is an expansion of GIS usually initiated by national or provincial governments. It facilitates infrastructure including hardware, software, organizations, people, and policies, which are used to produce, manage, disseminate and share geographic information with legal aspects.

I have also discussed the methods for developing an integrated environment for heterogeneous GI. I make special mention of the development of SDI using geoFOSS (free open source software) from the viewpoints of system development, system maintenance, and cost.

Finally, I am able to conclude that the aims of the study in the thesis have been successfully met. I devised a model for an integrated environment for heterogeneous GI, and realized the model as the prototype of the integrated information system for AGDC. The system has ability to accept various data types and formats (heterogeneity) of GI resources and to serve various kinds of GI services for ESRI and non-ESRI users. It also defines functionality for three types of users. It provides easy work process for administrators to manage, create, and publish map services, geodatabase, metadata, and Web mapping application. It provides metadata search facility (using in desktop GIS and Web based application) for decision makers to search GI in a metadata service and facilities to easily consume GI found in the metadata service through its map services using desktop GIS. It provides facilities for application developers to access various kinds of GI services including map services and geodatabase services.

The contributions of my PhD thesis are as follows:

- My study shows that the model is useful to design an integrated information system, which has to provide map services containing various types of geographic data format, and has to service different types of user. The model is effective to keep versatility of the system.
- My study shows that use of the model is a solution to 6th point of difficulties in the SDI implementation, because use of the model makes design of the integrated information system independent on a bottom-up model for creating geographic content.
- The 6 difficulties in the SDI implementation have mostly been resolved by the integrated information system designed for AGDC.
- Rare resources are important in geographic information science. I comprehensively collected GI generated by temporary project teams in the tsunami recovery processes, because this information is rare and high quality, and tends to vanish when the project teams (original GI providers) dissolves. Various data types or data formats of the collected geographic data or information have also motivated the idea of a model of an integrated environment for heterogeneous geographic information.

I plan to work on extending of the integrated environment for heterogeneous geographic information based on my model of the integrated environment to respond the requirements that emerge at AGDC in the future. I also plan to study the extension of new model with my students in Syiah Kuala University in the future.

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ABBREVIATIONS

AGDC	Aceh Geospatial Data Centreat the Aceh Development Board Office (BAPPEDA)
AMAP	AusAID funded the Asset Mapping Assistant Project which is managed by GTZ
API	Application Programming Interface
ARRIS	Aceh Rehabilitation & Reconstruction Information System
AusAID	Australian Agency for International Development
AXL	ArcXML Configuration File of ESRI ArcExplorer – an XML based configuration file
BAKOSURTANAL	Indonesia National Agency for Survey and Mapping
BAPPEDA	Aceh Development Board Office
BGR	Federal Institute for Geosciences and Natural Resources, Germany
BLOM	Norwegian Geographical Information Company
BPN-RALAS	National Land Agency, Indonesia - Reconstruction of Aceh Land Administration System, Indonesia
BRR	National Bureau for the Rehabilitation and Reconstruction
CF	Conservation Forest
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
ETESP-SPEM	Earthquakes and Tsunami Emergency Support Project – Spatial Planning and Environmental Management of ADB project in Aceh
FGDC	Federal Geographic Data Committee
GDAL	Geospatial Data Abstraction Library
GI Services	Geographic Information Services
GI	Geographic Information
GIS	Geographic Information System
GTF	Geospatial Task Force for the RR process Aceh - Nias
GTZ	German Agency for International Cooperation
IAIN	Ar-Raniry State Islamic Institute
JICA	Japan International Cooperation Agency
LAPAN	National Aerospace and Aviation Association, Indonesia
MCRMP	Marine & Coastal Resources Management Project
MGE	MapGuide Enterprise from Autodesk
MSD (.mxd)	Map Service Definition of ESRI ArcMap
MXD (.mxd)	Map Document of ESRI ArcMap
NAD Province	Nanggroe Aceh Darussalam Province – Name of Aceh province until 2006.
NORAD	Agency of The Royal Norwegian Governments
OGC	Open GIS Consortium
PMF (.pmf)	Published Map File (pmf) of ESRI ArcPublisher – an application extension of ESRI ArcMAP
QGIS	Quantum GIS
REST API	Representational State Transfer Application Programming Interface
RIA	Rich Internet Application
RR	Rehabilitation and Reconstruction

SDE (.sde)	Spatial Database Engine of ESRI ArcSDE
SDI	Spatial Data Infrastructure
SIM-C	Spatial Information and Mapping Centre
SOCs	Server Object Containers of ESRI ArcGIS Server
SOM	Server Object Model of ESRI ArcGIS Server
TLM	Topographic Line Maps
UMN MapServer	University of Minnesota MapServer
UN	The United Nations
UNDP	United Nation Development Program
UNIMS	The United Nations Information Management System
UNSYIAH	Syiah Kuala University
WCS	OGC's Web Coverage Service Interface Standard
Web ADF	Web Application Development Framework of ESRI ArcIMS and ArcGIS Server
WFS	OGC's Web Feature Service
WMS	OGC's Web Map Service

Chapter 1

Introduction

1.1 Overview of the thesis

The aims of the study described in this thesis are to devise an integrated environment for heterogeneous geographic information, and to realize the environment to support future development in the Aceh Province in Indonesia, as an example of an integrated environment. In the environment, three types of user can use functions provided by an integrated information system for heterogeneous geographic information. The three types of users are decision makers or planners for future development, software developers of geographic information application or system, and administrators or managers of the environment.

An integrated environment for heterogeneous geographic information provides three types of users with a number of functions and facilities that depend on users' needs. These functions and facilities are used to handle various data types and formats (heterogeneity) of geographic information (GI). If the integrated environment is available, the information administrators can easily manage and utilize various data formats of GI accepted by the environment, while creating and publishing various kinds of GI services provided to other users. So that the other users can search, retrieve, consume and display these GI services for many purposes.

The model of the integrated environment of heterogeneous geographic information is described in section 1.2.

The reasons why an integrated environment is necessary are as follows:

(1) Geographic information tends to be heterogeneous.

Geographic information tends to be heterogeneous, when it is produced by more than one producer. For example, during the rehabilitation and reconstruction process following the earthquakes and tsunami disasters in Aceh province in Indonesia, a large volumes, variety and heterogeneity of geographic information were produced by many temporal project teams. This will be described in detail in section 1.6.

Geographic information tends to be heterogeneous, when it is generated and provided by more than one application for geographic information or geographic information system, because various methods and software are available and used. The technologies and methods will be described in detail in chapter 2.

(2) The functions that decision makers, software developers and administrators need are different.

Decision makers need various kinds of geographic information and information system that has ability to display the information and analyze the information. Software developers need various geographic databases and map products to be used in the application or information system they are developing. Administrators need simple and reliable tools to manage a geographic information system. If a reliable integrated environment for geographic information exists, the environment will satisfy those different users' needs.

(3) No integrated environment for heterogeneous geographic information has been available in Aceh province.

Aceh Geospatial Data Centre (AGDC), which is one of the Aceh provincial organizations and established in 2006, does not yet have an integrated environment or integrated information system for geographic information. This will be described in detail in section 1.7. Although some sectors in the Indonesian government have Geographic Information System (GIS) or applications, neither an integrated environment for geographic information nor an integrated GIS is available.

For these reasons, I undertook the following researches and studies that form the aims of the study in this thesis.

(a) Researching and collecting various heterogeneous geographic information and relating documents and application software or methods for this geographic information.

I researched and collected them as many as possible as described in section 1.6.

(b) Researching and analyzing related works

I researched the applications or systems produced and used during the rehabilitation and reconstruction process, and investigated existing applications including the applications in AGDC. The results of the research and analysis will be described in section 3.5.

(c) Study and implementation of Web mapping applications for the collected geographic information. The results of the study will be described in section 4.2 and 4.3.

(d) Studying and realizing display functions for the collected geographic information

The results of the study will be described in chapter 5.

(e) Design, implementation and evaluation of an integrated environment for Aceh province

These results and a discussion about the integrated environment will be described in chapter 6.

Chapter 7 is discussion, and chapter 8 is conclusion of the thesis.

1.2 A model of an integrated environment for heterogeneous geographic information

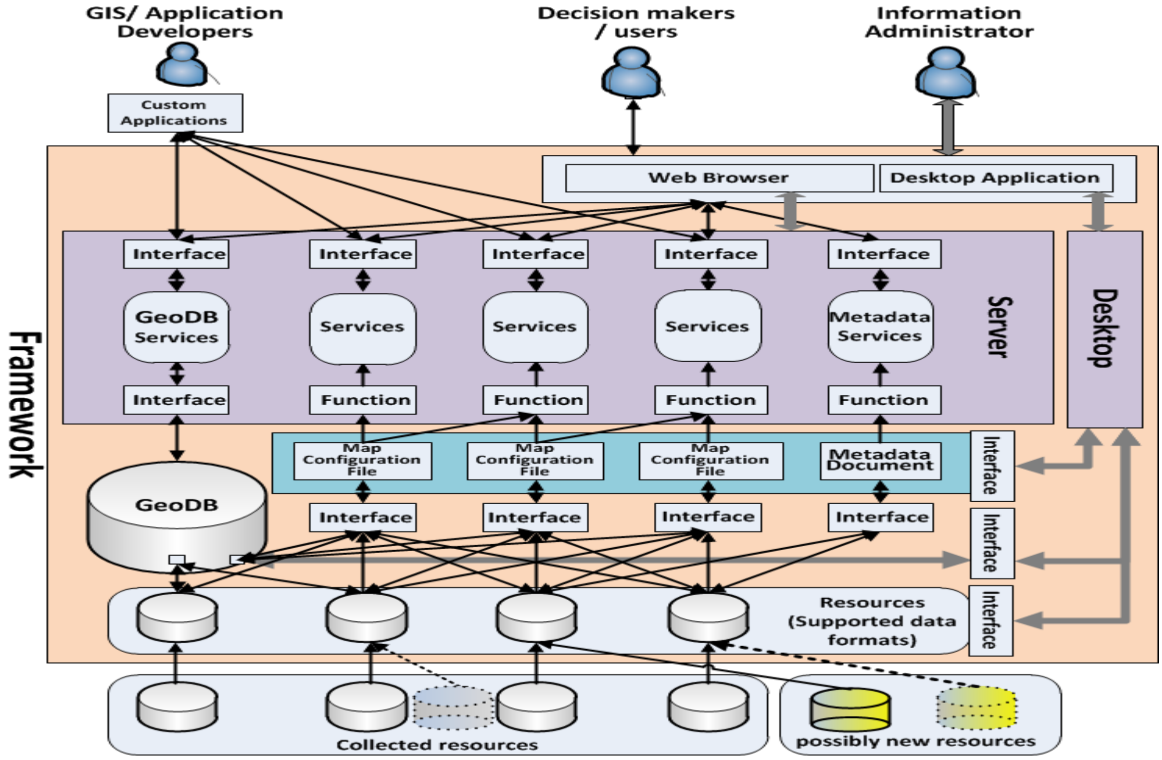


Figure 1.1 an integrated environment for heterogeneous geographic information

Many types of geographic information are used in many types of Geographic Information Systems (GISs) as mentioned in section 2.3 and 2.4. This situation causes heterogeneous geographic information and heterogeneous GIS in the world of geographic information, and also causes low interoperability of geographic information in GIS. It is inconvenient condition to be solved.

Therefore, I devised a model of an integrated environment of heterogeneous information where three types of user can use almost all of types of geographic information. The three types of user are decision makers or ordinary users who use the information, software developers who want to get the information, and information administrators who manage the information to provide to other users as mentioned in section 1.1.

A framework of the integrated environment for heterogeneous geographic information with three types of user and collected and possibly new resources of geographic information are shown in **Figure 1.1**. The framework allows information administrators to utilize various data types and data formats (heterogeneity) of GI used as resources while publishing various kinds of GI services provided to other types of users. The framework provides a number of functions facilitated by server GIS or desktop GIS. These functions can be used, such as, to manage, publish, discover, access and visualize geographic information and create and publish Web mapping application.

The three types of users can access various kinds of GI services including geodatabase (GeoDB) services, map services, and metadata services, which are served by server GIS, using Web applications, desktop GIS, or custom applications. However, only information administrators can access the resources of GI. The framework consists of various kind of GI services in a server GIS with their corresponding software interfaces or software functions. Three type of users use the framework through software functions assigned for each type of user. Geographic information in various types and formats are used as resource to the GeoDB or map services through the corresponding interfaces.

A service (image or feature service) in a server GIS may serve several selected layers connected to corresponding files in resources. These selected layers and other configurations, such as specific symbols and color for each layer, coordinated system, etc., are described in map configuration file. A digital map in desktop GIS also consists of several layers connected to corresponding files in resources. These layers and the other configurations are also described in map configuration file usually called map document. The map configuration file or map document is generated using desktop GIS. Server GIS uses this map configuration file when providing services. The mechanisms of map configuration file and map services and their acceptability of various data format of resource are explained in section 2.4.4 and 2.4.5.

The environment has ability to accept possibly new resources. When data format of the possibly new resource is available in accepted data formats in the environment, the new resource is acceptable. When the possibly new resource is not available in the accepted data types in the environment, a converter used to convert data formats of the possibly new resource into one of the accepted data types is needed. The environment has ability to extend new user types. When new types of users become necessary in the environment, the existing software functions will be assigned to new users' requirements. If software functions are not available, they are needed to be constructed.

I will describe a design of the integrated environment in section 6.3.

1.3 Aceh province and the December 2004 Tsunami

Aceh province, one of the Indonesian provinces, is located in between 2^o- 6^o north latitude and 95^o - 98^o east longitude with an elevation average about 125 meters above sea level. Until 2008, Aceh province was divided into 18 districts and 5 cities, consisting of 276 sub-districts and 16,424 villages. The northern part and eastern part of Aceh province border with Malacca Strait, the southern part with North Sumatra province and the western part with the Indian Ocean. The area of the Aceh province is about 5.95 million ha (59,500 km^2) consisting of forested areas (which is the largest type of area, reaching 3.5 million ha), plantation areas (about 1.05 million hectares), and other areas (about 1.4 million ha) [1]. Banda Aceh is the capital of Aceh province.

In December 2004, one of the largest earthquakes in recent history, measuring 9.1 on the Richter scale occurred 250 km south-west of the Aceh province of Indonesia [2] as shown in **Figure 1.2.** It generated the devastating tsunami that destroyed or otherwise badly impacted every sector in the Aceh province. During the emergency phase, on March 29, 2005, another earthquake hit and affected the Nias-Island, North Sumatera province of Indonesia. These two disasters are called the Aceh - Nias disasters.

A tsunami with a series of powerful waves swept around 6 kilometers inland from the coastline in the western and northern part of Aceh province. In the capital of Aceh provinces, the tsunami inundated everything at a speed of 800 kilometers an hour around six kilometers inland and destroyed a large part of the Banda Aceh area. The tsunami caused 126,741 people to lose their lives, with 93,285 people reported missing, 500,000 survivors lost their homes, and 750,000 people lost their livelihoods in Aceh Province alone. The tsunami paralyzed the life of the society and the administration of local government in most of the western part and northern part of Aceh, including Banda Aceh city in which the central provincial government offices of Aceh province are located. It also completely cut off the telecommunications [3] and main roads.

1.4 The Role of the Bureau for the Rehabilitation and Reconstruction (BRR)

The establishment of BRR was important for the following reasons: provincial governments could not handle the huge scale of the Aceh - Nias disaster, many international and national agencies and non-government organization (NGOs) providing support and aid during the emergency and recovery period in Aceh – Nias needed a coordinating center or bureau. In addition, the huge budget (US$ 7.2 billion) that had been pledged to support reconstruction needed to be carefully and transparently managed by an independent bureau.

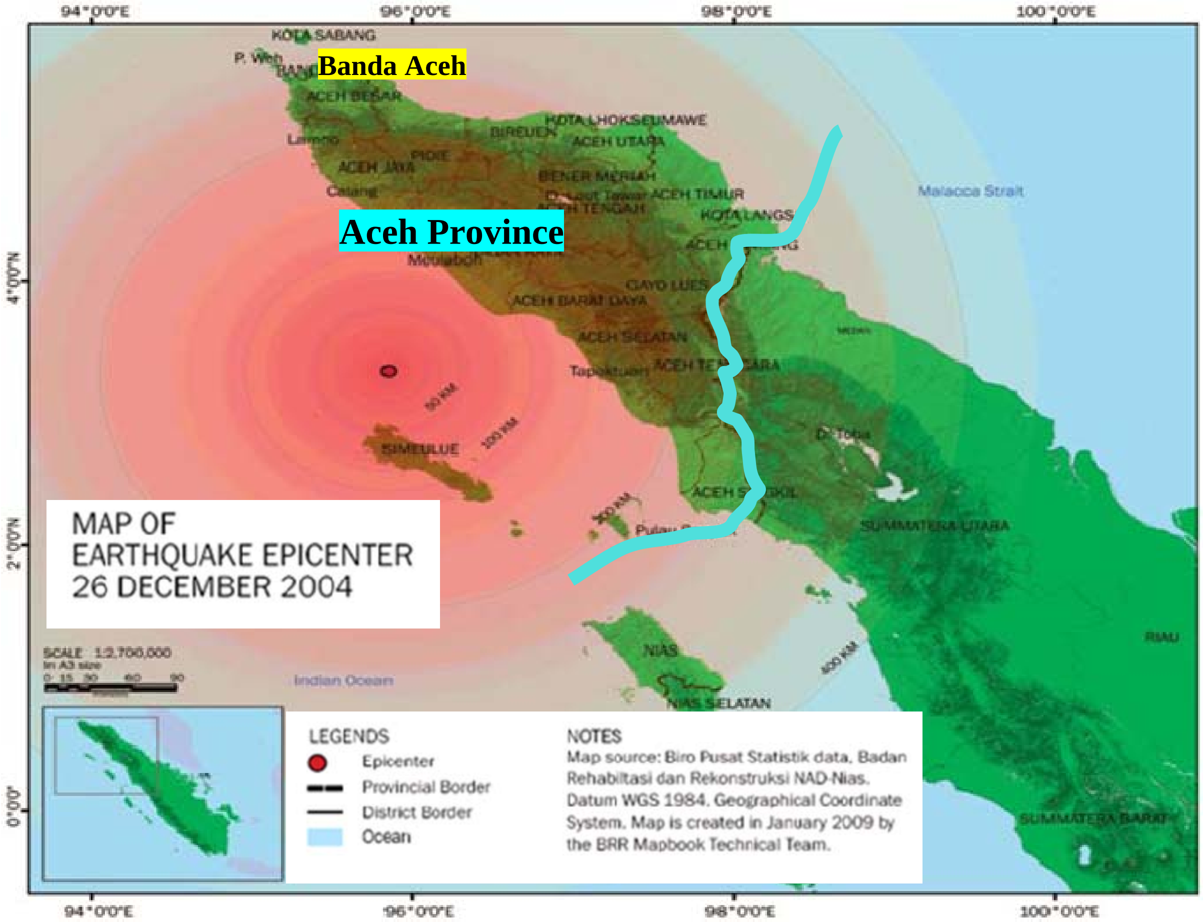


Figure 1.2 Map of earthquake epicenter captured from [3]

The huge catastrophes with their large number of victims and multi-sectoral damage in Aceh and Nias shocked the Indonesian government and many other countries. Thirty-four friendly countries offered helps by sending 16,000 humanitarian volunteers and aid, including a floating hospital, 9 aircraft carriers, 14 mother ships, 82 choppers, 31 airplanes, 117 medical teams for the beginning of the emergency phase [4]. The contributions from the Indonesian government and outside countries have shown that the emergency response went well. The aid workers have been working on cleaning activities, burying corpses, evacuating IDPs and constructing temporarily shelters and roads [5].

It would have been impossible for the Aceh provincial and the Indonesian government alone to quickly deal with the huge impact of the disaster. Local capacity in Aceh had been greatly weakened by nearly 30 years of conflict between the Indonesian government and the Free Aceh Movement (GAM). However, the tsunami has opened a road to peace and brought peace between the separatist movement and the government of Indonesia. These can be seen as a hidden blessing [2].

On April 15th, 2005, the Indonesian government declared the establishment of the National Bureau for the Rehabilitation and Reconstruction (BRR) for Aceh - Nias. **Table 1.1** shows the post tsunami RR timeline. Its main tasks were formulating strategies, preparing budgets, developing detailed plans and coordinating, controlling, and monitoring the RR activities in Aceh – Nias [6]. One hundred thirty-three countries have provided assistance to the humanitarian mission [7], committing about 6.72 billion USD [2] as shown in **Figure 1.3**. At the end of the four-year RR process, around 500 agencies have implemented 2,200 projects [7]. These projects included the building of 140,300 permanent houses, 1,759 schools, 1,115 health facilities, 996 government buildings and 363 bridges. Construction of around 2,696 kilometers of road, 23 ports, and 13 airports or airstrips have also been completed [2] [8].

Amin Subekti at el. [2] noted that there were three main factors that influenced the commitment of donors for the December 2004 tsunami, i.e. donor freshness (the last big natural disaster was the December 2003 earthquake in Bam, Iran, with 28,000 casualties), timing and media coverage (the tsunami was in new year holiday and had a high intensity of media publication because the tsunami killed people in 11 countries from 40 different nationalities). Also, recent shifts in the international aids landscape (In the 1990s, the aggregate trends in global aid have shifted away from low-income countries toward middle-income countries including Indonesia. Usually, multilateral donors provide the leading contribution of aid, in the case of Aceh and Nias, the amounts committed by NGOs were significant, as shown in **Figure 1.3**)

Table 1.1 timeline of post-tsunami RR adopted from [4]

1	December 26, 2004	December 26, 2004 Morning, tsunami occurs in the Indian Ocean, affecting the coasts of 11 Asian‑African countries (Indonesia, Thailand, Malaysia, Maldives, Myanmar, Bangladesh, Sri Lanka, India, Madagascar, Somalia, and Seychelles).
2	January 6, 2005	The Indonesian Government conducts a tsunami Summit attended by the UN Secretary General Kofi Annan and world leaders.
3	January 2005	In the weeks following the Consultative Group for Indonesia (CGI) meeting, US$ 7.2 billion had been pledged to support reconstruction [2].
4	March 10, 2005	The creditors joined in the Paris Club agree a moratorium debt to countries that were affected by the tsunami. For all such countries, the Paris Club agreed to provide a moratorium worth U.S. $ 2.6 billion until the end of 2005.
5	March 26, 2005	The emergency period ends. UNOCHA takes control while carrying out field coordination. Local and international NGOs still work in the field to help clean up trash and search for corpses.
6	April 16, 2005	Formation of BRR NAD‑Nias (Presidential Decree No. 2 / 2005)
7	April, 2009	The BRR was finished in Aceh. All RR-project have been taken over and continued by Aceh provincial government

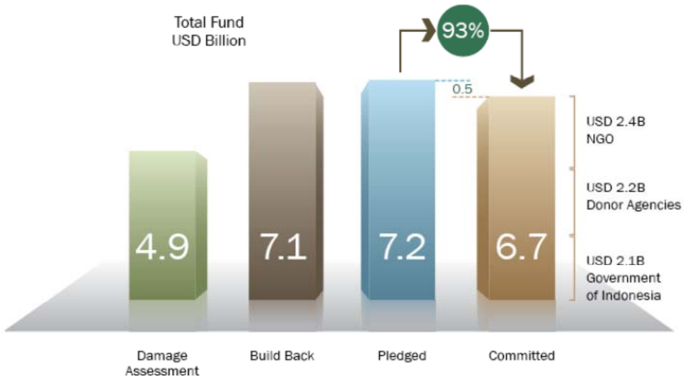


Figure 1.3 Aceh Nias reconstruction needs, pledges and commitment captured from [2]

1.5 Aceh Geospatial Data Center (AGDC) in Aceh province

BRR, supported by the SIM-C, GTF and other agencies, built and set up the AGDC at the Aceh Development Board Office (BAPPEDA) at the end of 2006. **Table 1.2** also shows several GIS centers with their activities, which supported the RR process in Aceh.

The Rehabilitation and Reconstruction (RR) process from April 2005 to April 2009 following the 2004 earthquake and tsunami has successfully built a better Aceh province. During the RR phase, GIS turned out to be necessary and useful. It played an important role in many sectors e.g. humanitarian, infrastructure, transportation, social and economic, etc. A huge amount and variety of geographic information has been compiled and produced with a large budget by international and national agencies to support the RR-process.

Table 1.2 The GIS centers and their activities

No	Name of Centers and its Activities	Period
1	**Name :** Indonesia National Agency for Survey and Mapping (BAKOSURTANAL) **Supported by :** Indonesian Government **Task and Activities :** To carry out the Indonesian governments tasks in the field of surveying and mapping [9]	1969 - Present
2	**Name :** The United Nations Information Management System (UNIMS) **Supported by:** The United Nations (UN) **Task and Activities:** To provide GIS services from the beginning of the emergency phase in Aceh-Nias [10]	2005 - 2006
3	**Name :** BRR - Spatial Information and Mapping Centre (SIM-C): **Established by:** UNIMS and BRR **Supported by:** NORAD (an Agency of The Royal Norwegian Governments), BRR, and United Nation Development Program (UNDP) [11] **Task and Activities :** Responsible for providing GIS services during the RR phase [10][11]	January 2006 - June 2009
4	**Name :** BRR - Geospatial Task Force (GTF) center **Established by:** BAKOSURTANAL and BRR **Task and Activities :** To provide GIS services based on national mapping standards including NSDI (National Spatial Data Infrastructure), base maps, thematic maps and geodatabase in Aceh–Nias [12]	April 2006 - June 2008
5	**Name :** Aceh Geospatial Data Center (AGDC) **Established by:** BRR, SIM-C, GTF and other agencies **Place :** The Aceh Development Board Office (BAPPEDA) **Task and Activities :** • The aim of establishing AGDC was to develop infrastructure (hardware, software and know-how) and to design a pilot project for an integrated system to support the planning of sustainable development in the Aceh province [13]. • Another short-term objective was that AGDC should become a center to facilitate the transfer of all geographic information and GIS applications from BRR and other agencies that worked in Aceh to the Aceh government after the RR process was finished [14]. • After the RR process, in 2009 AGDC would have a mandate to be the provincial Geodata center for archiving, managing and providing services around all geographical information that is available in the Aceh province [13][15]. AGDC has been chosen to implement the Spatial Data Infrastructure (SDI) and promote the use of spatial information to support economic development and decision-making in Aceh province [15]. • Particularly the main tasks are to (a) give access to spatial data and information easily and quickly, (b) encourage the utilization and the integration of data and information to support the decision-making systems, and (c) improve the understanding about the use of data of geospatial information [15].	December 2006 - Present

After the RR-process in 2009, as short-term objective, AGDC received a huge amount geographic information and GIS applications. This valuable and important geographic information will be useful for decision maker for the future sustainable development of Aceh province and for end-users who want to use this geographic information for other purposes. AGDC, that has a mandate as the provincial geodata center, and Aceh province have been faced with the difficulties of archiving, managing and providing services around all geographical information by using the existing application with less effective and efficient work processes.

1.6 Geographic information in Aceh province

In 2004, the only available and consistent digital base maps that could be used for the beginning emergency phase were the Topographic Line Maps (TLM) at scale 1:50,000 and 1:250,000 produced in the 1970s by BAKOSURTANAL [16], see item No. 1 in **Table 1.3**. In July 2005, NORAD funded a geospatial data project to support the acquisition of high resolution aerial photography over the Aceh province [11]. It produced high resolution Orthophoto Imagery, Digital Elevation Models (DEM) and TLMs in tsunami-affected areas [16] as shown in item No. 2 in **Table 1.3**. This geospatial data has been widely utilized by many agencies in their RR activities. **Figure 1.4** shows a map index of the available BAKOSURTANAL's topographic line map with scale 1:50,000 and scale 1:250,000, and NORAD/BLOM aerial imagery and its topographic Line Map.

During the RR activities, due to the partial lack of availability of geospatial data in some areas, BRR and other agencies that utilized GIS in their projects, sometimes had to carry out individual mapping to generate and compile relevant geospatial data. **Table 1.3** shows a list of the large amount of geographic information projects that were active over the course of the 4 years RR program.

SIM-C recorded a significant geographic information distribution from 2006 to 2008 at BRR, including around 2,773 hard copy maps, 706 digital copies of spatial data and 90 aerial imageries requested by users. Paul Harris stated that SIM-C has produced in excess of 9,000 maps and other information [10]. Suwandy [17] in 2009 reported that they discovered 30,000 ESRI (Environment System Research Institute) shapefiles, received from many agencies, when they did a quick data audit of the SIM-C's data server.

I realized that the international and national temporary teams would be leaving soon after their GIS projects were finished in Aceh province. At that point, the research, collection, and preparation of the huge and diverse store of geographic information produced in the tsunami recovery process became important, so that the geographic information can be effectively utilized in GIS for the future developments of the Aceh province. However, it is difficult to research and collect such a huge amount of geographic information. Therefore, I carried on field surveys and studies by regularly visiting the Aceh provinces for collecting data from January 2007 to October 2010. I had also participated in the RR process, from January

2007 until December 2008, and taken part in maintaining a large quantity (approximately 12 Terabyte) of geographic information, including around 2,000 important and useful ESRI ArcMap Documents, available on the GTF's and the SIM-C's data server.

I have collected around 2 Terabyte of geographic information for this study from several projects and centers, such as ESRI shapfiles, ArcMap documents, database, geodatabases, spreadsheet, report, map image, etc. I have classified and prepared geographic information to be used in integrated information system as shown in **Table 6.1** and **Table 6.2** in section 6.5.

In April 2009, at the end of the RR process, a large amount and variety of geographic information in various formats has been also handed-over by many temporary project teams or GIS centers to AGDC.

Table 1.3 The geographic information in Aceh province adopted from [18]

Item No.	Provider	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 - Scale1:2,500	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) [19]
*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).

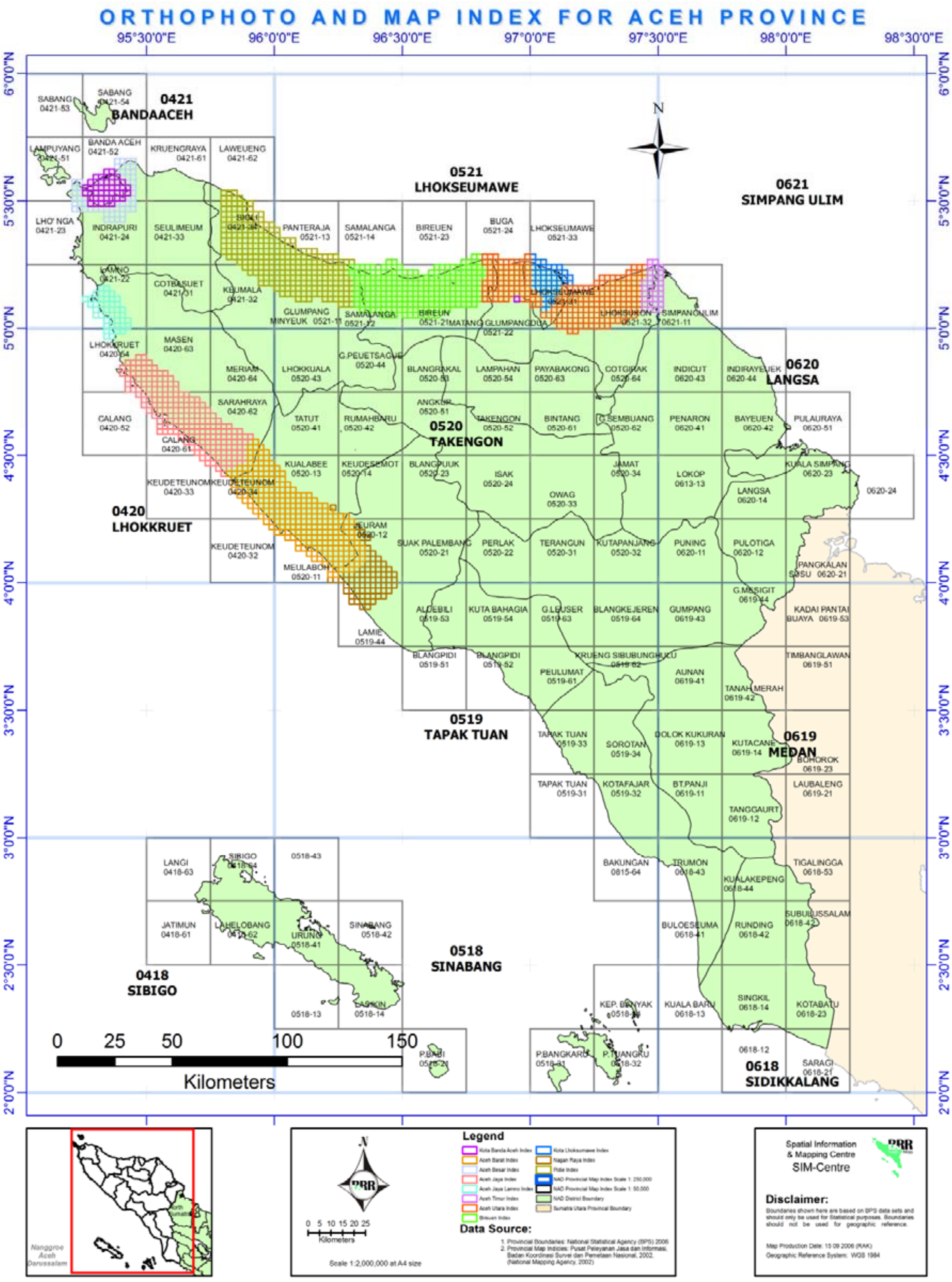


Figure 1.4 Orthophoto and map index for Aceh province reproduced using JPEG data from SIM-C

1.7 General problems of information sharing in Aceh province

AGDC has a substantial mandate and responsibilities for managing and providing geographic information services in Aceh province. Besides creating their geographic information, since 2007 AGDC has received (taken over) a lot of geographic information created during the RR process. This geographic information was created by national and international organizations in several large budget projects during the RR-process.

During the RR process, each user group (such as Government stakeholders, agencies and NGOs) required specific geographic information and GIS applications for decision-making or other specific purposes. Developers or staff of GIS centers, agencies and NGOs has developed several applications for specific GI used for specific users. Many applications have been developed to satisfy each user group during the RR-process. Each application has had advantages and disadvantages and the application could not meet the various needs.

It will not be realistic to build single applications or information systems used by each user group (such as for visualizing specific GI and analysis purposes) can be fit and used by others. It will be more effective to build and provide an integrated information system that will solve several disadvantages of existing application.

Figure 1.5 illustrates the period during the RR process and the period after the RR-process. AGDC have been available since the RR-process. The GI and GIS applications produced during the RR-process have been handed over to/taken over by AGDC. Most the applications were developed to suit a particular purpose during RR process, but they were not designed as an integrated system that can be used to easily manage and provide services for huge volumes of geographic information at AGDC. Most the taken-over GIS applications were inaccessible and the reasons will be explained in section 3.5. The disadvantages of the existing applications at AGDC will be explained in detail in section 6.2.

I have developed Web mapping applications for utilizing the GI available in Aceh province. The Web mapping application and many other GIS applications cannot be used to easily manage, disseminate and share GI available at AGDC. The existing GIS applications at AGDC cannot overcome the problems related to information sharing in Aceh province.

I have analyzed the existing problems and considered several issues relating to GIS at AGDC and in Aceh province. Based on the analysis I have developed a prototype of an integrated information system used to solve the existing application problems at AGDC. The integrated information system can be used to easily manage, publish, disseminate and share geographic information to support the future development of Aceh province as illustrated in **Figure 1.5**. The detailed discussion of the integrated information system will be explained in chapter 6.

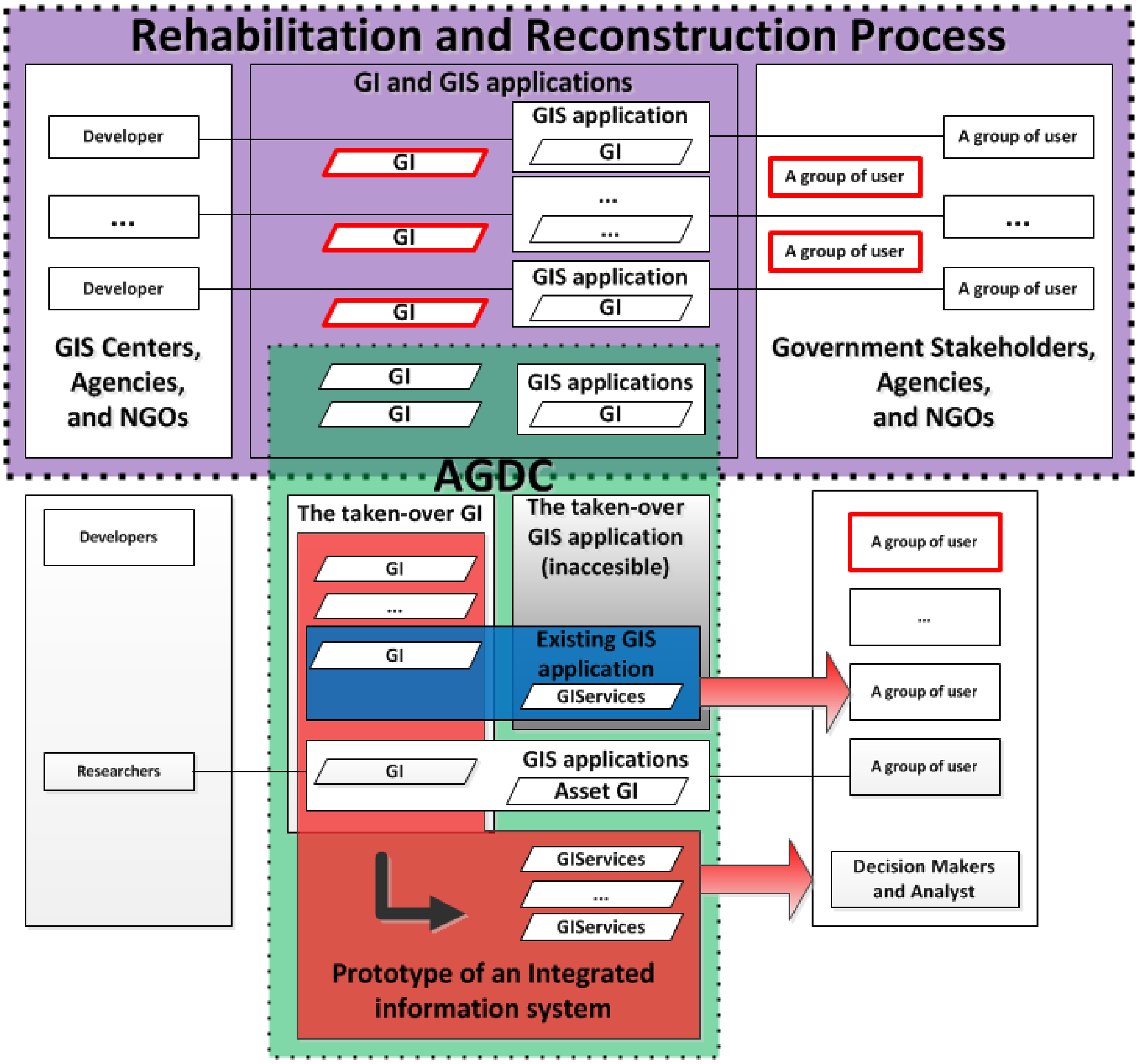


Figure 1.5 GI, GIS applications and the integrated information system

Chapter 2

Geographic Information System (GIS) and Geographic Information in GIS

2.1 Overview

Heterogeneous geographic information requires many technologies (software and applications) and methods (procedures, techniques, and processes) for handling geographic information. The proprietary and open source vendors have produced and released many different types of technologies and methods for creating, storing, managing, visualizing, publishing, and analyzing geographic information as well as for developing Web GIS, which tend to be the heterogeneous technologies and methods as well.

In this chapter, I focused on describing heterogeneous technologies and methods, closely related to my thesis. The technologies include the proprietary and open source servers (Web server, Geodatabase/database server, server GIS, and metadata catalog server), desktop GIS, Web mapping application framework, etc. The methods include techniques, procedures, and processes, which are commonly used for creating, storing, managing, visualizing, publishing and analyzing geographic information or for developing applications or integrated information systems.

I classify heterogeneous technologies and methods into two main parts i.e. GIS and geographic information in GIS. Methods will be explained along with the explanation of GIS components or geographic information in GIS. I will briefly describe the fundamental concept in GI sciences in section 2.2. I will explain parts of GIS components in details in section 2.3, which categorizes the explanation into two categories: desktop GIS and Server GIS. Several proprietary and open source desktop GIS and server GIS including some methods (e. g. methods for utilizing server GIS, creating Web mapping application, consuming map services, etc) are described in detail in section 2.3.

I will describe the geographic information in GIS and methods for handling geographic information in section 2.4. In section 2.4, I will also depict at glance the methods used, such as for storing geographic information in several formats (for instances proprietary GIS software file, geographic geodatabase, and metadata) and for visualizing geographic information in several types of map, map products and map services, etc.

2.2 Fundamental concepts in geographic information science

Fundamental concepts in geographic information science are as follows. Something new obtained through geographic analysis of geographic information is typical contribution in geographic information science. Geographic analysis can reveal things that might otherwise be invisible [20]. This means that raw data is turned by the analysis into useful information, in pursuit of scientific discovery, or more effective decision-making.

A geographic information system (GIS) is used as a tool [21] in geographic information science. In geographic analysis, a researcher intends to add value to geographic data and to turn the data into useful information using GIS as a tool.

GISs are mostly used on a project basis, for example, to perform a particular analysis [21]. In that situation, geographic data or geographic information is collected for the project, and GIS that manipulates the geographic information is called GIS application for the project.

Geographic information, especially rare geographic information is important in geographic information science. A considerable amount of money is necessary to collect geographic data or information. Then, a researcher in geographic information science needs a disseminating function of geographic data or information provided by a geographic information center. The needs generated the spatial data infrastructure (SDI) that will be introduced in section 3.2.

2.3 Geographic Information System

Geographic information systems are computer-based systems for storing and processing geographic information. GIS is used as a tool to efficiently and effectively manage information about geographic objects and events and to accomplish many useful tasks, including managing huge amount of geographic information in databases and creating useful maps.

GIS consists of six components, i.e., network or Internet, hardware, software, data or database, management or procedures, and people who design, program, maintain, and use GIS. GIS software system includes the following two types: Desktop GIS and Server GIS.

2.3.1 Desktop GIS

Since the mid-1990s, desktop GIS have been widely implemented and became the most popular application in GIS software category. The desktop GIS software can be classified into several categories including simple viewers (such as ESRI ArcGIS ArcReader and Pitney Bowes MapInfo ProViewer), desktop mapping and GIS Software systems (such as Autodesk AutoCAD Map 3D, ESRI ArcGIS ArcView, Pitney Bowes MapInfo Professional, and open source Quantum GIS), and the high end, full-featured professional editor/analysis systems (such as ESRI ArcGIS ArcInfo).

2.3.1.1 ESRI ArcGIS Desktop

ArcGIS Desktop is ESRI's desktop GIS software. It is used to deal with geographic information, such as for solving problems, making better decisions, increasing efficiency, visualizing and understanding of geographic information. Three functional levels are available, i.e. ArcView concentrated only for comprehensive data use, mapping, and analysis, ArcEditor provided with additional advanced geodatabase editing and data creation, and ArcInfo equipped with comprehensive GIS functionality including rich geo-processing tools [22]. Between them, ArcInfo is supported with the full range of GIS function such as data collection and import; editing, restructuring, and transformation; display; query and analysis.

Two ArcGIS Desktop applications commonly used for dealing with geographic information are ArcMap and ArcCatalog. The ArcMap application is used to handle tasks relating to the mapping and editing process as well as map-based query and analysis. The ArcCatalog application is used to organize and manage geographic information, such as maps, globes, data files, geodatabases, geo-processing, toolboxes, metadata and GIS services [22].

2.3.1.2 Quantum GIS (QGIS)

Quantum GIS (QGIS) is an open source GIS equipped with user-friendly tools. It supports numerous formats of vector, raster, map services, and databases, such as shapefile, GeoTiff, PNG, JPG PostGIS, MSSQL spatial layer, WMS, WFS, etc [23] [24].

Three QGIS' tools [24] [25] commonly used to deal with GI services are:

- **UMN MapServer Export** is the most important and convenient tool for administering the UMN Mapserver's mapfile. This tool allows users to load and symbolize layers in QGIS, and export the QGIS project (.qgs file) to UMN Mapserver's mapfile.

- **PostGIS Layers related tools** include ‘Loading a PostGIS Layer’ and ‘Importing Data into PostgreSQL using SPIT (Shapefile to PostGIS Import Tool)’.
- **Add WMS/WFS tools** are used to connect to WMS/WFS servers and add WMS/WFS layers to QGIS that will act as WMS/WFS client.

The main features provided by QGIS are summarized as follows [24] :

- Map Navigation tools for zooming in, zooming out, panning maps, and getting information.
- Attribute table for viewing thematic attributes of vector layers in a table
- Vector symbolization for changing the outline and fill of vector features
- Point symbols for customizing points with a number of predefined point symbols provided by QGIS. QGIS will also recognize new custom symbols, including any SVG file inserted by users.
- Labeling for creating labels of vector features
- Map editing for digitizing vector features in the map window; adding new Point/Line/Polygon or removing them from existing datasets; moving, adding and deleting existing vertices of features; and cutting, copying or pasting features between different layers
- Projection for providing on-the-fly projection for vector layers, which allows user to use maps with different coordinate systems
- Tree view legend for viewing each layer including its name and type of symbol,
- Print composer for creating cartographic output including layout of map, legend, north arrow, scale bar, etc.
- Project file for storing the settings of layers in a session (.qgs file), including formats for symbol, layout, etc.
- Raster pyramid/Spatial index for enhancing the efficiency of GDAL raster with pyramids and shapefile with spatial index
- Scale dependent rendering for showing maps depending on the specified map scale

2.3.1.3 uDig

uDig is an open source desktop application framework, whose goal is to provide a complete Java solution for desktop GIS data access, editing, and viewing [26]. uDig aims to be

- a user friendly application, that is equipped with a familiar graphical environment for GIS users
- Desktop located application, running as a thick client on Windows, Mac, and Linux
- Internet oriented application, consuming standard (WMS, WFS, WCS) and de facto (GeoRSS, KML, tiles) geospatial web services
- GIS ready application, providing the framework on which complex analytical capabilities can be built, and gradually subsuming those capabilities into the main application [26].

2.3.1.4 AutocadMap 3D

Autodesk's AutocadMap 3D can be classified into CAD [27] (or Computer-Aided Design)-based GIS. These are systems that first started life as CAD packages, and then later GIS capabilities were added on top of them. The GIS capabilities include database, spatial analysis, and cartographies. The systems have been designed for users who work with CAD applications and who also need geographic information and geographic analysis in their projects, such as architects, engineers and constructors.

2.3.2 Server GIS

A server GIS is a GIS that runs on a computer server that can handle concurrent processing requests from a range of networked clients and reply to the clients. The server GIS technologies have grown along with the development of computer servers, the Internet, and other information technology, including hardware, software, and network infrastructure. The users' needs for easy access to the GI services (Web services for mapping) has led GIS software vendors to introduce server-based GIS products such as ESRI ArcIMS and ArcGIS Server, Autodesk MapGuide, MapServer (open source), etc.

The server GIS provides a wide range of GIS ability through the Web compared to a Web mapping system that only focuses on visualizing and managing a small subset of GI services. Abilities of the server GIS include working with any base map and providing huge GI services to be accessed by users or Web mapping systems.

The server GIS usually provides and publishes Web services for mapping, including mapping services, feature services and metadata catalog services, etc. These Web services can be map images, features and data. The Open Geospatial Consortium (OGC) [28] specifications for the Web services, such as OGC-Web Mapping Service (WMS) [29], OGC-

Web Feature Service (WFS) [30], and OGC-Web Coverage Service (WCS) [31] are widely used. The WMS protocol serves maps of georeferenced data rendered in image format, such as PNG, GIF or JPEG [29]. This type of map service is usually used as a base map. The WFS protocol serves geospatial data encoded in Geography Markup Language (GML) [30], which can be used as a base map and can also be used to generate thematic maps. The WCS protocol serves both image and data (raster dataset) for client-side rendering [31].

2.3.2.1 ESRI ArcIMS Server

ArcIMS Server [32] is used to publish map, data, and metadata on Web [33]. ArcIMS contains three component tiers: The presentation tier, business logic tier, and data tier [33] as shown in **Figure 2.1**. ArcIMS also provide ArcIMS Management tools including a set of components for publishing Web services for mapping and managing a Web Mapping site [33].

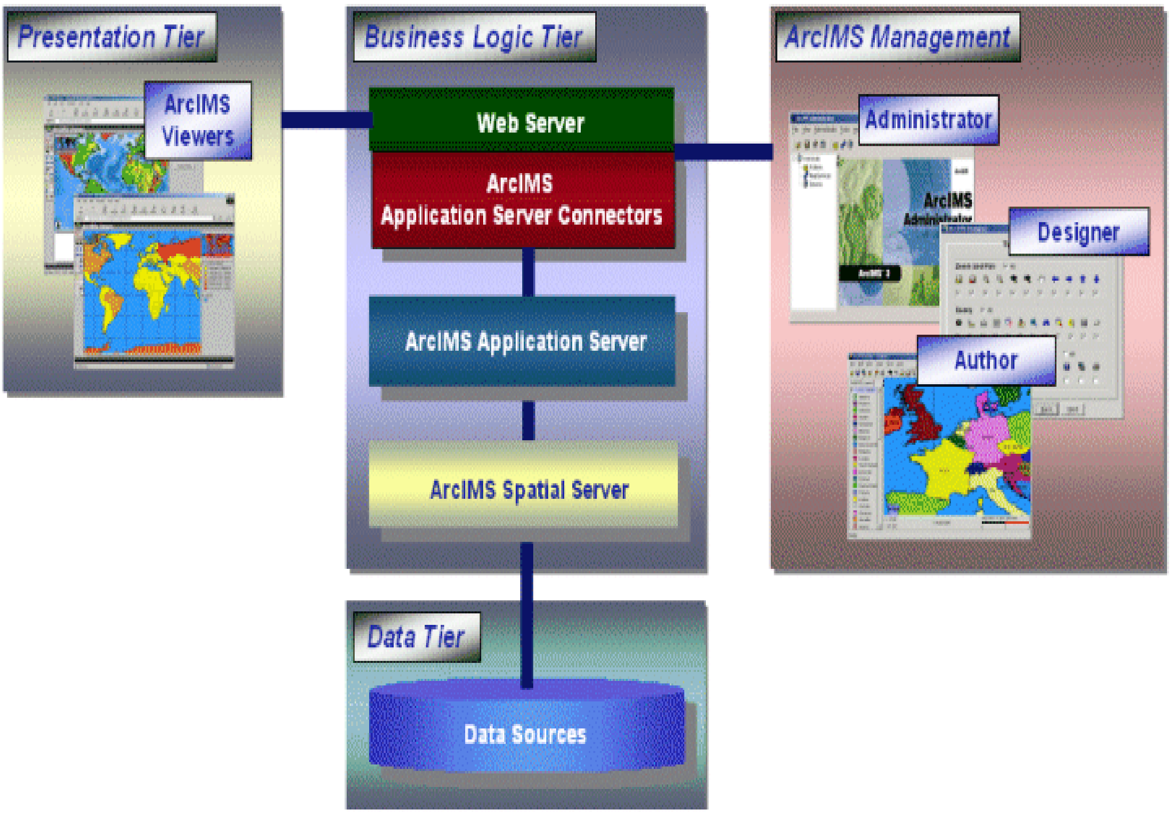


Figure 2.1 ArcIMS architecture overview captured from [33]

2.3.2.1.1 The presentation tier

The presentation tier contains the ArcIMS client viewers used for accessing, viewing, and analyzing geographic data.

2.3.2.1.2 Components needed to support ArcIMS

ArcIMS that works in a Java environment needs Web Server, JavaVM and a Servlet engine. The Web server is used to handle request from a client using HTTP, then forward a request to the appropriate application, and finally send response back to the requesting clients.

2.2.2.1.3 The business logic tier

The business logic tier consists of components used for handling requests and administering the ArcIMS site. They include:

(1) ArcIMS Application Server Connectors

The ArcIMS Application Server Connectors facilitate a communication pipeline between a Web server or third party application with the ArcIMS Application Server, The ArcIMS connectors include ArcIMS Servlet Connector, A Web Map Server (WMS) Connector, ArcIMS ColdFusion Connector, ArcIMS ActiveX Connector, ArcIMS .NET Link, ArcIMS Java Connector.

(2) ArcIMS Application Server

The ArcIMS Application Server that works as a background process (Windows service/UNIX or Linux daemon) has the following tasks: to manage the load distribution of incoming requests, to register which services are working on which ArcIMS Spatial Servers, and to send an incoming request to the appropriate Spatial Server.

(3) ArcIMS Spatial Server

The ArcIMS Spatial Server, the utility vehicle of ArcIMS, has tasks to access and bundle maps and data into the appropriate format before sending the data back to a client**.** ArcIMS Spatial server consists of various types of components that support the different functionalities as shown in **Figure 2.2**

The ArcIMS Spatial Servers shown in **Figure 2.2** include:

(a) **Image Server,** used to generate maps from shapefiles, ArcSDE data sets, or supported image formats. The generated map is sent to clients as JPEG, PNG, or GIF images.

(b) **Feature Server,** used to generate vector features from shapefiles and ArcSDE data sets. They are streamed to a Java Applet (in a compressed format) in the client Web browser, to ArcExplorer 9, or to other clients that can consume the stream such as ArcMap. Users on the client side can utilize the streaming feature for labeling and changing the appearance of a map, map tips, and spatial selection.

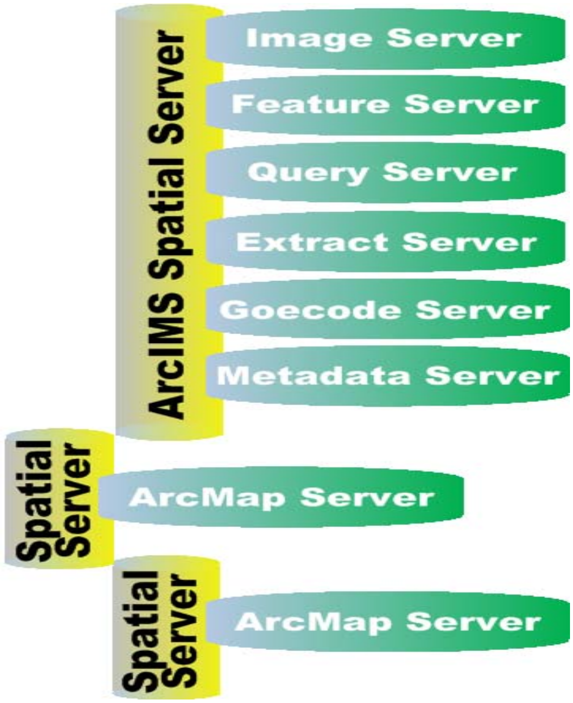


Figure 2.2 ArcIMS spatial server redrew based on image from [33]

(c) **Metadata Server,** used to store documents that contain information about maps, data, and services.

(d) **ArcMap Server**, used to generate images using an ArcGIS ArcMap document as the input. The behavior and types of requests are similar to the Image Server.

Communication in the business logic tier

ArcXML, an implementation of XML used with ArcIMS, is used to manage the communication between components in the business logic tier. The ArcXML elements and attributes are implemented in:

(1) Map configuration files, used as input to ArcIMS Image and Feature Services, describe information about how a map should be generated including the list of layers used and their symbology. Note that ArcMap documents are created using ArcMap application and not written in ArcXML. It is also used as an input to ArcIMS ArcMap Image service.

(2) Metadata configuration files, used to provide instructions on the location of metadata tables and other information needed to support Metadata Services.

(3) Requests, sent to an ArcIMS service requesting maps, attribute data, or metadata information.

(4) Responses, used to return information to the requesting client.

(5) Administration, in which ArcXML are used to handle the processes, such as adding, starting, stopping, and deleting ArcIMS Spatial Servers, Virtual Servers, and services.

Table 2.1 20 typical data formats and data types selected from of 53 data formats supported by ArcIMS Server adopted from [33]

Data Types	Data Format	Image	Feature	ArcMap
Shapefile	Shapefiles	Yes	Yes	Yes
Geodatabase	Geodatabases	No	No	Yes
Personal Geodatabase	Personal Geodatabases	No	No	Yes
ArcSDE	ArcSDE Features	Yes	Yes	Yes
Coverages	ArcInfo™ Coverages	No	No	Yes
	PC ARC/INFO Coverages	No	No	Yes
	ArcSDE for Coverages	Yes	Yes	Yes
CAD	DWG	No	No	Yes
	DXF	No	No	Yes
	DGN	No	No	Yes
Raster	ArcView® Image Catalog	Yes	No	Yes
	ArcSDE Embedded Raster Catalog	Yes	No	Yes
	Personal Geodatabase Managed Catalog	No	No	Yes
	Personal Geodatabase Unmanaged Catalog	No	No	Yes
	ADRG Image (.IMG)	Yes	No	Yes
	JPEG (.JPG)	Yes	No	Yes
	MrSID- LizardTech (.SID)	Yes	No	Yes
	Portable Network Graphics (.PNG)	No	No	Yes
	Tagged Image File Format (.TIF)	Yes	No	Yes
	TIFF with Geo Header (.TIF)	Yes	No	Yes

2.3.2.1.4 The data tier

The data tier consists of all geographic information that can be used as data sources for ArcIMS Services. **Table 2.1** shows several data types or data formats adopted from 53 supported data formats for the data resources used to create ArcIMS Image, Feature or ArcMap Image Services [33].

2.3.2.2 ESRI ArcGIS Server

ArcGIS Server environment is composed of some of the following components: Web server, GIS server, data server, manager administrator, ArcCatalog administrator, ArcGIS Desktop content authors, and clients as shown in **Figure 2.3** [34]. A service usually called GI service (GIS Service) is a representation of a GIS resource, which is provided by Server GIS to client applications. The GI services are consumed through a Web browser or custom application, or through ArcGIS applications, such as ArcMap and ArcGlobe that acts as client to GI services [35].

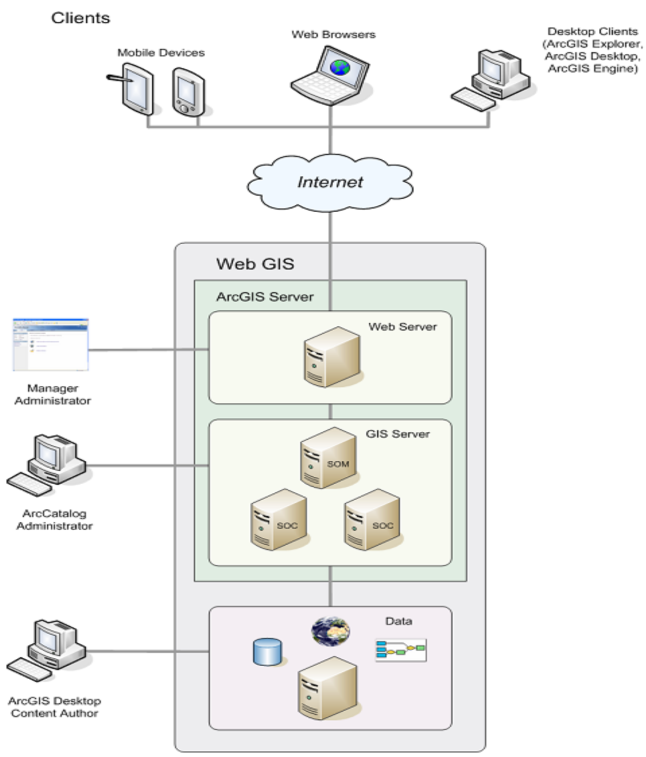


Figure 2.3 The ArcGIS Server system architecture captured from [34]

2.3.2.2.1 ArcGIS Server component

ArcGIS Server system consists of some of the following components [34] as shown in **Figure 2.3** and **Figure 2.4**:

- **GIS Server** is used to host GIS resources, such as maps, globes, and address locators, and to publish them as services to client applications. It is composed of two distinct parts: (a) The server object model (SOM) that manages the services running on the server (b) The server object containers (SOCs) in which the services are hosted. The SOM connects to one or more SOCs when a client application requests to use a particular service.
- **Web Server** is used to host Web applications and services that use the resources running on the GIS Server.
- **Clients** are Web, mobile and desktop applications that access the services from GIS Server.
- **Data Server** contains GIS resources, such as map documents and geodatabase, which is used to create GI services.
- **Manager and ArcCatalog administrators** (a) manager administrator, a Web application, which is used to publish services, administer the GIS Server, create Web application, and publish ArcGIS Explorer maps on the server. (b) ArcCatalog administrator has a GIS server node that allows adding connection to GIS server for either general server usage or administering the server's properties and services.
- **ArcGIS Desktop content author** is used to author the GIS resources for creating maps, geoprocessing tools, and globes, which will be published to server.

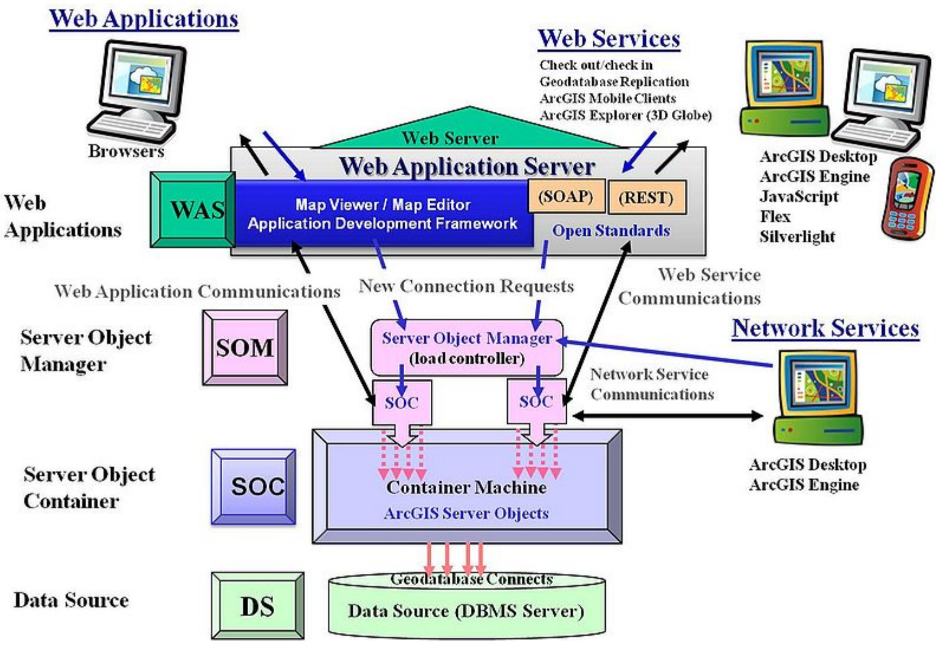


Figure 2.4 ArcGIS Server component architecture (WAS = Web applications) captured from [36]

2.3.2.2.2 ArcGIS Server Services

Table 2.2 summarizes various types of GI services produced by ArcGIS server and GIS resource required for each one [35].

Table 2.2 various types of GIS Services produced from ArcGIS server

Service type	Required GIS resources
Map Service • Mapping (the default of ArcGIS server map service) • WMS (map service that is compliant with OGC Web Map Service	Map documents (.mxd, .pmf) or map service definition (.msd)
Feature Service • WFS (feature service that is compliant with OGC Web Feature Service	Map documents (.mxd, .pmf) or map service definition (.msd)
Geodata Service • Geodata Service (Service that provides access to the contents of a geodatabase for data query, extraction and replication	Database connection file (.sde) or personal geodatabase or file geodatabase or map document referencing data from a versioned geodatabase

2.3.2.2.3 Application Developer Framework

ArcGIS server provides the ArcGIS Web Application Framework (ADF), containing tools for building Web mapping applications for Microsoft .NET framework [37]. During the installation of Web ADF 9.3.1, the following components, such as Web ADF controls, Web mapping application template, integrated library reference, Project context menus including ‘Add ArcGIS Reference’, ‘Add Toolbox Reference’ and ‘Add ArcGIS Identity’ will be automatically integrated to VS 2008 Integrated Development Environment (IDE) [38].

2.3.2.3 UMN MapServer

UMN MapServer Web mapping system is the most popular open source server GIS and Web mapping application today [20]. **Figure 2.5** shows the basic architecture of MapServer applications.

MapServer [39] utilizes two types of input: data stores including vector data and raster data, and Web services including WMS, WFS and Tiles. Here, “Tiles” mean pieces. Geographic data is sliced up into pieces about the same size in which they will be displayed as a map [39].

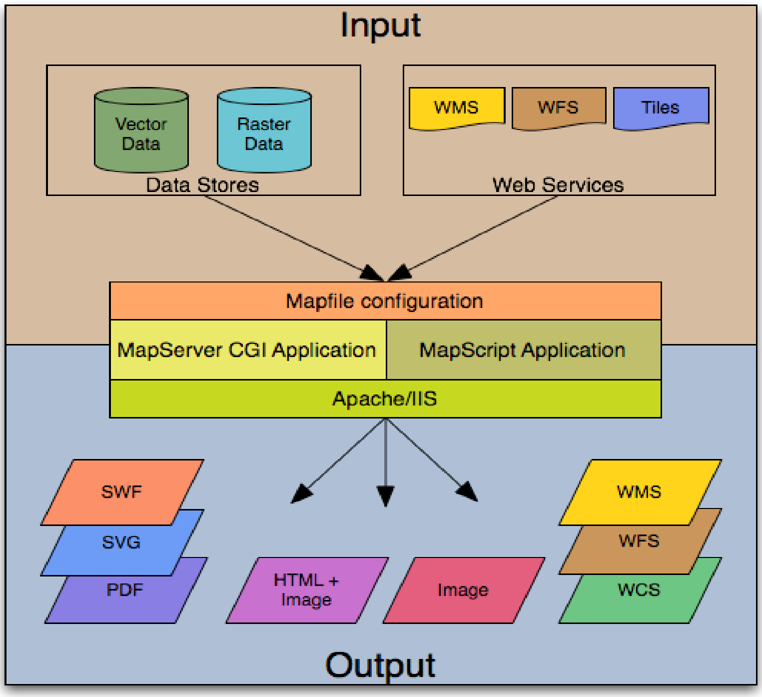


Figure 2.5 Architecture of MapServer applications captured from [39]

The core component of MapServer is Mapfile [40] which is a structured text file [39] called map configuration file. In a Mapfile, objects with hierarchical structure (such as MAP, LAYER, POJECTION, SCALEBAR, LEGEND and WEB) are defined [40] as shown in **Figure 2.6.** These objects will lead MapServer as to locate data sources, to utilize type of data sources, to produce geographic information (such as SWF, SVG, PDF, Image, and HTML + Image) or to serve Web services (such as WMS, WFS and WCS).

MapServer supports various standards (such as OGC WMS, WFS, WCS, GML, etc) [41] defined by OGC that focuses on the development of geospatial web standards provided to GIS communities. Two OGC-standards that are commonly used as the interoperable map services by server GIS are WMS and WFS. MapServer can be implemented either as a server or as a client of WMS/WFS environment.

2.3.2.3.1 Web Map Services server/client

MapServer that acts as a WMS server allows administrator to publish WMS to the client and that acts as a WMS client allows user to consume WMS. WMS servers interact with clients through HTTP protocol. In most cases, MapServer is implemented with a CGI program to serve WMS [42]. The function of MapServer as a WMS server or WMS client is defined in Mapfile configuration file.

```
MAP
    NAME "sample"
    STATUS ON
    SIZE 600 400
    SYMBOLSET "../etc/symbols.txt"
    EXTENT -180 -90 180 90
    UNITS DD
    SHAPEPATH "../data"
    IMAGECOLOR 255 255 255
    FONTSET "../etc/fonts.txt"

    #
    # Start of web interface definition
    #
    WEB
        IMAGEPATH "/ms4w/tmp/ms_tmp/"
        IMAGEURL "/ms_tmp/"
    END # WEB

    #
    # Start of layer definitions
    #
    LAYER
        NAME 'global-raster
        TYPE RASTER
        STATUS DEFAULT
        DATA bluemarble.gif
    END # LAYER
END # MAP
```

Figure 2.6 Example of Mapfile captured from [40]

WMS maps are generally generated in a standard format such as Graphic Interchange Format (GIF), Portable Network Graphic (PNG), JPEG, SVG, etc. The WMS maps is limited and only used for a background or reference map layer in other GIS software [43].

2.3.2.3.2 Web Feature Services server/client

MapServer can also be used as WFS server that publishes feature-level geospatial data or WFS client that retrieves and displays geospatial data from a WFS server. Web Feature Service is a pure vector feature, including information about both geometry and attributes, which is delivered to clients in GML [44].

2.3.2.4 Autodesk MapGuide Server

MapGuide is an important innovation that can be used by many users who have built valuable databases, and who want to make them available to other users inside or outside their organization [20]. MapGuide, available in two versions (MapGuide open source and Autodesk MapGuide Enterprise), is GIS software that used to distribute spatial data over the intranet and internet [45].

MapGuide has been widely implemented both in existing mature GIS sites when publishing data internally or externally, and in new sites for quickly publishing dynamic maps to a widely dispersed collection of users (for example, maps showing election results, or transportation network status). Autodesk MapGuide can be used to serve maps (using the OGC Web mapping Service (WMS) protocol) and features (using the OGC Web Feature Service Service (WFS) protocol). Autodesk MapGuide can be used as a client environment that consumes from an internal and external data repository, including data from other WMS and WFS sites. It can also be used as a server environment that publishes OGC WMS/WFS. As a further service, MapGuide allows organizations to share their vector data with authorized outside organizations [20].

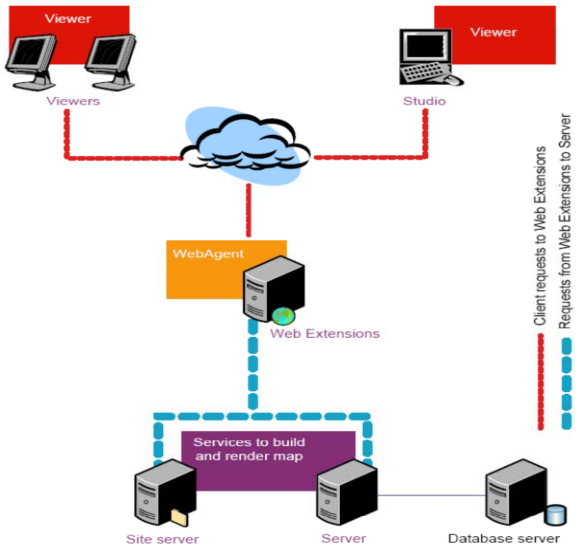


Figure 2.7 Autodesk MapGuide Enterprise components captured from [45]

MapGuide Enterprise consists of four separate components [45], as shown in **Figure 2.7**:

(1) MapGuide Server, used to hosts the MapGuide services and to responds to requests from client applications through TCP/IP protocol

(2) MapGuide Web Extensions (for application development) that expose the services offered by the MapGuide Server to client applications over the Internet or an intranet using HTTP protocol

(3) Autodesk MapGuide Studio (an authoring application for map authoring), used to handle all aspects from preparing collecting and preparing geospatial data until distribution map on the Internet

The MapGuide Studio can be used to perform the following tasks:

(a) to create resources from the source data, either by loading file-based data or by connecting directly to external databases,

(b) to customize styled and themed layers from the resources,

(c) to compile the layers into a map,

(d) to embed the map in a web page using a web layout [45].

(4) The MapGuide Viewer provides a means of viewing a map in a web browser.

There are two flavors of the MapGuide Viewer:

(a) The downloadable viewer (Autodesk DWF viewer) is based on a Microsoft ActiveX Control and has full support for the DWF format. It works with the Microsoft Internet Explorer browser only.

(b) The AJAX viewer (or “zero-client viewer”) does not need a download. It works with Microsoft Internet Explorer, running on Windows, or with Internet Explorer or Firefox on other operating systems, such as MacOS or Linux [45].

2.3.3 ArcSDE Geodatabase and DBMS Server

ArcGIS geodatabase is a collection of geographic datasets of various types stored in a common file system folder (called as file geodatabase), a Microsoft Access database (called as Personal Geodatabase), or a multiuser relational database such as Oracle, Microsoft SQL Server, PostgreSQL, Informix, or IBM DB2 (called as ArcSDE Geodatabse) [46].

ESRI ArcSDE Application Server

ArcSDE plays an important role in an integrated GIS by providing a gateway between ArcSDE client applications (for example, ArcGIS Desktop, ArcGIS Server, ArcIMS, custom applications) with one of the multiuser relational database (such as Oracle, MS SQL Server, PostgreSQL, Informix, or IBM DB2). ArcSDE allows users to use the ArcSDE client applications to store, use, and manage geospatial data in one of the multiuser relational database [47].

ArcSDE application server (ArcSDE connection for DBMS) bridges geospatial data between GIS application and relational database [48]. **Figure 2.8** shows how the ArcSDE acts as the gateway between ArcGIS applications and a relational database.

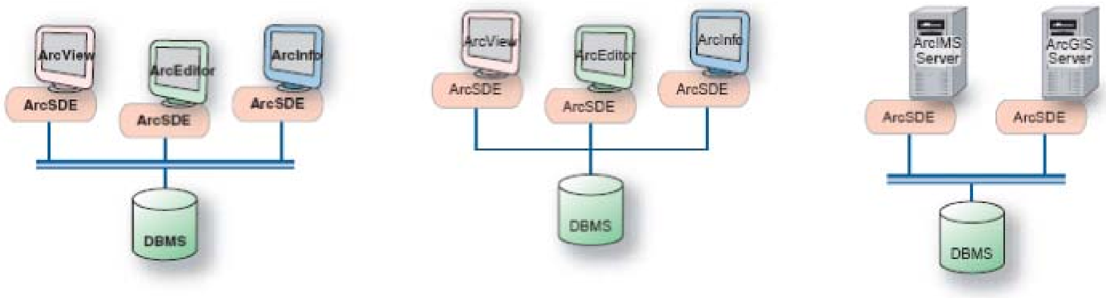


Figure 2.8 Several ways of ArcSDE configuration that acts as the gateway between ArcGIS applications and DBMS, captured from [47]

2.3.4 Geographic Metadata Servers

2.3.4.1 ESRI ArcIMS Metadata Server and its service

ArcIMS Matadata Server allows users to easily publish metadata document into Metadata Service and manage the published metadata document using ArcCatalog Catalog Tree, and allows clients to search the published metadata document. **Figure 2.9** shows the ArcIMS Metadata Services system [49].

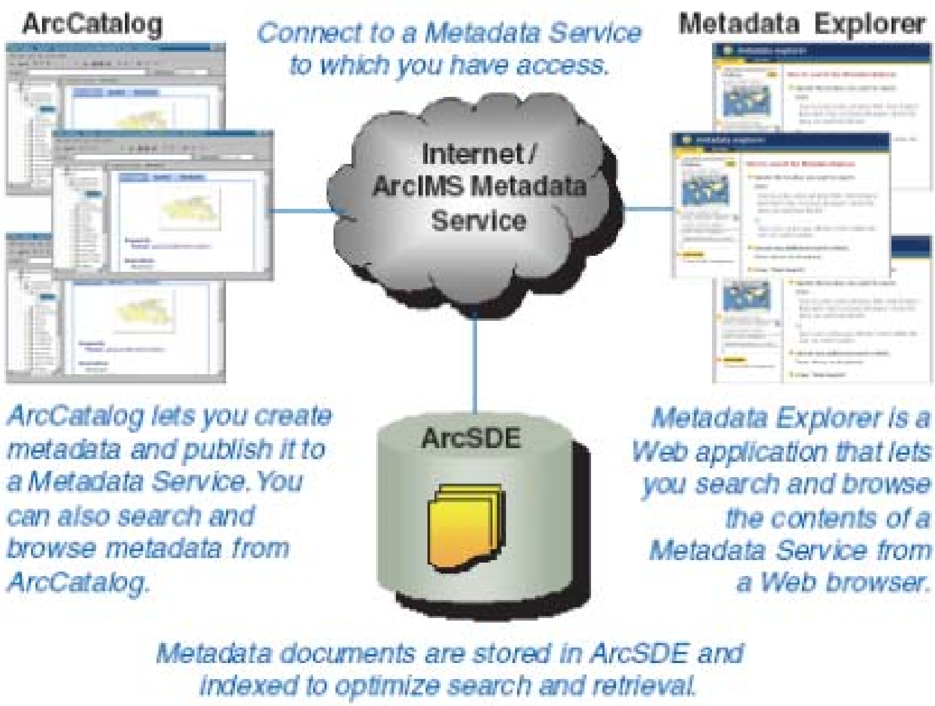


Figure 2.9 ArcIMS Metadata Service system captured from [49]

Component of ESRI ArcIMS Metadata Service

ArcIMS Metadata Service system requires the following components [49]:

- **ArcIMS Server** is used to create a Metadata Service and host it into ArcSDE Geodatabase. Metadata documents are stored in the Metadata Service in which contents of metadata documents are searched by clients.
- **ArcSDE** and the relational database are configured to store, index, and search the published metadata documents. When creating a Metadata Service, several tables are created in the ArcSDE geodatabase used to store the document and to index the documents for optimizing search and retrieval performance. When a client publishes a metadata document to the Metadata service, new records are added to the database tables.
- **ArcCatalog** is used to create metadata document, then publish it to a Metadata Service. ArcCatalog is equipped with built-in editors for creating metadata document. After crating metadata document and connecting to Metadata Services in ArcCatalog catalog tree, users can copy or drag and drop the metadata document onto Metadata Service. Metadata Services connection requires a username and password provided by the host of the Metadata Service. ArcCatalog can be used to search a Metadata Service and manage the published metadata documents.
- **Metadata Explorer** is a Web application developed with the ArcIMS Web ADF for the Java Platform. It allows people to search and browse the contents of a Metadata Service through a Web browser.

2.3.4.2 ESRI GeoPortal Server

ESRI have released ESRI GeoPortal Server [50] version 1.0 in January 2011, which is a free and open source product that can be used to discover and use geospatial resources. Two big changes between the previous ESRI ArcGIS Server Geoportal extension version 10 and Geoportal Server version 1.0 are that it has been released as open source and the Geoportal Web application has been updated to use the JavaServer Faces (JSF) 2.0 framework [51].

The Geoportal Server is a standalone application that can be integrated with many ArcGIS products including ArcGIS Desktop and ArcGIS Server. ESRI GeoPortal Server version 1.0 does not need ArcGIS for Desktop or ArcGIS for Server licensing. It also does not require ArcGIS server installed on the same machine, but it can use other locations of ArcGIS

Server services including ESRI Global ArcGIS server online service. The latest version of the Geoportal Server is version 1.2.2 released in July 2012 [51].

Software components required for ESRI Geoportal Server system [52] are as follows:

- ESRI Geoportal Server for server application including ESRI Geoportal Web application
- PostgreSQL for RDBMS
- Apache Tomcat for Web servlet
- Java Development Kit with Runtime Environment for Java controller
- JDBC Configuration File for connecting Tomcat to PostgreSQL

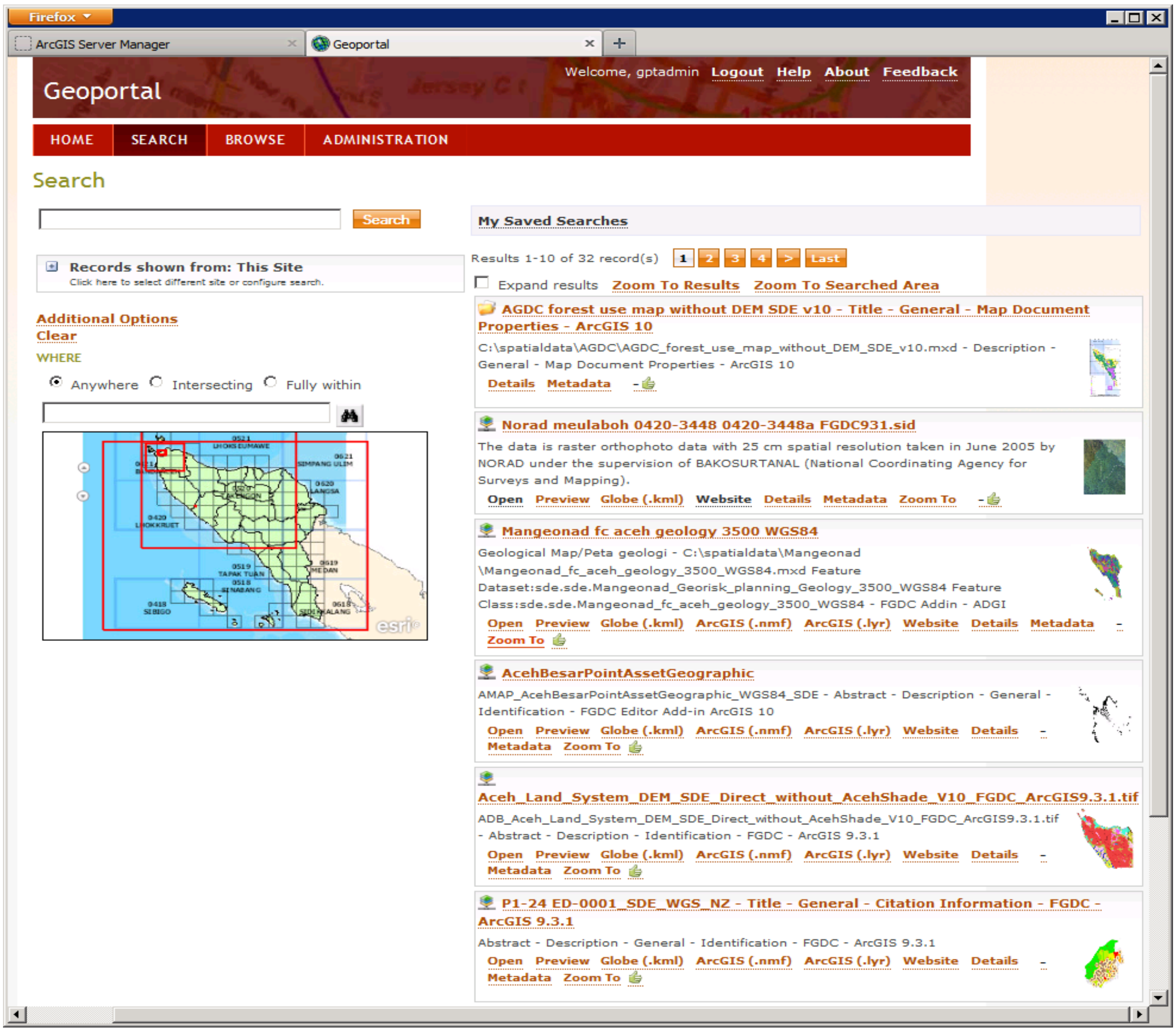


Figure 2.10 ESRI Geoportal Web application produced using Geoportal application

The Geoportal Server that supports standards-based clearinghouse and metadata discovery applications help organizations manage and publish metadata for their geospatial resources and let users discover and connect to the Geoportal metadata service [51]. **Figure 2.10** shows ESRI Geoportal Web application that consumes ArcGIS Server service with an interactive base map layer in the left side and the list of metadata documents with its online resources URL that also refer to ArcGIS to ArcGIS Server services.

2.3.4.3 GeoNetwork Opensource

GeoNetwork is a Geographic Metadata catalog application to manage and disseminate geographic information. GeoNetwork is equipped with three main functionalities, i.e. powerful metadata editing, search functions and an embedded interactive web map viewer. Geonetwork has been widely used by many Spatial Data Infrastructure (SDI) projects across the world [53].

The Food and Agriculture organization of the United Nations (FAO) developed the prototype of the GeoNetwork catalogue to systematically manage and publish the geographic information in 2001. In 2003, FAO with the contribution from the World Food Programme (WFP) released the first version of the software and established the operational catalogues in FAO and WFP [54].

The first version system implemented the ISO19115:DIS metadata standard and embedded InterMap as map viewer (the Web Map Client) that supported OGC WMSs. The standard Z39.50 catalogue protocol was implemented to provide distributed searches. GeoNetwork has been turned into a piece of Free and Open Source Software that allows the whole geospatial users community to participate in further development of the software. The second version was developed in 2004 by FAO with support from UN Environmental Programme (UNEP). The second version allowed users to work with multiple metadata standards (ISO 19115, FGDC and Dublin Core) in a transparent manner [54].

The current stable release of GeoNetwork is Version 2.6.4. The communities are working with version of 2.8. GeoNetwork Opensource is the result of the collaborative development of many contributors including the Food and Agriculture organization (FAO), the UN Office for the Coordination of Humanitarian Affairs (UNOCHA), the Consultative Group on International Agricultural Research (CSICGIAR), The UN Environmental Programme (UNEP), The European Space Agency (ESA) and many others [54].

GeoNetwork has been implemented using a combination of several Free and Open Source Software (FOSS) tools, which utilize International and Open Standards for services and protocols such as ISO/TC211 and OGC [54]. It is aimed at connecting spatial information communities and their geographic information with an easy to use GeoNetwork Web interface. The Web interface can be used to search geographic information between multiple catalogs, to overlay several published map services in the embedded map viewer, and to publish geospatial data using GeoNetwork Web-based metadata editing or importing tool and optionally the embedded GeoServer map server [53]. **Figure 2.11** shows the GeoNetwork Opensource Web application.

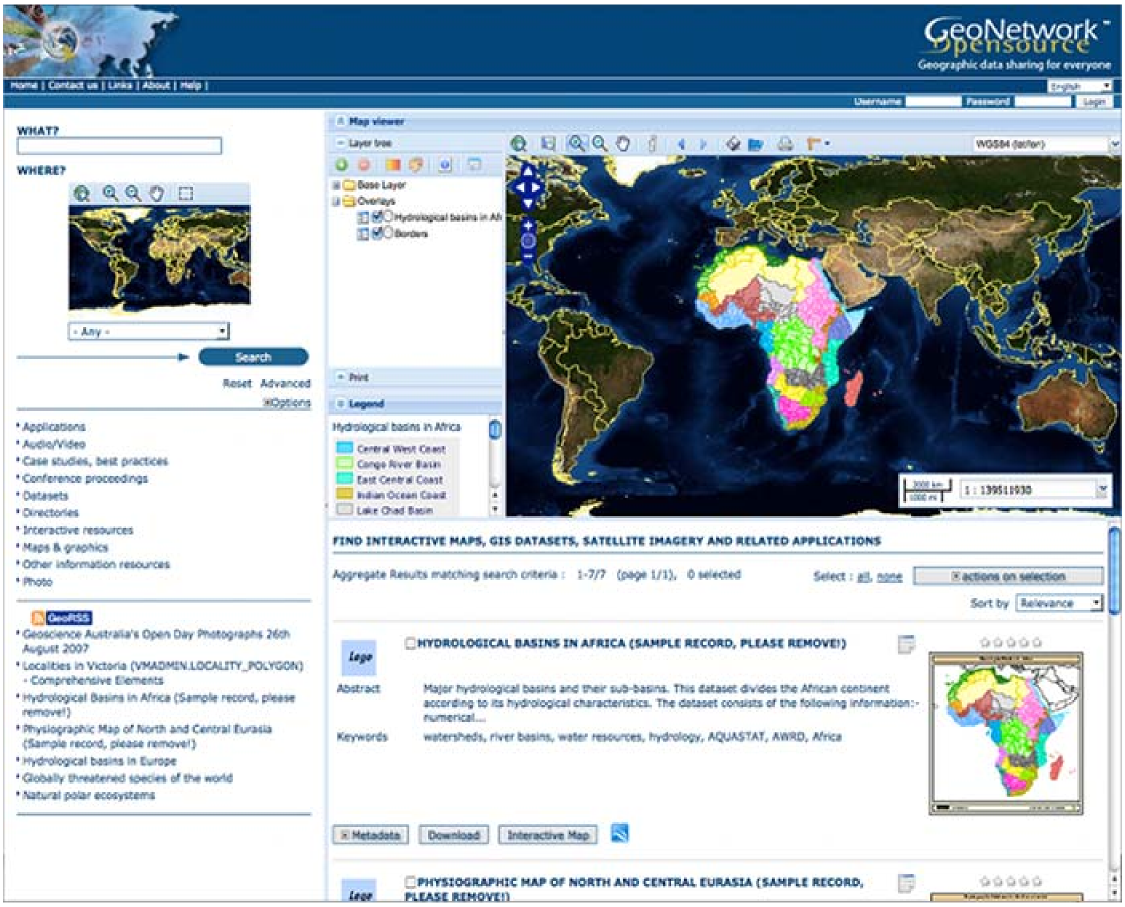


Figure 2.11 The GeoNetwork Opensource Web application produced using GeoNetwork application [53]

The software components required for GeoNetwork OpenSource system consist of [54]:

- GeoNetwork Opensource Server including GeoNetwork Web interface application
- A Java Runtime Environment (JRE 1.5.0)

- Jetty for Web Server and Java Servlet container (Apache Tomcat can be used instead of Jetty)
- McKoiDB for database system (A dedicated JDBC compliant DBMS (such as MySQL, PostgreSQL, Oracle can be used instead of McKoiDB)
- GeoServer for providing Web Map Service

The main features of GeoNetwork Opensource application are as follows [53]**:**

- Immediate search access to local and distributed geospatial catalogues
- Up- and downloading of data, graphics, documents, pdf files and any other content type
- An interactive Web Map Viewer to combine Web Map Services from distributed servers around the world
- Online editing of metadata with a powerful template system
- Scheduled harvesting and synchronization of metadata between distributed catalogs
- Support for OGC-CSW 2.0.2 ISO Profile, OAI-PMH, Z39.50 protocols
- Fine-grained access control with group and user management
- Multi-lingual user interface

2.4 Geographic information in GIS

Geographic information can be assumed to be any real world information that relates to the Earth's surface or near the Earth's surface [55]. Geographic information is managed, analyzed, produced, disseminated or shared in a geographic information system (GIS). Geographic information is produced with a series of GIS processes from a series of geographic data and additional information. The forms of geographic information include the processed geographic data, final product of map or map services, metadata, etc.

2.4.1 Geographic data

Each object in the real world is digitally represented in geographic data. Geographic data is stored using geographic data models. Raster and vector data model are two methods commonly used to represent geographic data in digital computers [20]. Raster model is usually used to represent real world information in continues form, which not clearly distinguishes boundaries, lines and the point of objects. A vector data model is usually used to represent real world information in discrete form, which clearly distinguishes object between boundaries, lines, and the point of objects [56].

2.4.1.1 Raster data model

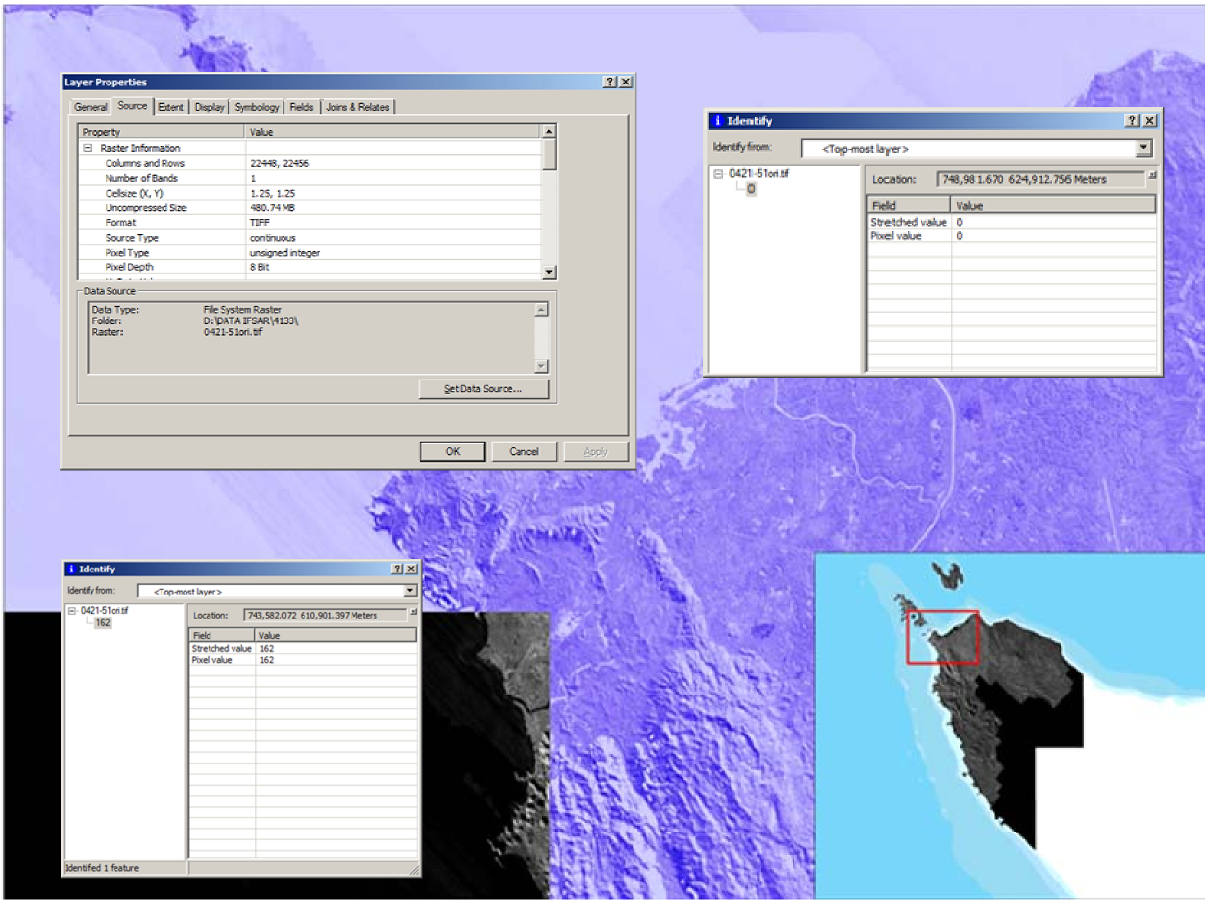


Figure 2.12 IFSAR raster data for Banda Aceh city area produced using ESRI ArcMap

In raster representation, the world is split into arrays of cells and attributes are assigned to each cell. Raster data model represents real-world objects using an array of cells, or pixels. The cell holds attribute value based on one of several encoding schemes, such as binary counting called integer system, 8-bit ASCII system, and number with decimal place system coded using real or floating-point system (called real system). These three conventions are adequate for most data, but in some cases, GIS users have to utilize binary large object (BLOB) systems [20].

In the simplest case, a binary or integer system is used (for example to show the presence or absence of vegetation). In more advanced cases, floating-point systems are preferable (for example to describe the height of terrain above the sea level in meters). In some systems, multiple attributes can be implemented and they are stored for each cell in a type of value attribute table where each column is an attribute and each row either a pixel or a pixel class [20].

Raster data includes images (e.g. an aerial photograph, a satellite image, or a scanned map) and grids [57]. **Figure 2.12** shows IFSAR (Interferometric Synthetic Aperture Radar) raster data, which uses integer system (pixel type), with 8-bit depth capacity for raster dataset cell (pixel depth) that can have 256 unique values (0 to 255) for an attribute that is assigned to a cell.

2.4.1.2 Vector data model

In a vector representation, all lines are represented as the points connected by precisely straight lines or by curves allowed only by some GIS software. An area is represented as a series of points or vertices connected by straight lines [20] as shown in **Figure 2.13.**

In vector data models, each object in the real world is classified and stored by the following geometry types [20]:

a. Point is used to describe objects as point with a single pair of (x, y) coordinate. Point usually refers to the center location of object in real world. The examples of point include the location of houses, capital of cities, and stores.

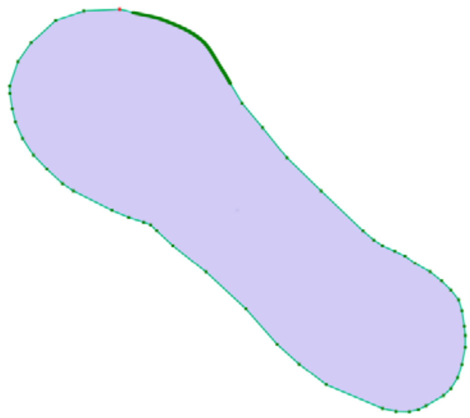


Figure 2.13 Polygon feature class produced using ESRI ArcMap

b. Line/polyline is used to describe object as a series of ordered coordinate pairs. The examples of line/polyline include roads, stream, drainage, and geology fault.

c. Polygon is used to describe objects that contain an area. It is described as one or more line segments that close to form polygon areas. The examples of polygon include building, parcel, and forest area.

2.4.1.2.1 Simple Feature and Topological Feature

Geographic entities encoded using the vector data model are usually called Feature. Features are vector objects of the type point, line/polyline, or polygon [20]. Feature class is the feature of the same geographic type that is stored in the geographic database [20]. Topological features are essentially simple features structured using additional topological rules.

2.4.1.2.2 Geospatial vector data format

Proprietary desktop GIS store geospatial vector in the following formats:

(a) ESRI ArcMap stores vector data in ESRI shapefile (polyline, polygon and point) in an ESRI Shapefile (SHP)

(b) MapInfo stores geospatial data in a MapInfo TAB file.

(c) Autodesk Auctocad Map stores in an Autocad dxf/dwg.

2.4.1.3 Attribute (tabular) data

Attribute (tabular) data related to geospatial data is descriptive data that is used by GIS to link to map features [58]. The Attribute data can be stored either in the same or in a separate table within raster and vector data in geodatabase. The separate table of attribute data can be joined with spatial data to fill additional information when developing a thematic map. This attribute table is collected and compiled for specific areas such as provincial, district or sub-district areas.

2.4.1.4 Primary or secondary geographic data

Two categories of data collection are primary data sources specially captured by direct measurement and secondary data sources reused from early studies or obtained from other systems. Primary geospatial data capture includes Raster data capture and Vector data capture such as surveying and LiDAR (Light Detection and Ranging). Secondary geospatial data capture includes Raster data capture using scanner and Vector data capture such as Heads-up and vectorization, Measurement error, Photogrammetry, and coordinate geometry (COGO) data entry [20].

2.4.2 Geographic database

Longley et al. described that a database can be thought of as an integrated set of data on a particular subject. Then, geographic databases are similar to ordinary databases but they contain geographic data for a particular area and subject [20].

Longley et al. [20] outline a number of advantages with the database approach for storing geographic data over a traditional file-based dataset. These advantages include reducing redundancy, decreasing maintenance costs, reducing data duplication, using the same data for multiple applications, facilitating data sharing, providing corporate view of data to all managers and users, establishing and enforcing security and standards for data and data access.

2.4.2.1 Database management system (DBMS) and type of DBMS

Longley et al. [20] classify three main types of Database Management System (DBMS) according to the way they organize, store and manipulate data. The types of DBMS that have been used in GIS are Relational (RDBMS), Object (ODBMS), and Object Relational (ORDBMS).

As outlined by Longley et al. that ODBMS was developed to overcome several limitations of the RDBMS, such as:

- It lacks the ability to store complete objects directly in the database.
- It was never designed to handle rich data types, e.g. geographic objects, sounds, and videos
- It has poor performance for many types of geographic query.
- The difficulty of extending RDBMS to support geographic data types and processing functions.

Longley et al. explained that in ODBMS, objects can be stored persistently and object oriented query tools are also offered. Regardless of the technical advantages of object-oriented technology, ODBMS have not proven to be successful in commercial markets. This is mainly due to the massive installation and implementation of RDBMS in the market itself and many vendors of RDBMS have also included many of the important ODBMS capabilities in their standard RDBMS to create hybrid object-relational model DBMS (ORDBMS). An ORDBMS can be constructed using RDBMS with some additional capabilities for dealing with objects, and a number of them have now been extended to support geographic object types and functions [20].

2.4.2.2 Geographic DBMS extensions

In order for traditional DBMS to handle spatial data, the traditional DBMS architecture and functionality has to be extended [59]. Breuning et al. classify three base variant of extending system architectures of spatial-temporal database management system (STMBMS) [59]:

1. The layered approach (dual architecture approach) keeps using an off-the-shelf database system and then implements application program on the top of the database systems to add some new needed functionality.
2. In the monolithic approach, the database manufacturer integrates all the necessary application-specific extensions (built-in extension) into the database system (in the core of DBMS).
3. In the extensible approach, user-defined extensions are allowed to be plugged into a database system.

Longley et al. highlighted a number of the major commercial DBMS vendors have released spatial database extensions to support their standard ORDBMS products or added spatial capabilities to their core of RDBMS products. IBM has released two extensions: DB2 spatial extender and Informix Spatial Datablade. Microsoft offers spatial capabilities in the core of SQL Server. Oracle provides spatial capabilities in the core of Oracle DBMS and Oracle Spatial extension that adds more advanced features. The open source DBMS PostgreSQL has released PostGIS spatial extension to support geographic types and functions.

DBMS vendors that release spatial extension on their ORDBMS only focus on data storage, retrieval and management. The ORDBMS with spatial extension do not have the advanced capabilities necessary for some GIS tasks, such as geographic editing, mapping and analysis [20].

2.4.2.3 GIS spatial database engine

GIS software vendors have implemented a layered architecture approach to handle geospatial data. ESRI ARC/INFO’s spatial database engine (SDE) is the representative of the layered architecture (dual architecture) approach [59].

ArcSDE is server software that provides ArcSDE client software (for example, ArcGIS Desktop, ArcGIS Server, and ArcIMS) a gateway for storing, managing, and using spatial data in one of the following database management systems [47] [60]: IBM DB2 Universal

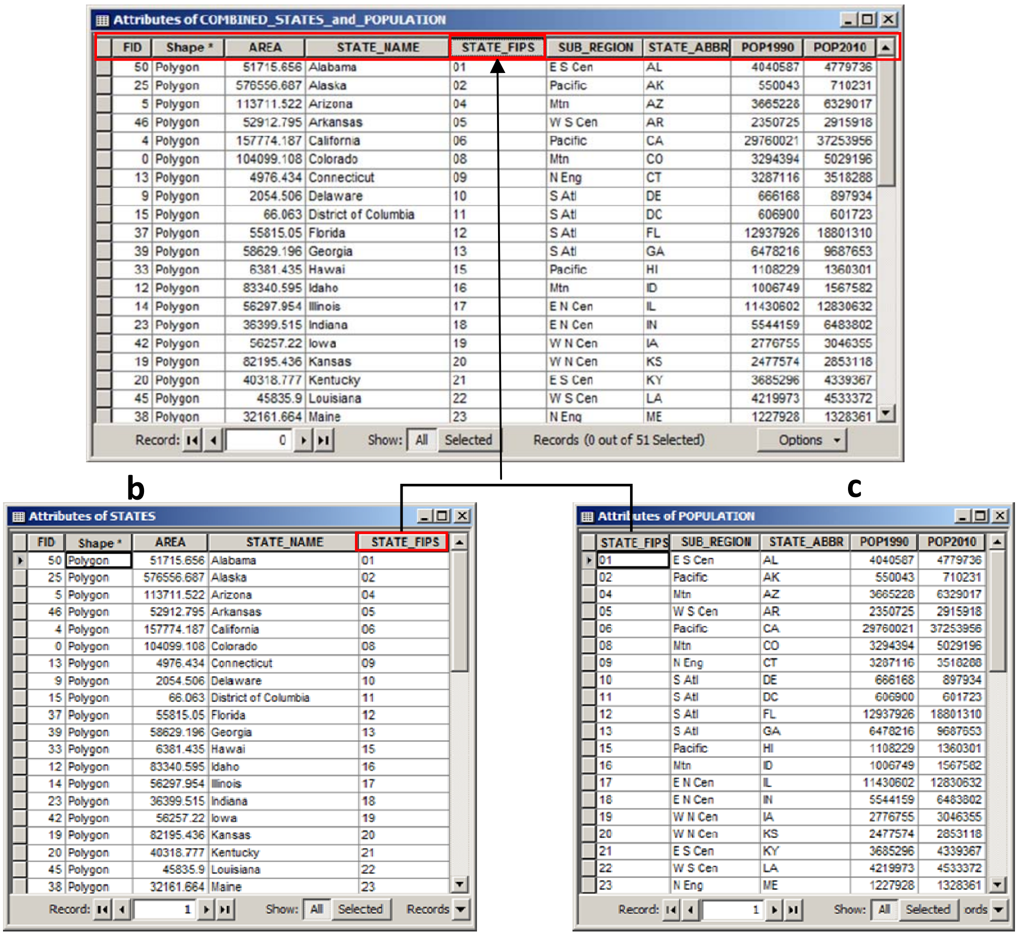
Database (UDB), IBM Informix, Microsoft SQL Server, Oracle and PostgreSQL. ArcSDE is an open, high-performance spatial data server that employs client/server architecture to perform efficient spatial operations and manage large, shared geographic data [48].

2.4.2.4 Storing data in DBMS table

The object class, also sometimes called a layer or feature class, is the lowest level of user interaction with geographic database. The object class, an organized collection of data on a particular theme, is stored in a standard database table (two-dimensional array and columns). A single database table in a DBMS is used to store each object class. Table rows contain objects, which store instance of objects classes, e.g. data for single pipe, and table columns contain object properties frequently called as attributes. Values are data that are stored at the intersections between individual row and column. The difference between geographic and non-geographic database tables is the presence of a geometry column often called the shape column whose actual coordinate values are usually stored in a highly compressed binary form to save space and to improve performance [20].

Relational database are created from tables, in which geographic classes (layers) are also stored. Tables are joined together using common row/column values or keys as they are known in the database world. **Figure 2.14** shows two tables containing data about U.S. states and one table resulted from the join process of two tables. The STATES table (**Figure 2.14**(a)) contains the geometry and other attributes containing a unique STATE FIPS (STATE_FIPS [Federal Information Processing Standard] code) identifier. The POPULATION table (**Figure 2.14** (b)), created entirely independently, also contains a unique identifier column called STATE_FIPS. Using standard database tools the two tables can be joined together based on the common STATE_FIPS identifier column (the key) to create a third table, COMBINED_STATES_and_POPULATION (**Figure 2.14** (c)). The single table (**Figure 2.14** (c)), resulted from the join process, can be used for all GIS operations such as query, display, and analysis [20].

a



Attributes of COMBINED_STATES_and_POPULATION

FID	Shape *	AREA	STATE_NAME	STATE_FIPS	SUB_REGION	STATE_ABBR	POP1990	POP2010
50	Polygon	51715.656	Alabama	01	E S Cen	AL	4040587	4779736
25	Polygon	576556.687	Alaska	02	Pacific	AK	550043	710231
5	Polygon	113711.522	Arizona	04	Mtn	AZ	3665228	6329017
46	Polygon	52912.795	Arkansas	05	W S Cen	AR	2350725	2915918
4	Polygon	157774.187	California	06	Pacific	CA	29760021	37253956
0	Polygon	104099.108	Colorado	08	Mtn	CO	3294394	5029196
13	Polygon	4976.434	Connecticut	09	N Eng	CT	3287116	3518288
9	Polygon	2054.506	Delaware	10	S Atl	DE	666168	897934
15	Polygon	66.063	District of Columbia	11	S Atl	DC	606900	601723
37	Polygon	55815.05	Florida	12	S Atl	FL	12937926	18801310
39	Polygon	58629.196	Georgia	13	S Atl	GA	6478216	9687653
33	Polygon	6381.435	Hawai	15	Pacific	HI	1108229	1360301
12	Polygon	83340.595	Idaho	16	Mtn	ID	1006749	1567582
14	Polygon	56297.954	Illinois	17	E N Cen	IL	11430602	12830632
23	Polygon	36399.515	Indiana	18	E N Cen	IN	5544159	6483802
42	Polygon	56257.22	Iowa	19	W N Cen	IA	2776755	3046355
19	Polygon	82195.436	Kansas	20	W N Cen	KS	2477574	2853118
20	Polygon	40318.777	Kentucky	21	E S Cen	KY	3685296	4339367
45	Polygon	45835.9	Louisiana	22	W S Cen	LA	4219973	4533372
38	Polygon	32161.664	Maine	23	N Eng	ME	1227928	1328361

Record: 0 Show: All Selected Records (0 out of 51 Selected) Options

b

Attributes of STATES

FID	Shape *	AREA	STATE_NAME	STATE_FIPS
50	Polygon	51715.656	Alabama	01
25	Polygon	576556.687	Alaska	02
5	Polygon	113711.522	Arizona	04
46	Polygon	52912.795	Arkansas	05
4	Polygon	157774.187	California	06
0	Polygon	104099.108	Colorado	08
13	Polygon	4976.434	Connecticut	09
9	Polygon	2054.506	Delaware	10
15	Polygon	66.063	District of Columbia	11
37	Polygon	55815.05	Florida	12
39	Polygon	58629.196	Georgia	13
33	Polygon	6381.435	Hawai	15
12	Polygon	83340.595	Idaho	16
14	Polygon	56297.954	Illinois	17
23	Polygon	36399.515	Indiana	18
42	Polygon	56257.22	Iowa	19
19	Polygon	82195.436	Kansas	20
20	Polygon	40318.777	Kentucky	21
45	Polygon	45835.9	Louisiana	22
38	Polygon	32161.664	Maine	23

Record: 1 Show: All Selected Records

c

Attributes of POPULATION

STATE_FIPS	SUB_REGION	STATE_ABBR	POP1990	POP2010
01	E S Cen	AL	4040587	4779736
02	Pacific	AK	550043	710231
04	Mtn	AZ	3665228	6329017
05	W S Cen	AR	2350725	2915918
06	Pacific	CA	29760021	37253956
08	Mtn	CO	3294394	5029196
09	N Eng	CT	3287116	3518288
10	S Atl	DE	666168	897934
11	S Atl	DC	606900	601723
12	S Atl	FL	12937926	18801310
13	S Atl	GA	6478216	9687653
15	Pacific	HI	1108229	1360301
16	Mtn	ID	1006749	1567582
17	E N Cen	IL	11430602	12830632
18	E N Cen	IN	5544159	6483802
19	W N Cen	IA	2776755	3046355
20	W N Cen	KS	2477574	2853118
21	E S Cen	KY	3685296	4339367
22	W S Cen	LA	4219973	4533372
23	N Eng	ME	1227928	1328361

Record: 1 Show: All Selected ords

.

Figure 2.14 (a, b, c) the joining table modified from [20]

2.4.2.5 SQL

SQL (Structured or Standard Query Language) is a standard database query language. Three key types of SQL are DDL (data definition language), DML (data manipulation language), and DCL (data control language). The third major revision of SQL (SQL 3) was released in 2004, in which spatial types and functions are defined as part of a multimedia extension called SQL/MM.

Data definition language

In SQL, the statements of data definition language are implemented to create, alter, and delete relational database structures. The CREATE TABLE command is utilized to define a table, the attributes, and the primary key (the column used to identify records uniquely). The following example and explanation are adopted and modified form [61]. The SQL statement used to create a table that stores data about lakes containing three columns (fid, name and shore (geometry)) is as follows:

```
CREATE TABLE lakes (
    fid             INTEGER NOT NULL PRIMARY KEY,
    name            CHARACTER VARYING (200),
    shore           Polygon NOT NULL,
    CONSTRAINT  spatial_reference  CHECK (SRID(shore) = 4326)
)
```

During the creation of the lakes table, SQL statement also utilized several table parameters. The fid column is of the type INTEGER. Fid cannot be null (NOT NULL) and must have a value. It is also defined as the PRIMARY KEY, which means that its entries must be unique. The name column is of the type VARCHAR (variable character) and can store values up to 200 characters. The name column cannot be null (NOT NULL). The shore column is of the type POLYGON with an additional spatial reference constrains (projection), which means that a spatial reference is enforced for all shapes (type SRID (Spatial Reference System Identifier) 4326 refers to EPSG (European Petroleum Survey Group) identifier for World Geodetic System coordinate WGS 84).

In most of the implementation, the stored procedures, such as used to add and drop geometry columns to and from a feature table shall be implemented [61]. The following examples [61] show the syntax of AddGeometryColumn and DropGeometryColumn:

```
AddGeometryColumn(FEATURE_TABLE_CATALOG,
    FEATURE_TABLE_SCHEMA, FEATURE_TABLE_NAME,
    GEOMETRY_COLUMN_NAME, SRID)
AddGeometryColumn(FEATURE_TABLE_CATALOG,
    FEATURE_TABLE_SCHEMA, FEATURE_TABLE_NAME,
    GEOMETRY_COLUMN_NAME)
```

Data can be inserted into the lakes table using the SQL INSERT command:

```
INSERT INTO lakes VALUES (101, 'BLUE LAKE',
    PolyFromText('POLYGON((52 18, 66 23, 73 9, 8 6, 52 18))', 4326));
```

Data manipulation language

The statements of data manipulation language are implemented to retrieve and manipulate data. For example, objects with a size greater than 11,000 can be retrieved from the lakes table using a SELECT statement:

```
SELECT    lakes.name,
    FROM       lakes
    WHERE Area (lakes.shore) > 11000
```

In this implementation, the Area is calculated automatically from the shape field using a DBMS function and does not need to be stored.

Data control language

The statements of data control language are used to handle authorization access. The DCL has two main keywords: GRANT and REVOKE. They are used to authorize and rescind access privileges respectively.

2.4.2.6 PostgreSQL/PostGIS

The implementation of SQL with spatial capabilities in PostgreSQL/PostGIS is as follows:

```
CREATE TABLE lakes (
    fid         INTEGER NOT NULL PRIMARY KEY,
    name     VARCHAR(64)  )
SELECT AddGeometryColumn('OGC','public','lakes','shore','4326','POLYGON','2');
```

OpenGIS Consortium defines the attributes of AddGeometryColumn stored procedure [62], and the definition is applicable to PostgreSQL/PostGIS. In the statement of the AddGeometryColumn, the value of ‘OGC’ corresponds to FEATURE_TABLE_ CATALOG, ‘public’ corresponds to FEATURE_TABLE_SCHEMA, ‘lakes’ corresponds to FEATURE_ TABLE_NAME, ‘4326’ corresponds to SRID (spatial reference ID), ‘POLYGON’ corresponds to GEOMETRY_COLUMN_NAME, and ‘2’ is a dimensional value.

INSERT INTO lakes VALUES (101, 'Blue Lake', PolygonFromText('POLYGON((52 18,66 23,73 9,48 6,52 18))', 4326) (shown in **Figure 2.15)**

The final property status of lakes table in PostgreSQL is as follow:

```
CREATE TABLE lakes(
    fid integer NOT NULL, "name" character varying(64),  shore geometry,
    CONSTRAINT   lakes_pkey PRIMARY KEY (fid),
    CONSTRAINT   enforce_dims_shore CHECK (ndims(shore) = 2),
```

CONSTRAINT enforce_geotype_shore CHECK (geometrytype(shore) = 'POLYGON'::text OR shore IS NULL),

CONSTRAINT enforce_srid_shore CHECK (srid(shore) = 4326))

The CONSTRAINT enforce_srid_shore CHECK (srid(shore) = 4326 is corresponding to the CONSTRAINT spatial_reference CHECK (SRID(shore) = 4326) initiated by OGC.

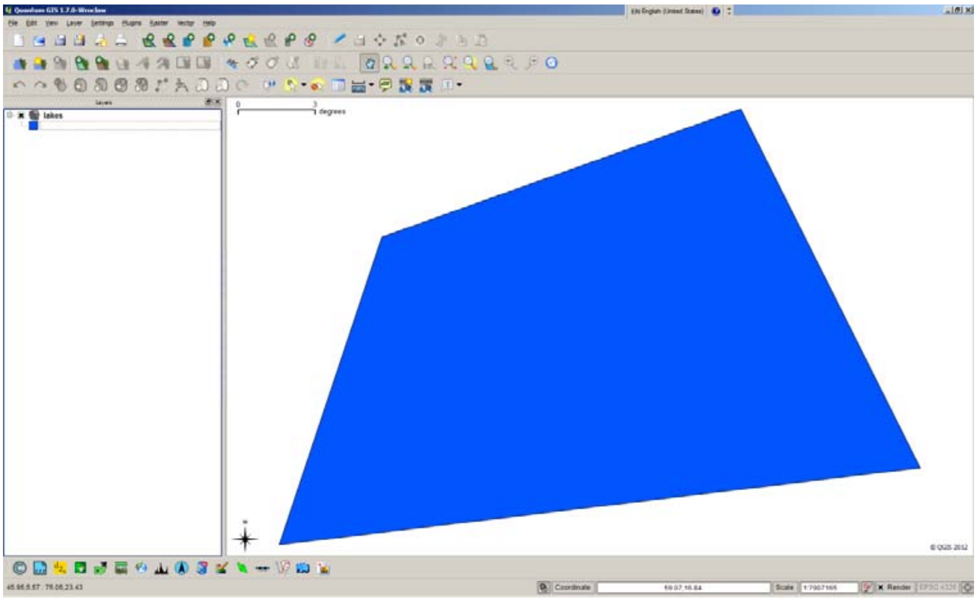


Figure 2.15 Result of PolygonFromText('POLYGON((52 18,66 23,73 9,48 6,52 18))', 4326)

2.4.2.7 SQL Geometry Type Hierarchy

The SQL Geometry class hierarchy based on OGC standards is shown **Figure 2.16**. In the hierarchy, the root class is called Geometry class, and has an associated spatial reference (coordinate system and projection). It contains the subclasses that are Point, Curve, Surface and Geometry Collection. A Geometry Collection is a Geometry that contains a collection of possibly heterogeneous geometric objects. Geometry Collection has specific subclasses that are MultiSurface, MultiCurve and MultiPoint. They are used to manage homogenous collections of Surfaces, Curves and Points. The other classes (boxes) and relationships (lines) describe how geometries of one type are specified from others (e.g., LineString is a collection of Points) [62]. In the implementation, Well-known Text (WKT) representations are used to describe geometry object [62].

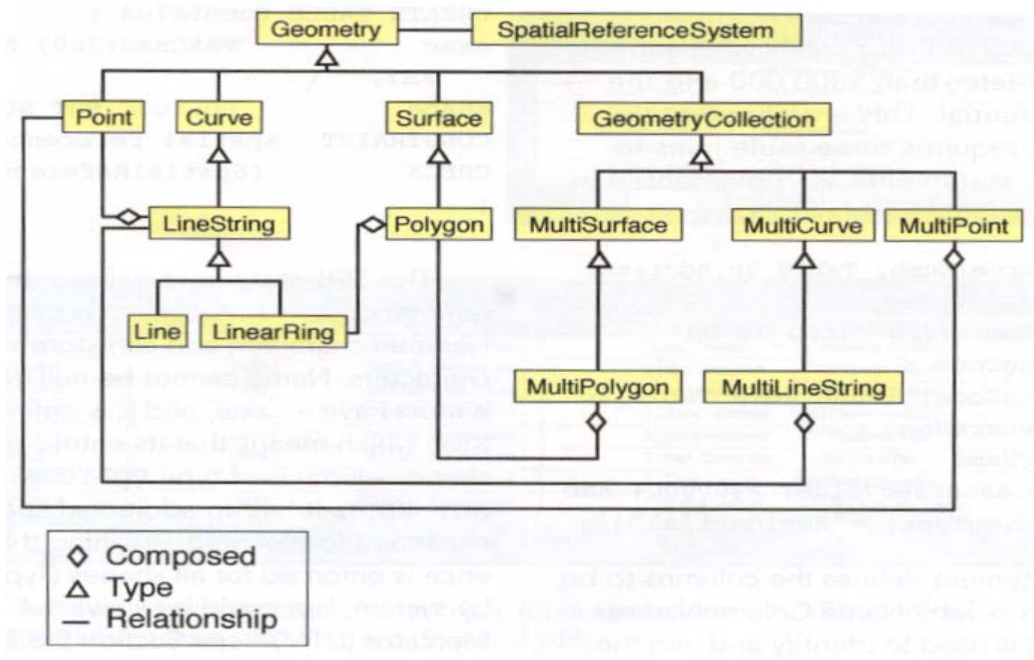


Figure 2.16 The SQL Geometry class hierarchy scanned from [20]

2.4.3 Metadata

Strictly defined, metadata are data about data, and object-level metadata (OLM) describe the contents of a single dataset in geographic information science [20]. Object-level metadata are formal descriptions of datasets that satisfy many different requirements.

Four primary uses of the OLM are as follows [20]:

1. OLM is needed to automate the process of search and discovery over archives.
2. OLM is needed to determine whether the discovered dataset will satisfy the user's requirements for spatial resolution.
3. OLM must provide the information needed to handle the dataset effectively. For instance, OLM may provide information about technical specifications of format, or the names of software packages that are compatible with the data, along with information about the dataset's location, and its volume.
4. OLM may provide useful information relating to the contents of datasets. For instance, OLM of the remotely sensed images may include information relating to the percentage of cloud obscuring the scene.

The US Federal Geographic Data Committee's Content Standards for Digital Geospatial Metadata (FGDC's CSDGM), first published in 1993, is the most widely used standard for OLM. This standard has been the basis for many other standards worldwide [20].

Another OLM standard is the ISO 19115 standard for metadata developed by the International Organization for Standardization (ISO) in 2003. This metadata standard is also widely implemented by GIS vendors, e.g., ESRI ArcCatalog and GeoNetwork Opensource. ESRI ArcCatalog provides the metadata editor both for FGDC's CSDGM and for ISO.

2.4.3.1 FGDC's CSDGM

U.S. Federal Geographic Data Committee (FGDC) defined the metadata standard for geographic information. Major features of the FGDC's Content Standards for Digital Geospatial Metadata (CSDGM) are described as the following 10 sections [63].

1. Identification Information - basic information about the dataset.
2. Data Quality Information - a general assessment of the quality of the dataset.
3. Spatial Data Organization Information - the mechanism used to represent spatial information in the dataset.
4. Spatial Reference Information - the description of the reference frame for, and the means to encode, coordinates in the dataset.
5. Entity and Attribute Information - details about the information content of the dataset, including the entity types, their attributes, and the domains from which attribute values may be assigned.
6. Distribution Information - information about the distributor of and options for obtaining the dataset.
7. Metadata Reference Information - information on the currentness of the metadata information, and the responsible party.
8. Citation Information - the recommended reference to be used for the dataset.

9. Time Period Information - information about the date and time of an event.
10. Contact Information - identity of, and means to communicate with, person(s) and organization(s) associated with the dataset.

Sections 1 through 7 can be classified as main sections of the standard. Sections 8 through 10 will be used to support other sections, which provide a common method to define citation, temporal and contact information, and are never used alone [63].

2.4.3.2 ISO 19115 standard

In ISO 19115 "Geographic Information - Metadata', metadata for describing geographic data is defined using an abstract object model in the Unified Modeling Language (UML). Core elements of ISO 19115 are the followings [64]:

1. Metadata entity set information - information about the entity (UML class).
2. Identification Information - information that uniquely identifies the data. Identification information includes information about the citation for the resource, an abstract, the purpose, credit, and the status of points of contact.
3. Constraint Information - information about the restrictions placed on data.
4. Data Quality Information - information about general assessment of the quality of the dataset.
5. Maintenance Information - information about the scope and frequency of data updates.
6. Spatial Representation Information - information that concerns the mechanisms used to represent spatial information in a dataset.
7. Reference System Information - the description of the spatial and temporal reference system(s) used in dataset.

8.	Content Information	- information that identifies the feature catalog used and/or information describing the content of a coverage dataset.
9.	Portrayal Catalog Information	- information that identifies the portrayal catalog used.
10.	Distribution Information	- information about the distributor of, and options for obtaining, a resource.
11.	Metadata Extension Information	- information about user specified extensions.
12.	Application Scheme Information	- information about the application scheme used to build a dataset.
13.	Extent Information	- datatype is an aggregate of the metadata elements that describe the spatial and temporal extent of the referring entity.
14.	Citation and Responsible Party Information	- datatypes that provide a standardized method for citing a resource, as well as information about the party responsible for a resource.

2.4.3.3 Correspondence between CSDGM and ISO 19115

CSDGM and ISO 19115 are both used to describe a geographic information resource, but their elements present some differences in organizations between the two standards. The CSDGM standard (left side of **Table 2.3**) is classified in 10 sections (7 main sections and 3 reusable sections). CSDGM contains 469 different elements, from which 119 are composite elements, which their existence is justified to contain other elements [21].

Regarding semantic information, the ISO standard tries to overcome some deficiencies that can be found in the CSDGM standard. For example, ISO standard provides the data types raster and imagery, whereas in the CSDGM standard only provides the first one of these.

Table 2.3 Correspondence between CSDGM and ISO 19115 [21]

CSDGM Section	ISO Package
Main Sections	
Identification information	Identification information (including the references to the sections constraint information, maintenance information)
Data quality information	Data quality information
Spatial data organization information	Spatial representation information
Spatial reference information	Reference system information
Entity and Attribute information	Content information
Distribution information	Distribution information
Metadata reference information	Metadata entity set information (including references to the Constraint information, Maintenance information, and Metadata extension information sections) Portrayal catalogue information
	Application schema information
Reusable sections	
Citation information, contact information	Citation and responsible party information
Time period information	

Moreover, there are slight differences in the terminology between these two standards. For instance, the “bounding box” element of the CSDGM standard and ISO standard is same and contains four coordinate elements. The short names are terminologically different but they are semantically equivalent. CSDGM uses *westbc*, *eastbc*, *northbc* and *southbc* and the ISO standard uses *westBL*, *eastBL*, *northBL* and *southBL* [21].

Nogueras [21] states that one of the similarities between these two standards is the fact that they can both use XML for data exchange and encoding. This means that the most accurate solution for a crosswalk implementation is by using style sheet. Nogueras [21] created the CSDGM to ISO style sheet that enables the transformation of five of the seven main sections of the CSDGM to ISO. However, the matching was not possible yet, especially for two sections (Spatial Reference Information, and Entity and Attribute Information) because their organization and conception were totally different in both standards [21].

2.4.4 Map configuration file: map produced by desktop GIS

A digital map is the final outcome of a series of GIS data processing steps: beginning with data collection, editing and maintenance, data management and analysis, and concluding with a map [20]. GIS produces a digital map that contains several layers. It is useful, because GIS users may interactively select suitable layers and overlay them to display the overlaid map.

Table 2.4 Map configuration file produced by desktop GIS and acceptability of typical sources [27] [33][65] [66]

Sources : Files, Geodatabase or Services		**Types of map configuration file produced by desktop GIS**					
Data Types	**Data Formats**	**AXL *1**	**MXD, PMF *2**	**DWG *3**	**WOR *4**	**QGS *5**	**UDIG *6**
Shapefile	ESRI Shapefiles (*.SHP)	Yes	Yes	Yes	Yes	Yes	Yes
Geodatabase file	ESRI Geodatabases (*.GDB)	-	Yes	-	Yes	-	-
Personal Geodatabase file	ESRI Personal Geodatabases (MS Access *.MDB)	-	Yes	-	-	Yes	-
ArcSDE Geodatabase	ArcSDE Features	Yes	Yes	Yes	+	-	Yes
Coverages	ArcInfo™ Coverages	-	Yes	Yes	-	-	-
	PC ARC/INFO Coverages	-	Yes	-	-	-	-
	ArcSDE for Coverages	Yes	Yes	-	-	-	-
CAD	*.DWG	-	Yes	Yes	+	-	-
	*.DXF	-	Yes	Yes	+	Yes	-
	*.DGN	-	Yes	Yes	+	Yes	-
MapInfo	*.TAB	-	+	Yes	Yes	Yes	-
	*.MIF	-	+	Yes	Yes	Yes	-
OGC	*.GML	Yes	+	Yes	+	Yes	Yes
Raster	ArcView® Image Catalog	Yes	Yes	-	-	-	-
	ArcSDE Embedded Raster Catalog	Yes	Yes	-	-	-	-
	Personal Geodatabase Managed/ Unmanaged Catalog	-	Yes	-	-	-	-
	ADRG Image (*.IMG)	Yes	Yes	-	-	Yes	-
	JPEG (*.JPG)	Yes	Yes	Yes	Yes	Yes	Yes
	MrSID- LizardTech (*.SID)	Yes	Yes	Yes	Yes	Yes	-
	Portable Network Graphics (*.PNG)	-	Yes	Yes	Yes	Yes	Yes
	Tagged Image File Format (*.TIF)	Yes	Yes	Yes	Yes	Yes	Yes
	TIFF with Geo Header (*.TIF)	Yes	Yes	Yes	Yes	Yes	Yes
Map Services	ArcIMS Image Service	Yes	Yes	-	-	-	-
	ArcIMS ArcMap Image Service	Yes	Yes	-	-	-	-
	ArcIMS Feature Service	Yes	Yes	-	-	-	-
	OGC-WMS	-	Yes	Yes	Yes	Yes	Yes
	OGC-WFS	-	Yes	Yes	Yes	Yes	Yes

*1) ArcExplorer or ArcIMS Designer is used. *2) ArcMap is used. *3) Autodesk AutoCAD Map 3D is used. *4) MapInfo is used. *5) Quantum GIS is used. *6) uDiq is used. They are software of desktop GIS. +) Converter or transfer tool is needed, ESRI ArcMap uses ArcGIS data interoperability tool [67].

A desktop GIS and a server GIS produce such an interactive digital map. In this section, I describe the digital map produced by a desktop GIS, since the map is somewhat different from the map produced by a server GIS.

A digital map created or displayed using desktop GIS is called as “map configuration file” or “map document”. The map configuration file or map document contains configuration data of the digital map, such as associated layers, layouts, and projection. I mainly use the term of “map configuration file” in this thesis. When a map configuration file is produced using desktop GIS, map configuration data is stored in a map configuration file. A desktop GIS accesses associated layer using its access path to the corresponding geographic information file in the system, overlays layers and displays layers’ symbol, color, etc., based on layouts data available in the map configuration file.

Several types of map configuration file are available, and its type (file extension name) is determined by the desktop GIS used to produce the map configuration file; For example, when a map configuration file is produced by Quantum GIS, the file extension name is *.QGS.

There are many data types and formats of geographic data. Some of data formats can be accepted by some types of map configuration file. I summarized typical types of map configuration file produced by desktop GIS and their acceptability of various data formats of sources (files, geodatabases or map services) in **Table 2.4**. When a map configuration file is produced, specific software is used. Then, I noted the name of software used in the caption of **Table 2.4**. **Table 2.4** shows map configuration file stored in various types and produced by proprietary or open source desktop GIS.

In **Table 2.4**, MXD typed map configuration file can accept all data format of source in the table. The MXD typed file that has an .mxd extension [68], is also called ESRI ArcMap Document, and has been widely used.

ArcMap document generated using ESRI ArcMap software contains one map, its layout, and its associated layers, tables, charts, and reports. ArcMap documents can be printed or embedded in other documents. ArcMap Documents [69] contain information about map layers, symbols and label properties, and other map elements in a layout as well as information about how map is stored, shared and managed on the computer. This map configuration file not only stores the traditional cartographies of a map such as layer, symbol but also the environment, or user interfaces (toolbars) used during working with the map[68].

Several map configuration files produced by desktop GIS, such as ESRI ArcMap document (*.MXD and *.PMF) and ESRI ArcExplorer (*.AXL) file can be used to create map services (image services or feature services) in server GIS.

2.4.5 Map service: map produced by server GIS

A digital map produced by server GIS is served as services by server GIS through internet or intranet. The digital map is called "map service" in this thesis. Map service consists of several layers that are connected to the corresponding files in the resource. Map service also contains configuration data of the map, such as associated layers, layouts, and projection.

Two types of map service commonly used are called "image service" and "feature service". The image service's layer consists of image data. The feature service's layer consists of streaming data of feature data (vector data).

Server GIS creates map service by utilizing map configuration data available in map configuration file, and provides the map service for users of GIS. A map configuration file utilized by server GIS is created by desktop GIS as mentioned in section 2.4.4 or by text editor.

ArcIMS Services supports 53 data formats that can be used as resource for map services [33] and I summarized 22 of them in **Table 2.5**. I also summarized various types of map services produced by typical server GIS and their acceptability of various data formats of sources (files and geodatabase) in **Table 2.5**. ArcIMS ArcMap Image Service and OGC-WMS (Web Map Service) indicate the highest acceptability of various data format of sources as shown in **Table 2.5**. ArcGIS Server Service includes image service and feature service. OGC-WMS means Web oriented image service, and can be produced using the software function of ESRI ArcIMS Server or ArcGIS Server. OGC-WFS (Web Feature Service) can also be produced using the software function of ESRI ArcIMS Server or ArcGIS Server. UMN MapServer is the most popular server GIS used to produced OGC-WMS and WFS.

A server GIS creates map service using map configuration data available in a map configuration file. Types of map services and the accepted data formats for map configuration file used by server GIS are shown in **Table 2.5**. I noted the type of map configuration file used for each map services in the caption of **Table 2.5**.

Table 2.5 Map services produced by server GIS and acceptability of typical sources [33] [70][66]

Source : Files or Geodatabase		Types of map services produced by server GIS							
Data Types	**Data Formats**	**ArcIMS Image Service *1**	**ArcIMS Feature Service *1**	**ArcIMS ArcMap Image Service *2**	**ArcGIS Server Service *3**	**OGC-WMS through ESRI Server *4**	**OGC-WFS through ESRI Server *5**	**OGC-WMS through UMN MapServer *6**	**OGC-WFS through UMN MapServer *6**
Shapefile	ESRI Shapefiles (*.SHP)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geodatabase file	ESRI Geodatabases (*.GDB)	++	++	Yes	Yes	Yes	++	Yes	Yes
Personal Geodatabase file	ESRI Personal Geodatabases (MS Access *.MDB)	++	++	Yes	Yes	Yes	++	Yes	Yes
ArcSDE Geodatabase	ArcSDE Features	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coverages	ArcInfo™ Coverages	++	++	Yes	Yes	Yes	++	++	++
	PC ARC/INFO Coverages	++	++	Yes	Yes	Yes	++	++	++
	ArcSDE for Coverages	Yes	Yes	Yes	Yes	Yes	Yes	++	++
CAD	*.DWG	++	++	Yes	+	Yes	++	++	++
	*.DXF	++	++	Yes	+	Yes	++	++	++
	*.DGN	++	++	Yes	+	Yes	++	++	++
MapInfo	*.TAB	++	++	+	+	+	++	Yes	Yes
	*.MIF	++	++	+	+	+	++	Yes	Yes
OGC	*.GML	++	++	+	+	+	++	Yes	Yes
Raster	ArcView® Image Catalog	Yes	-	Yes	-	Yes	-	-	-
	ArcSDE Embedded Raster Catalog	Yes	-	Yes	-	Yes	-	-	-
	Personal Geodatabase Managed/ Unmanaged Catalog	-	-	Yes	Yes	Yes	-	-	-
	ADRG Image (*.IMG)	Yes	-	Yes	Yes	Yes	-	Yes	-
	JPEG (*.JPG)	Yes	-	Yes	Yes	Yes	-	Yes	-
	MrSID- LizardTech (*.SID)	Yes	-	Yes	Yes	Yes	-	Yes	-
	Portable Network Graphics (*.PNG)	-	-	Yes	Yes	Yes	-	Yes	-
	Tagged Image File Format (*.TIF)	Yes	-	Yes	Yes	Yes	-	Yes	-
	TIFF with Geo Header (*.TIF)	Yes	-	Yes	Yes	Yes	-	Yes	-

*1) AXL is used. *2) MXD or PMF is used. *3) MXD, PMF or MSD is used. *4) AXL, MXD, PMF, or MSD is used. *5) AXL, MXD or MSD is used. *6) MAP is used.
AXL, MXD, PMF, MSD, and MAP are types of map configuration file.
+) Converter or transfer tool is needed, ESRI ArcMap uses ArcGIS data interoperability tool [67]. ++) Other desktop GIS's converter or transfer tool is needed to convert to the acceptable data formats

A few desktop GISs also provide add-in (plug-in) applications used to export or create map configuration file of the active layers and its configurations, which are shown on desktop GIS's "Map View". For example, ArcMap's MXD2AXL is used to create or convert the active layers to an AXL and a MAP file, and Quantum GIS's MapServer Export plug-in is used to export the active layers to MAP file. ESRI ArcMap from version 9.3.1 also provides the "Map Service Publishing" toolbar, used to publish map services or produce MSD file. MAP and MSD configuration files are only used in server GIS, i.e. UMN MapServer and ArcGIS Server consecutively.

2.4.6 Finding geographic information

Users can use functions in GIS software or server client software for finding geographic information. There are two type of information that can usually be found: information of GI through metadata document and content of GI through SQL command.

2.4.6.1 Using metadata

Metadata can be used to find geographic information. GIS software, for example, ESRI ArcGIS desktop's ArcCatalog, ArcIMS Metadata Explorer, and GeoNetwork Opensource's Catalog application provides metadata-searching functions. GeoNetwork Opensource is a catalog application to manage spatially referenced resources. It provides metadata editing and search functions as well as an embedded interactive web map viewer.

2.4.6.2 Using SQL

SQL commands can be used to find content of geographic information. GIS software, for example ArcGIS Desktop, Quantum GIS, and uDig, provides functions to retrieve a geographic data from geographic database with SQL command.

Chapter 3

Related Works

3.1 Overview

In this chapter, I will present related works: Spatial Data Infrastructure (SDI) and Geospatial One-Stop which have been developed to provide geographic information in developed countries, and GIS applications in Aceh province and their issues to be solved.

I will describe SDI and its concept, developing a SDI using GeoFOSS (Free Open Source Software), and difficulties in SDI in section 3.2. I will also describe technological points relating to my studies: the server GIS and its services in section 3.3 and the approaches used to visualize geographic information on the browser in section 3.4.

In section 3.5, I will describe GIS applications created and used during the RR-process and the existing GIS applications at AGDC. In section 3.6, I will explain two important issues relating to GIS in Aceh province that should be considered during developing an integrated information system i.e. the availability of many ArcMap documents at AGDC and the GIS software used in Aceh.

3.2 Spatial Data Infrastructure and Geospatial One-Stop

3.2.1 Spatial Data Infrastructure and its concept

Many books and reports have been written on SDIs. I adopted the 22 pages of detailed review on SDIs in the book [20] authored by Longley et al. and Craglia and Campagna's report [71] on regional SDIs. The former reviews the origins of SDI, varying concept of SDI, various SDIs depending on countries and circumstances: national, regional or local government or private organization, and difficulties on SDIs. The latter consists of insightful analysis on regional SDIs in Europe and in Australia. The latter shows suggestive issues for AGDC, because AGDC is a provincial governmental organization. In addition, key factors influencing regional SDI development are discussed in the paper [72].

The detailed review [20] and the report [71] have shown the following facts. I comment on each fact as follows.

- Origins of SDIs were the Mapping Science Committee (MSC) of the United States National Research Council and U.S. Geological Survey in 1990. A national SDI (NSDI) was viewed as a comprehensive and coordinated environment for the production, management, dissemination, and use of geospatial data, involving the totality of the relevant policies, technology, institutions, data, and individuals. The NSDI was a vision. FGDC participate in the activity in 1994.

The facts indicate that origin of SDI comes from researcher's expectation that it is necessary for national institution to provide national GI.

- In April 1994, President Clinton signed Executive Order 12906: Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure. This is an important lever for realizing the vision: NSDI. This order directed that federal agencies, coordinated by FGDC, carry out specified tasks to implement the NSDI.

Vice President Gore urged NII (National Information Infrastructure) and NSDI with President Clinton. NII was progressive policy to promote Internet technology and various information systems including NSDI.

- However the U.S.NSDI was a pioneer, important SDI developments occurred even earlier in Australia and some other countries. From SDI's original concept as a national enterprise, the SDI has spread upward to the global scale and downward to the local one. The meaning of the term differs in different countries, though in essence it normally describes a widely available GIS search and mapping and additional institutional and legal elements including license to use GI. SDIs are not concrete things but visions of how to make better use of scarce geographic data or information resources.

AGDC is provincial organization, therefore it is necessary to research and analyze situations of regional or local SDIs and situations in Indonesia.

- Research regional SDIs were performed in Lombardia and Piemonte in Italy, in Catalonia and Navarra in Spain, Brittany in France, Wallonia and Flanders in Belgium, North-Rheine Westfalia and Bavaria in Germany, Northern Ireland in UK, and Vysocina in Czech Republic. Geoportals are widespread in all regions as an entry point for discovery view, and download services. Invoke services, or service chaining are still very limited, and advanced geoprocessing services providing data analysis are seen only in few cases.

SDI's functions or services are not fixed in developed countries except for functions or services of discovery and download of GI which are essential in primary SDI.

- A substantial impetus for the NSDI and local SDIs was given by several emergencies in the United States such as 9/11 in 2001 and the destruction by Hurricane Katrina in 2005.

In the 2004 tsunami recovery processes, AGDC were established and various GI were generated and handed over to AGDC.

3.2.2 Development of Spatial Data Infrastructure

SDI is a geographic information system that disseminates and shares geographic information through Internet. Then, commercial software vendors like ESRI have developed software components for SDI and shown how to assemble them. There is also an approach using GeoFOSS (free open source software) to develop SDI, as the following.

Stefanakis and Prastacos [73] have developed a spatial data infrastructure using various GeoFOSS components. Their development components are as follows:

(1) Client application, including
   (a) desktop client (QuantumGIS and GoogleEarth), (b) Web client (OpenLayers),
(2) Interfaces between client application and servers, including
   (a) WMS (PNG and KML, (b) WFS (GML and SHP), (c) WCS (Web catalog service) (GeoTIFF), (d) CSW (Catalog services for the Web) (ISO19115/19139),
(3) Server, including
   (a) Map Server (MapServer [40]), Catalog Server (GeoNetwork)
(4) Databases, including
   (a) GeoDatabases (PostreSQL/PostGIS)
   (b) File system: (i) vector (shapefiles), (ii) Raster data (satellite image).

The method using GeoFOSS components for system development is inexpensive and sophisticated. However, it is difficult for a novice programmer to maintain the software of developed SDI because of the following reasons.

The GeoFOSS components and their combination have been updated often. For example, the Web client OpenLayers has been used in GeoNetwork since version 2.6 [54] instead of InterMap, which was used until version 2.4 [74]. The design of GeoNetwork version 2.8 [75] has also begun. It is possible for professionals of software development to maintain a SDI or an integrated GIS based on combining the various GeoFOSS. AGDC has implemented some GeoFOSS components in the existing applications at AGDC. However, there are three reasons why GeoFOSS based SDI or integrated GIS has not been suitable for AGDC at the present. These are software maintenance, huge volumes of MXD files at AGDC, and GIS users in Aceh province. These problems will be discussed in detail in Chapter 6.

3.2.3 Difficulties in Spatial Data Infrastructure

Longley et al. [20] have reviewed SDI partnerships at the global level, at the multi-country level, at the national level, and at the sub-national or local level, in order to discuss whether SDIs have been success. Then, they have pointed out the following six difficulties in SDI.

The 1st point:

There are multiple models for an SDI. In particular, the regional level of SDIs is often not simply an intermediate level from global to local, subservient to the higher administrative authority. SDIs at this level are often leading the field, predating national developments, or setting the example and framework, including technical specifications, for the national levels. In Italy, Spain, Belgium, and Germany they are the key building blocks of the national SDIs, with the national level providing a thin layer on regional infrastructures.

The 2nd point:

Adequate funding is crucial. In many SDIs this support has been lacking, in part because so many organizations are involved and all see themselves as contributors rather than taking lead responsibility. It helps if there is a business plan with clear benefits projected to the public-sector organizations intimately involved. Where the benefits accrue to organizations other than those that contribute resources, this slows progress.

The 3rd point:

Surprisingly few professional quality assessments of the social and economic impacts of SDIs have been carried out. We have much anecdotal and some financial indicators of success, but these need to be supplemented.

The 4th point:

Inter- and intra-organizational conflict is inevitable in implementing an SDI. Thus successful SDIs are above all networks of people and organizations, in which technology only plays a supporting role. Building the technological foundation can be relatively easy, but building and maintaining the social back-end is much harder, takes longer, and is more resource intensive.

The 5th point:

Since no single organization can build an SDI, the success of all SDIs is totally dependent on the quality and effectiveness of the partnerships on which they are founded.

The 6th point:

If SDI has been the big idea of the last 15 years, the landscape is now more complicated: the Open Source movement has produced a different, bottom-up model of creating content on a collaborative basis which is very different to the largely top-down, public sector-driven SDI model. Alongside this is the rapidly increasing role of the private sector in providing content. At the time of writing it is not at all clear which – if any one – of these will triumph or whether they will co-exist.

In the paper [72], three key factors influencing regional SDI development are discussed. The factors are environmental factors, capacity factors, and SDI organization factors. The issues of environmental factors and capacity factors are included in 6 points mentioned above. But, the 6 points does not include the following the issues of SDI organization factors: the availability of spatial data and metadata, the integration and inter-flow of datasets from different parties (this has important implications for the ownership and control of information), access networks, and multiple trusted data sources.

I will analyze the results of integrated environment for heterogeneous geographic information realized in my study, and discuss the integrated environment on the 6 points and the SDI organization factors described above in chapter 7.

3.2.4 Geospatial One-Stop

As described on the 4th point of difficulties in SDI in section 3.2.3, “inter- and intra-organizational conflict is inevitable in implementing an SDI [20]” including a problem with ownership or license of GI. In the situation, a user has to search several SDIs to find geographic information that the user needs, because no single SDI that owns all of existing geographic information. Then several SDIs exist, because each SDI provides only geographic information that the SDI owns or have license of. An expected solution of SDI’s problem mentioned above is Geospatial One-Stop or Geoportal One-Stop.

Like SDI, the Geospatial One-Stop or Geospatial One-Stop portal (GOS) is based on conceptual model of geographic information sharing. Goodchild et al. [76] have reviewed GOS's concept and architecture as follows.

With providing a single point of entry, GOS proposes to solve the problem faced by a user of GI in the contemporary world: because there are many providers, some means must be found for searching among them for geographic information that meets the user's needs.

The architecture of GOS consists of the three layers: users layer, where one user uses Web browser (thin client) and the other user uses an application (thick client), geoportal layer, where GOS server works, and providers layer, which is connected to each provider's geographic service or data.

I will also discuss GOS and the integrated environment for heterogeneous geographic information devised and realized in my study in chapter 7.

3.3 Server GIS and its services

Over the last decade, there has been significant growth in open source and proprietary server GIS (*map server*) for publishing GI services, such as UMN MapServer [39], GeoServer [77], ESRI ArcIMS server, ESRI ArcGIS server, and Autodesk MapGuide Enterprise (MGE) server. The GI services produced by server GIS can be either in the vendors' format for map services (such as ArcIMS Feature/ Image /ArcMap Image service and ArcGIS server map service) or in Open Geospatial Consortium's (OGC) standards Web Map Service (WMS) and Web Feature Service (WFS). Almost all server GIS have the ability to publish OGC's WMS/WFS. The most popular and widely used open source server GIS is UMN MapServer.

Each server GIS has its advantages. I have used four server GISs (i.e. MapGuide Enterprise Server, UMN MapServer, ESRI ArcIMS and ArcGIS Server) in the applications and in the integrated information system.

I implemented MGE Server version 2008 when creating Web GIS for the RR process [78]. MGE Server is easy to be implemented for creating the Web GIS because it provides a wizard-driven tool. However MGE Server's services (except OGC-WMS/WFS) can be only used for MGE studio and cannot be consumed by any desktop GIS.

I implemented UMN MapServer, a free and open source server GIS, when developing the Web mapping application [79] [80] using open source application framework. It is good to be implemented for publishing GI as OGC-WMS/MFS using Mapfiles when geographic resources are available in shapefiles or PostgreSQL/PostGIS. However, it needs a lot of time to convert and edit many ArcMap documents (MDX) files, such as those available at AGDC, to Mapfiles using MDX2AXL [81] converter. The published OGC-WMS/MFS can be consumed by the open source and proprietary desktop GIS or by the custom Web mapping application.

I have implemented ArcIMS and ArcGIS server in the integrated information system [18]. The reasons are that the availability of MDX at ADGC and coupled with the fact that most of GIS users in Aceh province are using ArcGIS desktop. It will be easy for GIS users to directly consume or add the ArcIMS/ArcGIS Server Services found in Metadata documents to GIS desktop.

3.4 Visualization geographic information on the Browser

There have been many methods or techniques for the visualization of geospatial data on Web browser. Both open source and proprietary GIS vendors provide interfaces/tools (desktop or Web) and application frameworks used to visualize geographic information or to create and manage Web mapping applications. The tools for developing Web mapping applications include Chameleon [82], Autodesk MapGuide Enterprise Studio, ESRI ArcIMS Designer [83], ESRI ArcGIS Server Web application manager [84], etc. The application frameworks used to create Web mapping application include MapFish [85], OpenLayers [86] JavaScript library, UMN MapServer, ESRI Web Application Development Framework (ADF) [38] for Visual Studio .NET, etc.

The UMN MapServer provides interfaces to visualize geographic information on the browser such as Common Gateway Interface (CGI) program called Mapserv [87] or MapScript [88] that supports several programming languages such as PHP, Perl, Ruby, etc. ESRI provides application-programming interfaces (API) for developing Web mapping application including ArcGIS API for JavaScript [89], Silverlight.NET [90] and Flex [91].

I have used MapFish framework along with OpenLayers and MapServer’s Mapserv CGI when developing Web mapping application, using open source application frameworks[79]

[80], MapGuide Enterprise Studio when developing a Web GIS used in RR-process [78], and ESRI ArcIMS Designer, ArcGIS Web application manager and ArcGIS Web ADF in the integrated information system.

Open source framework needs some effort to design and write code even for creating simple and basic GIS function. The combination of the MapFish framework with OpenLayers and MapServe's Mapserv CGI or MapScript can be used to build interactive Web mapping applications, such as those in AGDC. A proprietary authoring tool can be used to easily and quickly develop Web mapping applications with complete GIS functionality for publishing huge geographic information services.

3.5 GIS applications in Aceh province

I will describe the GIS applications, created and used during the RR-process, which most of them were in accessible, in section 3.5.1 and the existing GIS applications at AGDC in section 3.5.2.

3.5.1 GIS applications used during the RR-Process

Many GIS applications have been implemented during the RR phase at BRR, such as:

1) GeoNetwork Opensource [54], implemented by SIM-C in 2006 as a metadata catalog service that allows a spatial data users to easily assess spatial data available at BRR [11].
2) GeoSamba, developed by NGIS Australia in 2006, is used to provide simple searching and reporting tools, which allow users to easily integrate information and images in reports [10] [11].
3) Huntara Online, developed by BRR and SIM-C in 2006, is used to manage and deliver information related to the relocation of internally displaced persons (IDP) [11].
4) GEOTEC Germany Camtrixx, developed in 2006, is used as an aerial imagery dissemination tool [11].
5) BRR-GTF Web Mapping Application [78], implemented by BRR-GTF using Autodesk MapGuide Enterprise [45] in 2007, is used to deliver BAKOSURTANAL's map product to internal user via BRR's intranet.
6) AGDC Web mapping for concession areas in Aceh province [92], developed by SIM-C in 2009, was implemented as part of a pilot project to support Spatial Data Infrastructure (SDI) in Aceh province.

In April 2009, at the end of the RR process, the applications explained above have been handed-over to AGDC. Almost all the applications have been inaccessible for several reasons, e.g. license issues, the lack of maintenance staff, compatibility between the operating system, database server, and application platforms, etc.

I had the opportunity to use those applications and to take part in developing the BRR-GTF Web mapping application (No. 5) [78], when working at the BRR-GTF center. Most the applications were well developed to suit a particular purpose during the RR process but they were not designed as an integrated system that can be used to easily manage and provide services for huge volume of geographic information at AGDC.

3.5.2 Existing GIS applications at AGDC

The ADGC have implemented Geoportal (http://gdc.nad.go.id) and used it since October 2007 as shown in **Figure 3.1**. The Geoportal was initially developed by AGDC with support from a national consultant [13] and SIM-C. It was also equipped with the GeoNetwork Opensource metadata catalog service that allows users to search and discover spatial metadata.

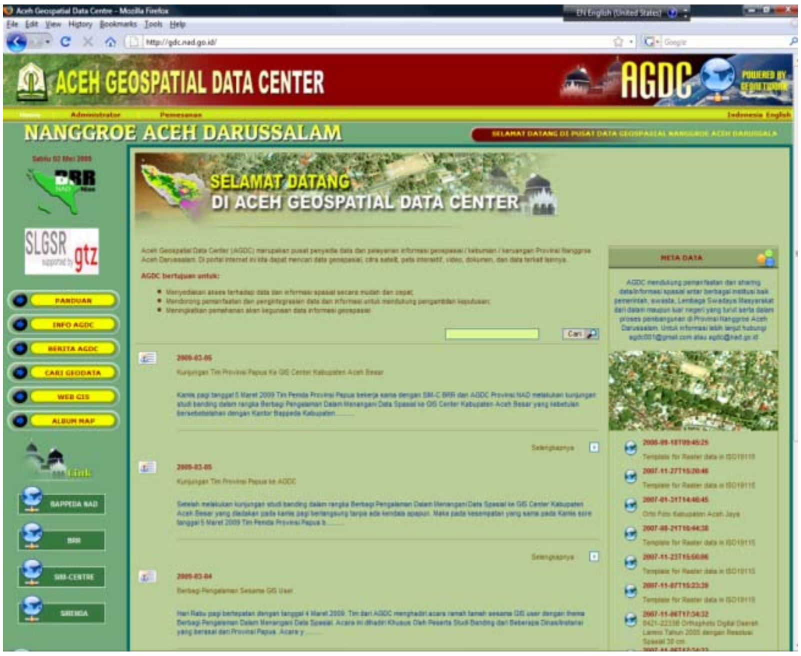


Figure 3.1 AGDC Geoportal

In 2009 SIM-C developed Web mapping applications [93] for the visualization of thematic maps of district and sub-district areas and attached its URL link in AGDC Geoportal. I have analyzed the problems of the existing application, and I will explain in detail in Chapter 6.

3.6 Issues relating to GIS in Aceh province

I will explain 2 important issues relating to GIS in Aceh province that should be considered during the development of an integrated information system, i.e. the availability of many ArcMap Documents at AGDC discussed in section 3.6.1 and the GIS software used in Aceh explained in section 3.6.2

3.6.1 ArcMap Documents produced during RR-process

Many important and useful ArcMap Documents are available at AGDC. These ArcMap Documents, generated using ESRI ArcMap software contain information about map layers, symbols and label properties, and other map elements in a layout. The ArcMap Documents produced during the RR-process have not only been useful when creating and saving maps for use in the RR activities, but should also be useful when reopening and recreating maps and providing map services in the future. The presence of geographic information including ArcMap Documents produced during the RR-process should be fully and easily utilized when providing the map services to support the process of standardization of the map layout at AGDC.

3.6.2 GIS software used in Aceh province

The SIM-C reported that SIM-C staff has already trained 796 local government staff on operating the ArcGIS Desktop in beginner, intermediate and advanced training programs [11].

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 in Aceh province [94].

These studies [11] [94] clearly showed that AGDC staff and Aceh local government staff, who have tasks related to spatial planning, are familiar with operating the ArcGIS Desktop.

Chapter 4

Study and implementation of Web mapping applications for the collected geographic information

4. 1 Overview

In this chapter, I describe my two studies related to the implementation of Web mapping applications. I successfully developed the two Web mapping applications using both proprietary and open sources technologies, including a server and desktop GIS and an authoring tool and framework as follows.

In the first study, I developed the WebGIS called BRR-GTF WebGIS using a proprietary server GIS called Autodesk's MapGuide Enterprise (MGE) Server and the proprietary tool for authoring Web mapping applications called MGE Studio. The BRR-GTF WebGIS was used to disseminate geo-spatial data supporting the RR process. I took part in developing the BRR-GTF WebGIS and maintaining the spatial data used with it. The details of the first study are described in section 4.2.

In the second study, I implemented both a proprietary and open source server GIS for creating and publishing WMS, and an open source desktop GIS for consuming the published WMS. I developed a Web mapping application with a function called "Add WMS" to add additional WMS layers to be overlaid with other layers available in the Web mapping application. The application was built using the MapFish framework. The second study aimed to utilize the WFS/WMS created using MGE server and MapServer in developing the geo-hazard and geo-risk map of Aceh province. The details will be described in section 4.3.

4.2 Implementation of WebGIS to disseminate geo-spatial data in supporting the RR-process in Aceh-Nias

The objective of the study was to develop a Web based GIS application called BRR-GFT WebGIS using MGE Server and MGE studio. The BRR-GTF WebGIS was used to provide important, interesting, and up-to-date maps to the user. The BRR-GTF center also provided the published WMS/WFS directly requested by the user on the client side. As a result, we were able to reduce the conventional method of disseminating spatial data to online Web based GIS applications in RR-process in Aceh-Nias. I had the opportunity to take part in maintaining the geospatial data and in developing the BRR-GFT WebGIS when working at GTF-BRR from January 2007 until June 2008.

In the early year of the rehabilitation and reconstruction process, BRR faced some crucial problems in how to quickly disseminate spatial data to users, how to integrate databases from several system or projects, and how to provide geographical information and GIS services based on the national standard. This was coupled with a lack of a user-friendly WebGIS. In order to address these problems, BRR in collaboration with BAKOSURTANAL established the Geospatial Task Force (GTF) in April 2006.

GFT-BRR was one of supporting units in BRR that played a crucial role in supporting every BRR's program that used geospatial data, including Topographic line Map (TLM), Benchmarking data, and NORAD funded Imagery for NAD province. GTF-BRR was working in Aceh from April 2006 until June 2008. The main objective of the unit was to disseminate and distribute spatial data produced by BAKOSURTANAL and to provide GIS services based on national standards.

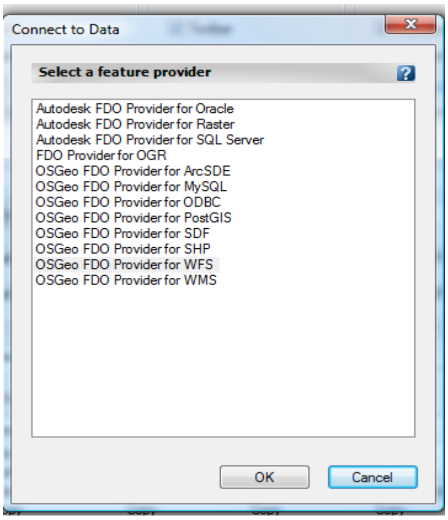


Figure 4.1 Feature Data Object (FDO) connections from MapGuide Enterprise Studio

4.2.1 The implemented system

The GTF had chosen and utilized Autodesk's MapGuide Enterprise (MGE) Technology to develop Web-based GIS applications. In developing WebGIS, MapGuide Studio provides several data connections to internal and external repositories, including databases or services received from Feature Data Objects (FDO) [95] providers, such as PostGIS, Web Feature Services (WFS), Web Map Services (WMS), etc. as shown in **Figure 4.1.**

Autodesk's MapGuide consists of four components: (1) MapGuide Server that hosts the MapGuide services and responds to requests from client applications through the TCP/IP protocol, (2) MapGuide Web Extensions for application development that expose the services offered by the MapGuide Server to client applications, (3) Autodesk MapGuide Studio (for map authoring) and (4) MapGuide Viewer [45] as shown in **Figure 2.8**.

4.2.2 Result

By utilizing MGE technology GTF BRR was able to quickly build an interactive WebGIS and provide an important, interesting, and up-to-date online maps to users including several natural resources maps, thematic maps, Orthophoto and topographical maps. The BRR-GFT-WebGIS Nad-Nias as shown in **Figure 4.2** first launched in March 2007 for internal users, but was only accessible via BRR's intranet.

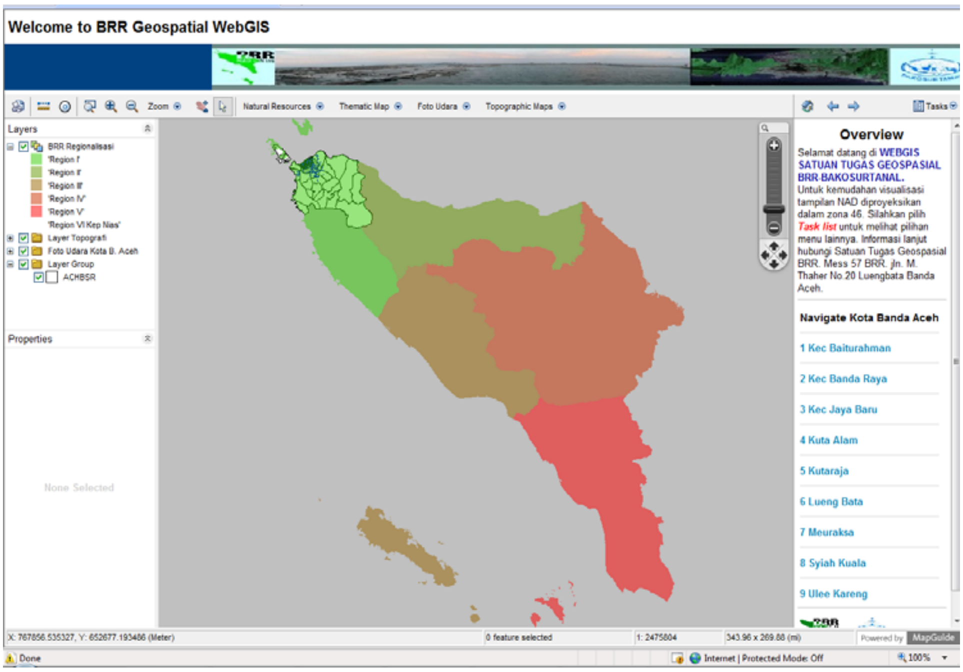


Figure 4.2 WebGIS for Nanggrou Aceh Darussalam

1) WebGIS for Nanggrou Aceh Darussalam (NAD)

WebGIS NAD consists of several links to natural resources, thematic, orthophoto and tophographic line maps. It also provides standard built-in WebGIS functions such as zoom in, zoom out, pan, initial map, zoom by rectangle, and query area based on district name as shown in **Figure 4.3**.

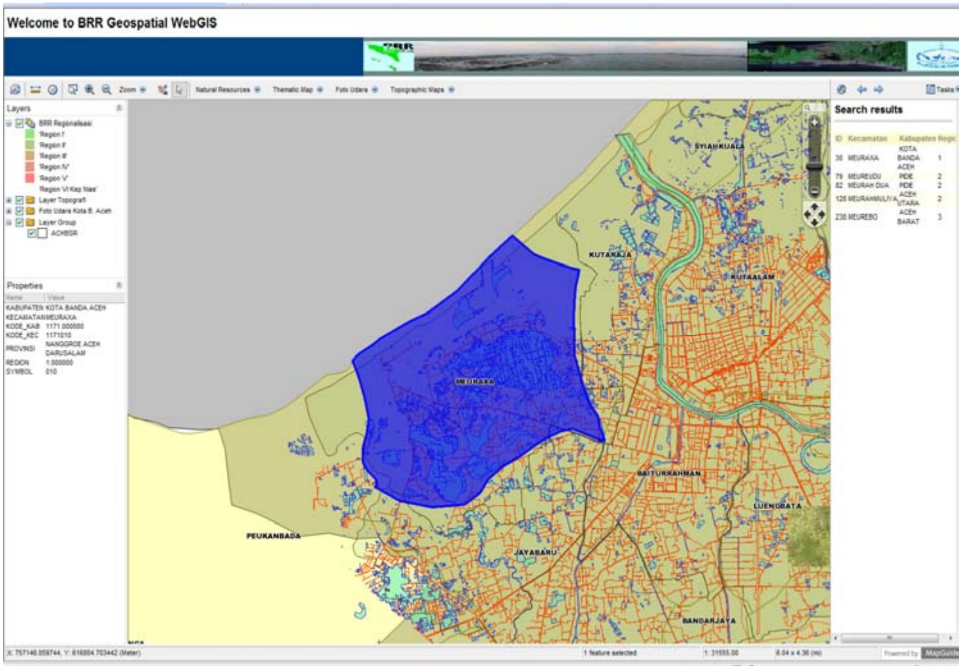


Figure 4.3 WebGIS for NAD showing a search result based on District Name

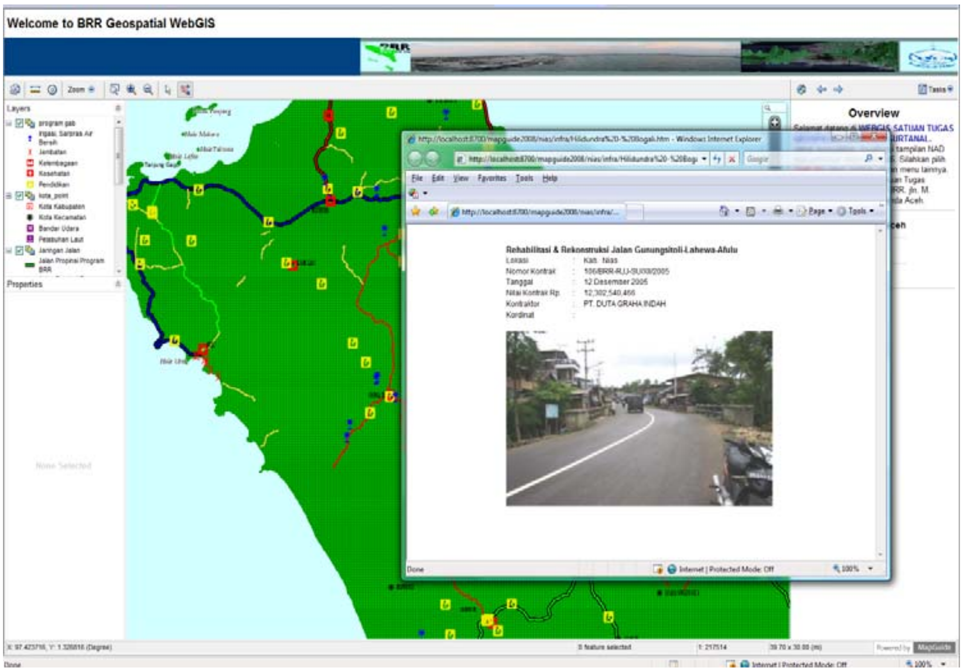


Figure 4.4 WebGIS for Nias

2) WebGIS for Nias Island

WebGIS for Nias in **Figure 4.4** has the same functionality as WebGIS for NAD in **Figure 4.2** and **Figure 4.3**, but it also provides an URL link to the implemented RR- project page.

4.3 Utilization of WMS/WFS in developing a Geo-Hazard/Geo-risk Map in Aceh province

The main objective of this study was to utilize WMS/WFS in developing a Geo-hazard/Geo-risk Map for Aceh Province. This study shows the functionality of a number of FOSS desktop and Web-mapping applications in utilizing the WMS/WFS specification for developing a Geo-hazard/Geo-risk map. I developed the Web mapping application including a function called “Add WMS” to add a WMS layer to be overlaid with other layers available in the Web mapping application. The application is built using the MapFish framework.

In a paper written about this study, I have used various techniques, such as desktop and web based GIS applications for creating maps, where some map’s layer are requested from WMS/WFS. Web-based GIS applications implement WMS/WFS as an interoperability tool to communicate with other geospatial software. A MapSever, produced by the University of Minnesota, is an excellent example providing both WMS and WFS. The WMS/WFS services can be consumed by many free and/or open source software desktop GIS (such as uDig, Quantum GIS (QGis)) and proprietary desktop GIS (such as Map Windows, Autodesk’s AutoCAD MAP 3D, ESRI’s ArcGIS and MapInfo), and most open source and proprietary Web-based GIS application, (such as ESRI’s ArcIMS and Autodesk’s Mapguide).

4.3.1 Hazard/Risk Map in Aceh province

Multi hazard mapping could provide a complete description of the potential and historical natural disasters in an area, which will be useful for decision makers to assess benefits and risks in that area. A disaster is generally classified as a geological disaster (earthquake, tsunami, volcano, and landslide), meteorological disaster (flood, wave, forest fire, drought and storm), and anthropogenic disaster usually caused by interference, errors or negligence that can have great impact on the environment (transportation accidents, industrial damage, natural exploration, and so on). Information systems generated for multi hazard can be effective tools, if they follow established standards, such as in geometry for coordinate system, methodology for spatial data representation, codification for the name of spatial data and map file and visualization for symbol of cartography for hazard map [96].

Spatial data and hazard maps used in this study for testing the WMS/WFS and developing maps in the browser were collected from digital data originating from “Atlas Tematik Provinsi Nanggroe Aceh Darusalam” [97], BRR-GTF WebGIS [78] and other resource from the SIM-C-AGDC Web mapping application [98].

4.3.2 Map resources and Map development

In developing web based GIS application, Map resources can be collected from internal resources, geospatial databases, or from web services.

4.3.2.1 Server GIS

a. MapServer

```
MAP
  NAME 'Gerakan_Tanah'
  SIZE  300 300
  UNITS dd
  IMAGECOLOR 192 192 192
  IMAGEQUALITY 95
  IMAGETYPE gif
  EXTENT 94.079447 1.878253 99.219183 6.004520
  PROJECTION
    'proj=longlat'
    'ellps=WGS84'
    'datum=WGS84'
    'no_defs'
  END
  WEB
    METADATA
      'wms_title'           '"WMS_Gerakan_Tanah"'
      'wms_onlineresource'  'http://localhost/cgi-bin/mapserv?map=wms.map
      'wms_srs'             'EPSG:4326'
    END
  END
  LAYER
    NAME 'gerakan tanah_'
    TYPE POLYGON
    DATA 'D:/MAPFILE/ThematicA1/grktanah_pol_WGS84_1_potensi_tinggi.shp'
  END
END
```

Figure 4.5: Publishing WMS using MapServer by utilizing a Mapfile

The original MapServer was developed by the University of Minnesota before OGC specification was publicly announced. The integration of WMS with MapServer was aimed to develop native WMS compatibility into the MapServer, which will allow users of CGI applications and those writing custom applications using MapScript to get benefits of WMS [99]. The publishing WMS can be defined in a Mapfile as shown in **Figure 4.5**.

b. Autodesk's MapGuide Server

MapGuide Studio provides a tool to publish spatial data using either WMS (Web Mapping Service) or WFS (Web Feature Service) protocols. MapGuide Studio publishes layer resources using WMS and publishes feature data resources using WFS. MapGuide Studio allows users to easily use the properties dialog of the layer resources or feature data resources to publish WMS/WFS and add metadata to WMS/WFS as shown in **Figure 4.6**.

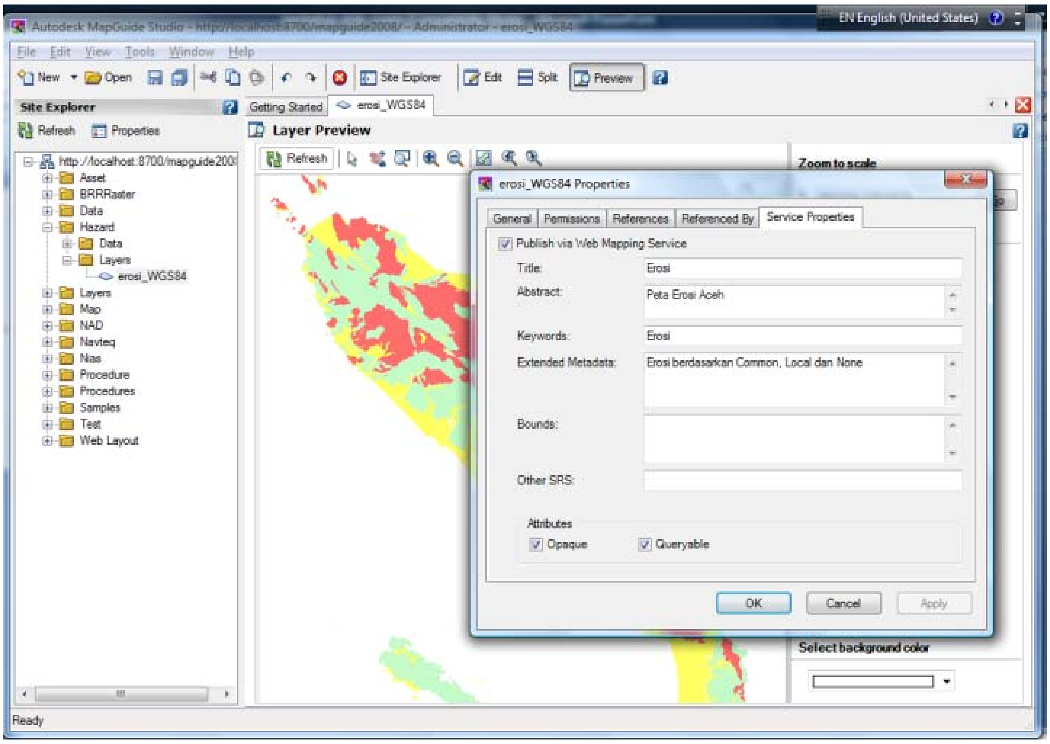


Figure 4.6: Publishing WMS using MapGuide Studio

4.3.2.2 Desktop GIS

a. uDiq

uDig (User-friendly Desktop Internet GIS) is sponsored by Refractions Research, the same people who released PostGIS. By combining the Shapefiles and PostGIS, uDig allows users to seamlessly integrate local resources with OGC web services. The following example shown in **Figure 4.7** shows how to consume WMS from MGE server by requesting the following URL: http://localhost:8700/mapguide2008/mapagent/mapagent.fcgi. The result from WMS Map using uDig is shown in **Figure 4.8**

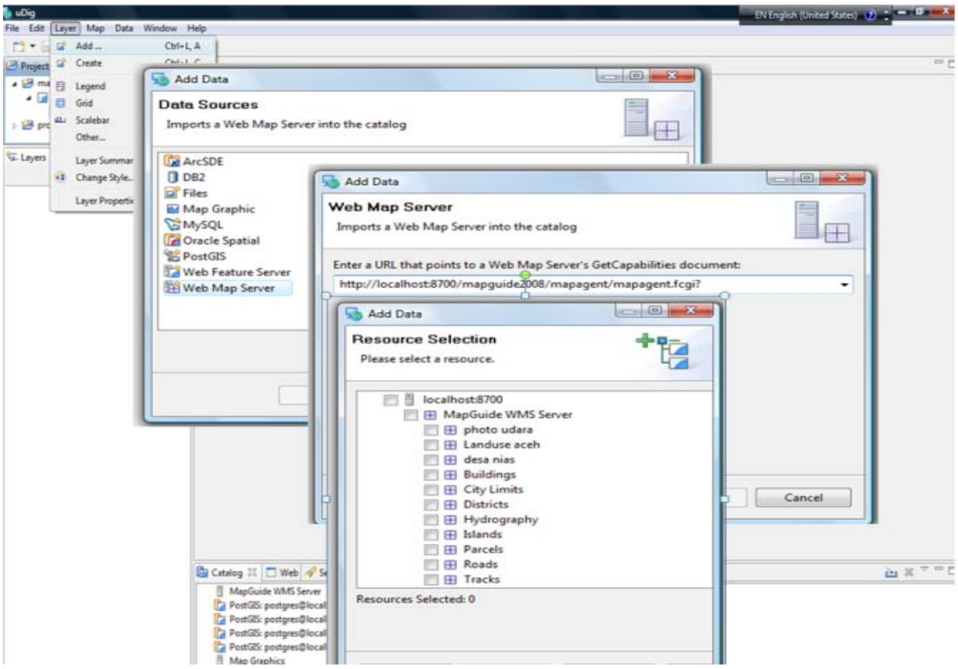


Figure 4.7 Requesting WMS using uDig

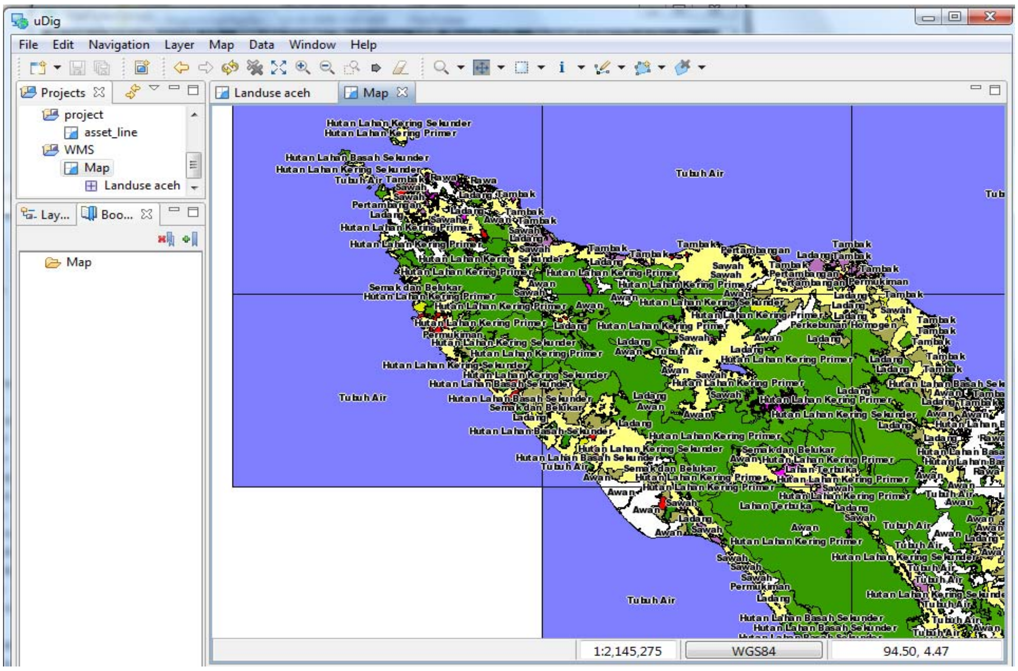


Figure 4.8 Result of WMS Map using uDig consumed the MapGuide's WMS

b. Quantum GIS

Quantum GIS (QGis) is an open source desktop GIS that acts as a client that consumes WMS/WFS or as a server GIS that publishes WMS/WFS. **Figure 4.9 and Figure 4.10** shows the process of adding WMS layer published by MapServer and the result of WMS map.

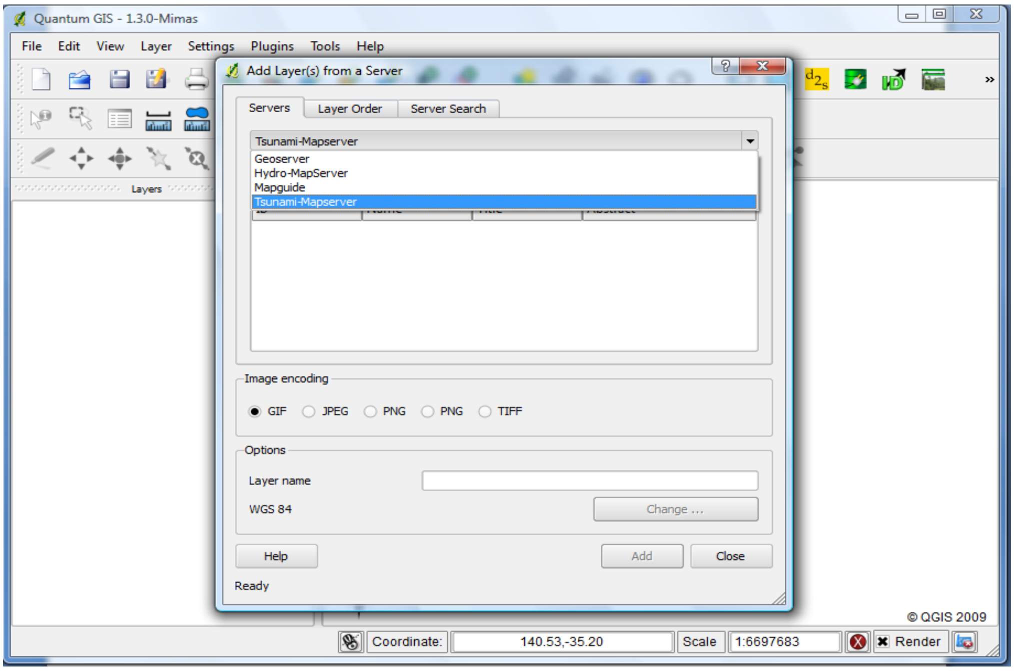


Figure 4.9 Adding WMS to QGIS

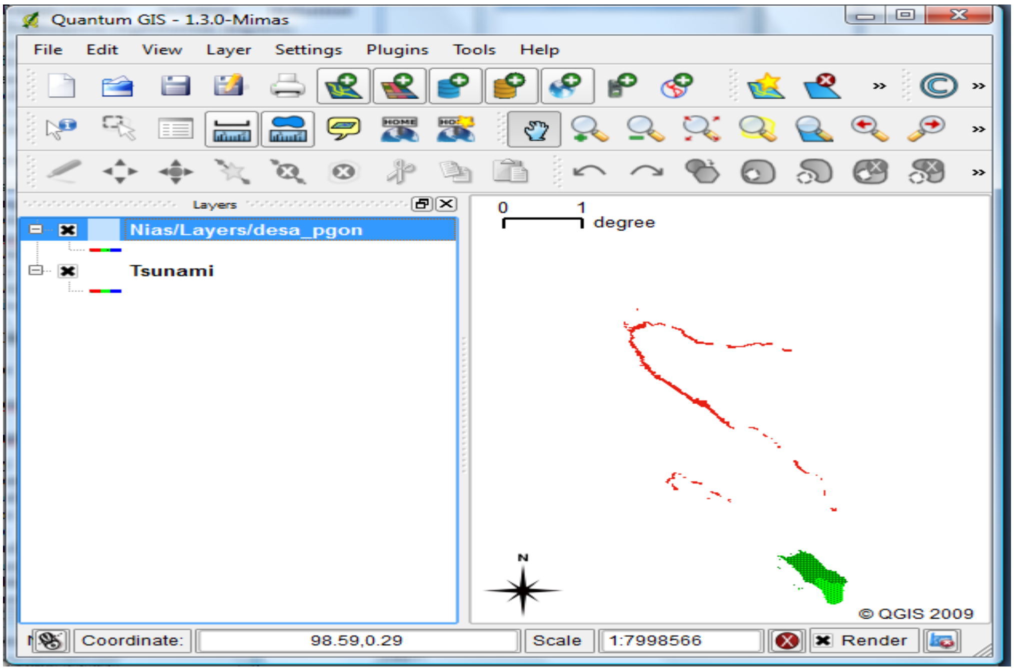


Figure 4.10 Result of WMS Map using QGIS from MapServer's WMS

4.3.2.3 Autodesk's MapGuide Web mapping application

While creating Web GIS, Autodesk's MapGuide Studio allows one to bind map layers from internal and external repositories using the Feature Data Objects (FDO) data connection tool [45]. A number of feature providers are available including PostGIS, OSGeo Web Feature Services (WFS)/Web Map Services (WMS) as shown in **Figure 4.1**. By utilizing MGE technology, we were able to quickly build an interactive WebGIS called BRR-GTF WebGIS and provide important, interesting, and up-to-date maps to user during the RR-process [78].

4.3.3 The proposed Web mapping application developed using MapFish

I developed a Web mapping application with a function called "Add WMS" to add additional WMS layers to be overlaid with other layers available in the Web mapping application. The application was developed using MapFish, a flexible and complete framework for building web mapping. The framework is designed based on the JavaScript toolbox, composed of ExtJS and OpenLayers as shown in **Figure 4.11**

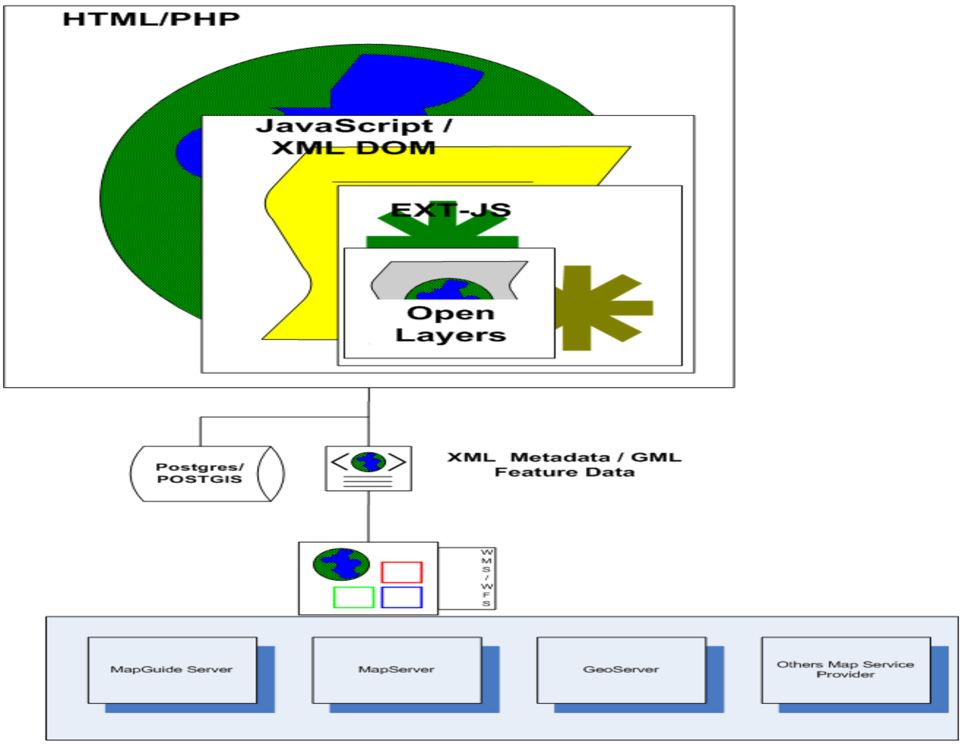


Figure 4.11 System Outline

4.3.4 Result

a. Figure 4.12 and **Figure 4.13** show the Web mapping application and hill slope map of Aceh province

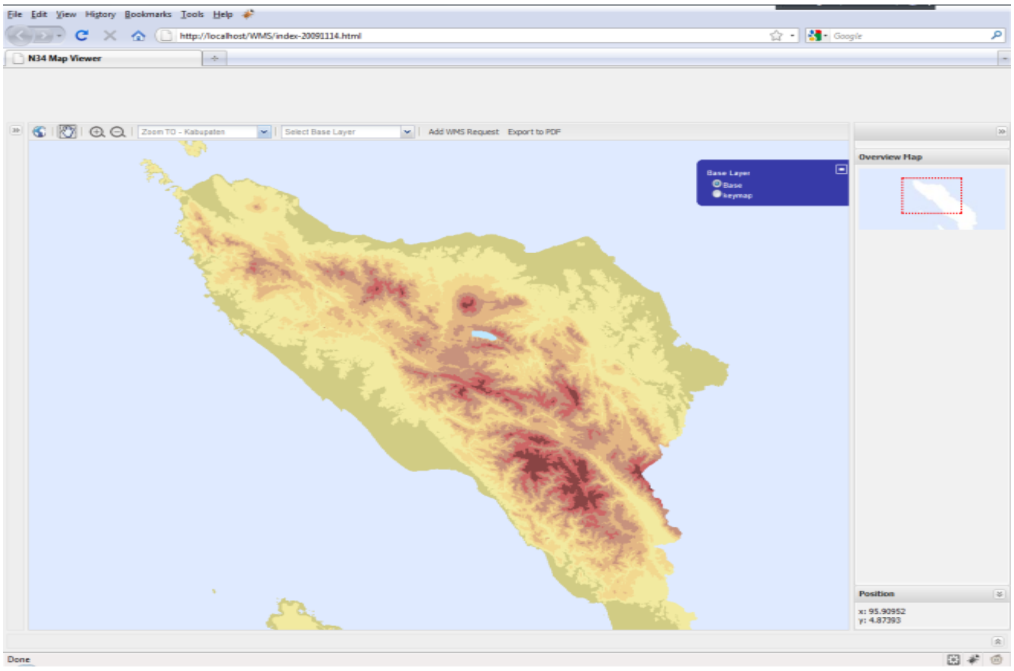


Figure 4.12 Web mapping application developed using the MapFish framework

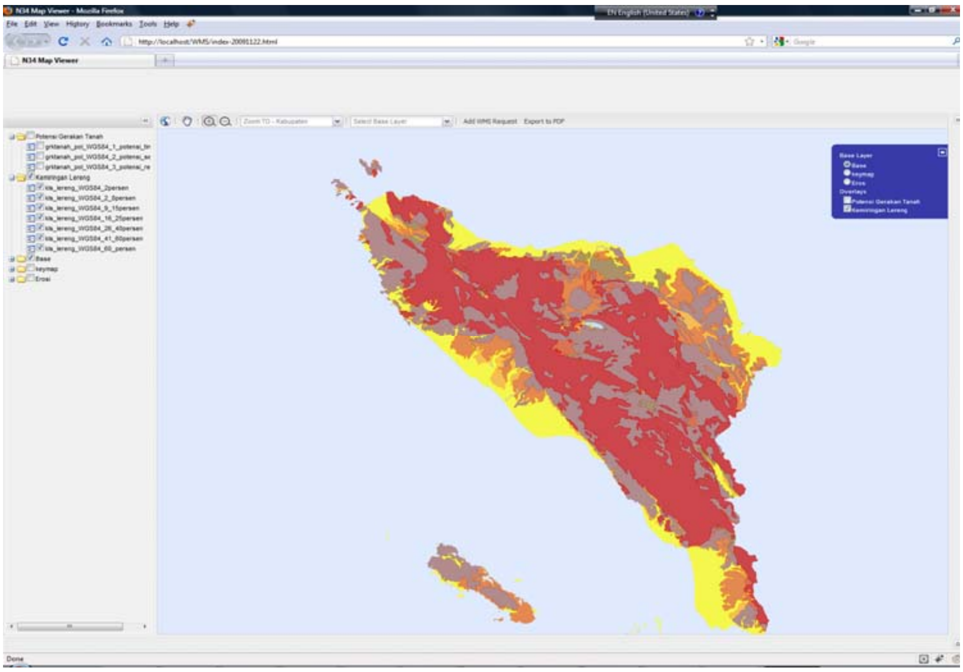


Figure 4.13 WMS of hill slope map relating to Aceh province

b. **Figure 4.14** shows the "Add WMS" tool for adding additional layer and **Figure 4.15** shows the result of the tsunami WMS layer added to the Web mapping application

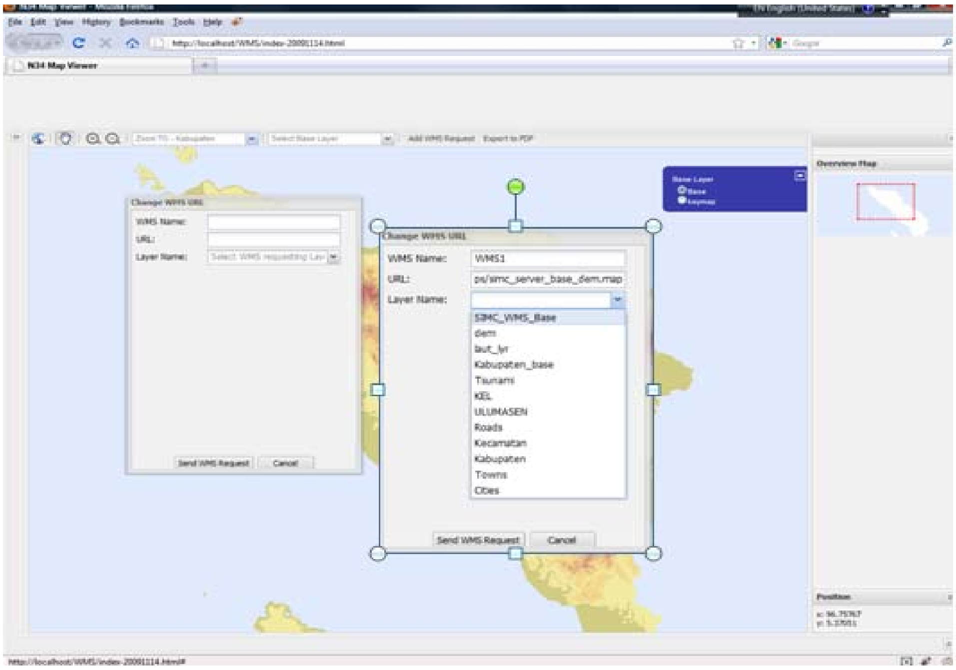


Figure 4.14 Requesting WMS using "Add WMS" function

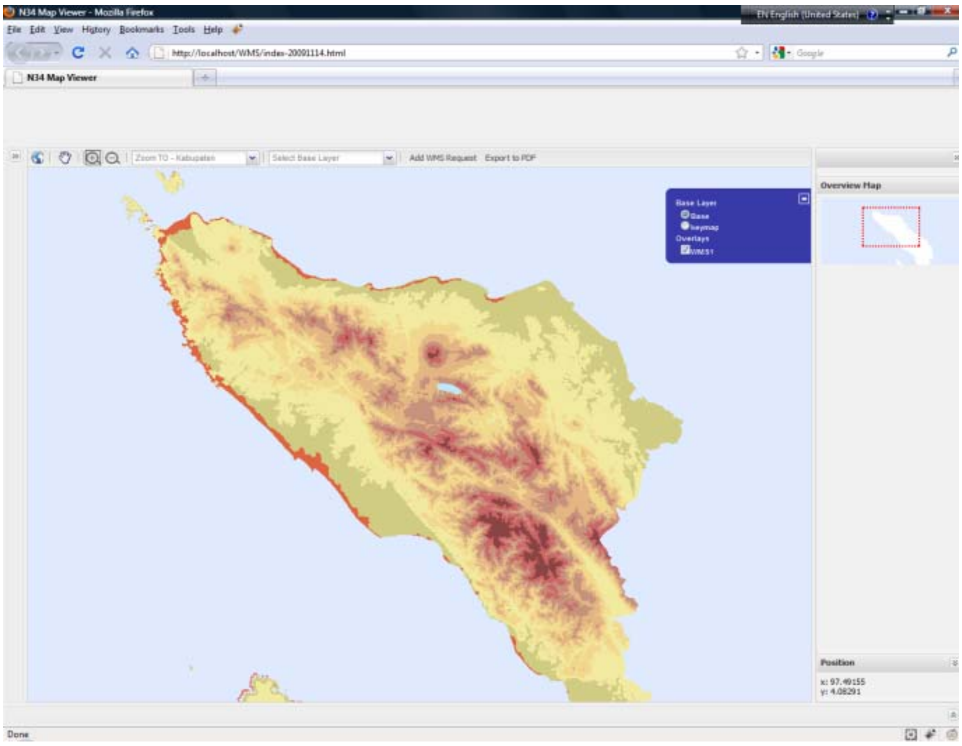


Figure 4.15 Result of the tsunami WMS layer added from MapServer's WMS

Chapter 5

Interactive Web-based application for the visualization of spatial data from the four-year rehabilitation and reconstruction process of tsunami and earthquake in Aceh-Nias, Indonesia

5.1 Overview

In this chapter, I demonstrate the importance of combining diverse geographic information through a Web-based application. I collected much spatial data in shapefiles and database formats from many projects at the end of the RR-process including from BRR's asset management information system, and from housing and barrack project. Because there has been no web-based application at AGDC for visualization of the spatial data generated during of the four years RR-process combined with other spatial data (such as natural resources, natural hazard, topographic maps, etc), I decided to develop this system. I believe that the Web-based application will be useful not only for Indonesian people, but for people all over the world. The aim of the study is to develop an interactive Web-based mapping application for visualization of the four-year rehabilitation and reconstruction process after the tsunami and earthquakes in Aceh and Nias. The application also provides an overview of natural resources, hazard and topographic maps.

5.2 Outline of Web-based application

I utilized MapFish for developing an interactive Web based application. MapFish is "a flexible and complete framework for building rich Web-mapping applications [85]." I combined JavaScript and PHP coding, SQL comments, OpenLayers and Mapfiles in order to request data from servers and display information in the browser. I managed spatial data received from several projects in both shapefiles and database to provide a diversity of geographic information coming from WMS layers.

I stored the administrative, asset, housing and barrack spatial data in a PostgreSQL/PostGIS database from which information needed for user selections or requests are queried. There are two connection types to the PostgreSQL/PostGIS database in this system. One is the direct connection used for internal process inside the application and the other is the connection in a Mapfile used to create dynamic layers while generating the WMS layers.

The WMS layer is generated using the MapServer CGI program (mapserv.exe) and Mapfile in MapServer. The request to generate the WMS layer is as follow http://myserver/cgi-bin/mapserv.exe?map=C:\Mapfile.map. The processes of requesting of WMS layers are called through the OpenLayers. Then, OpenLayers displays the WMS layers on the browser.

The Mapfile consists of several static or dynamic layers. I defined static layers referring to local shapefile resources (such as administrative boundaries, roads, forests, topographic maps, etc.), compiled from a thematic atlas map of Aceh province [97] and others projects. To get a dynamic layer based on user requests, I included the request parameters in the LAYER's DATA inside the Mapfile. I then sent the value of the parameters based on the user requests while calling Mapfile to generate WMS. **Figure 5.1** shows an overview of the application.

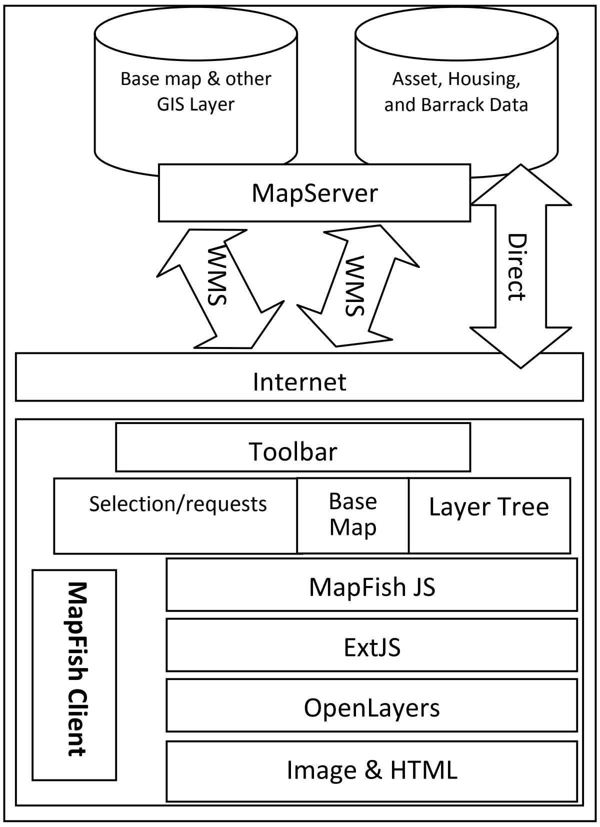


Figure 5.1 The Outline of System

In creating a spatial database especially for the administrative layer, I adopted a database structure from the fundamental data sets defined by SIM-C/AGDC [100]. I utilized databases received from BRR's asset management information system [101], housing and barrack project. **Figure 5.2** shows the entity relationship diagram of the database used in this application. **Figure 5.3** shows the Mapfile with a dynamic value parameter (%sentquery%) of the LAYER's DATA of Asset. After processing user requests, the result of WMS layer is overlaid with other geographic information, which is generated from several other WMS layers containing administrative boundaries, hazards, forests, concession areas, and maps of Aceh province.

The Web based application is equipped with some basic GIS functionality (such as zoom to full extent, zoom-in, zoom-out), layers selection and some tools (such as dropdown menu, search facility, a tool tip, and Add WMS layers). Users are able to visualize the geographic information in the browser. The information is generated based on the user request for several categories, such as district, sub-district location, year, sector, and donor. Users can also search asset spatial data using the search facility and request/add other WMS layers from other MapServers.

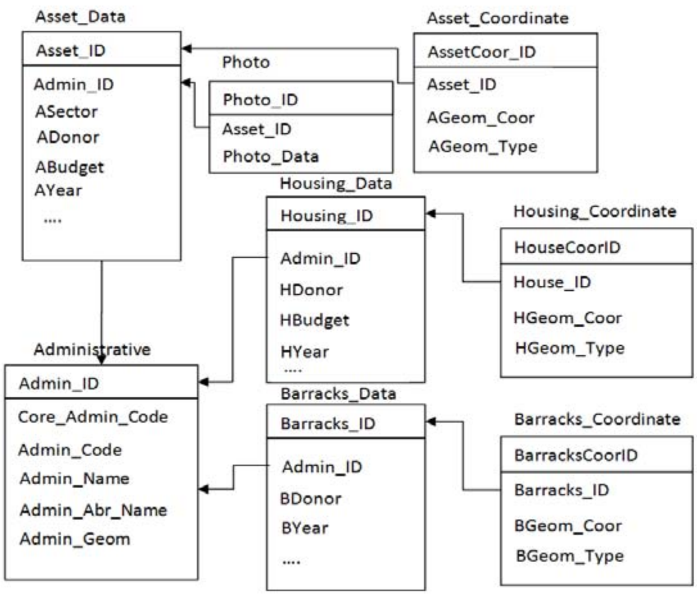


Figure 5.2 Entity relationship diagram of RR_DATABASE

In developing the application, I used five common areas of the MapFish framework consisted of north, center, west, east and south areas. The implementation is as follows:

a. The North area and South area are left empty,

b. The Center area is used for the main map area and the top bar of the center area is used for placing the GIS functionalities icon, dropdown menu and tools icon.
c. The West part is divided into four items. Three items are used for selections for the users and the fourth item is used for the map legend.
d. The East part is used for the layer switcher.

The result of the implementation of the MapFish framework is the Web-based application shown in **Figure 5.4** containing district and sub district navigator and some basic GIS functionality.

```
MAP
    NAME "Aset_WMS_Base"
    STATUS ON
    SIZE 256 256
    UNITS DD
    FONTSET "fonts/fonts.txt"
    SYMBOLSET "symbols/symbols.sym"
    PROJECTION
        "init=epsg:4326"
    END
    WEB
        IMAGEPATH "C:/ms4w/tmp/ms_tmp/"
        IMAGEURL "/ms_tmp/"
        METADATA
            WMS_TITLE "Asset WMS Base"
            WMS_SRS "epsg:900913 epsg:4326"
        END
    END
    LAYER
          NAME 'Asset'
          CONNECTIONTYPE postgis
          CONNECTION "user=postgres dbname=rr_database host=localhost password=****"
          DATA %sentquery% #Receive the dynamic value for the Layer's DATA
          PROJECTION
            "init=epsg:4326"
          END
          STATUS ON
          METADATA
            WMS_TITLE "Asset"
            WMS_SRS "epsg:900913 epsg:4326"
          END
          TYPE POINT
          CLASS
                    NAME 'Education'
                    EXPRESSION (("[kelompok]" = "Education"))
                    STYLE
                        SIZE 8
                        SYMBOL 'education'
                    END
          END
          .
          .
          .
    END
    LAYER
          NAME 'Housing'
          .
          .
          .
    END
```

Figure 5.3 Asset Mapfile with a Dynamic Value Parameter of Layer’s DATA

5.3 Result and discussion

5.3.1 Map view navigator

I navigated the map view based on district and sub-district locations and MapFish’s map toolbar (zoom to whole Aceh area, Pan, Zoom-in and Zoom-out).

In centering to district or sub-district locations on the map, I called the value x(centroid (the_geom)), y(centroid(the_geom)) of district and sub-district from “Admin_Geom” FIELD of “Administrative” TABLE of “RR_DATABASE” from PostGIS DATABASE, and then implemented the result with the OpenLayers function. This will set the map center to a specific location with map.setCenter(new OpenLayers. LonLat(x,y), zoom).

Indonesia follows the “district, sub-district and village” administrative boundary system and the navigation map to district and sub-district location was implemented in the SIM-C’s Web mapping application project [92] from which I adopted the techniques in navigating the map. The result of district and sub-district navigation is shown in **Figure 5.5**.

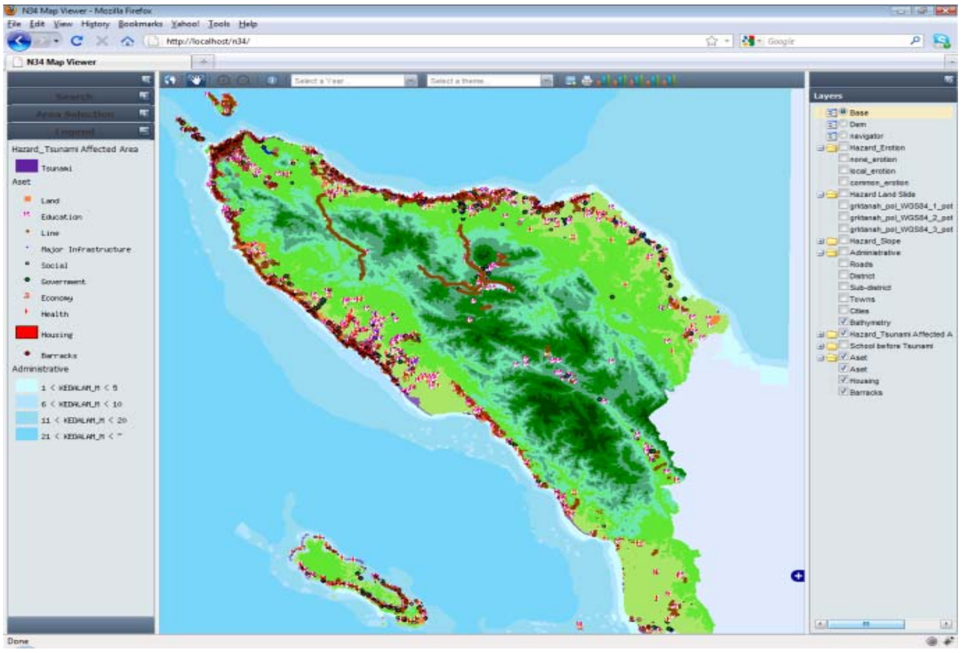


Figure 5.4 The Web-based application

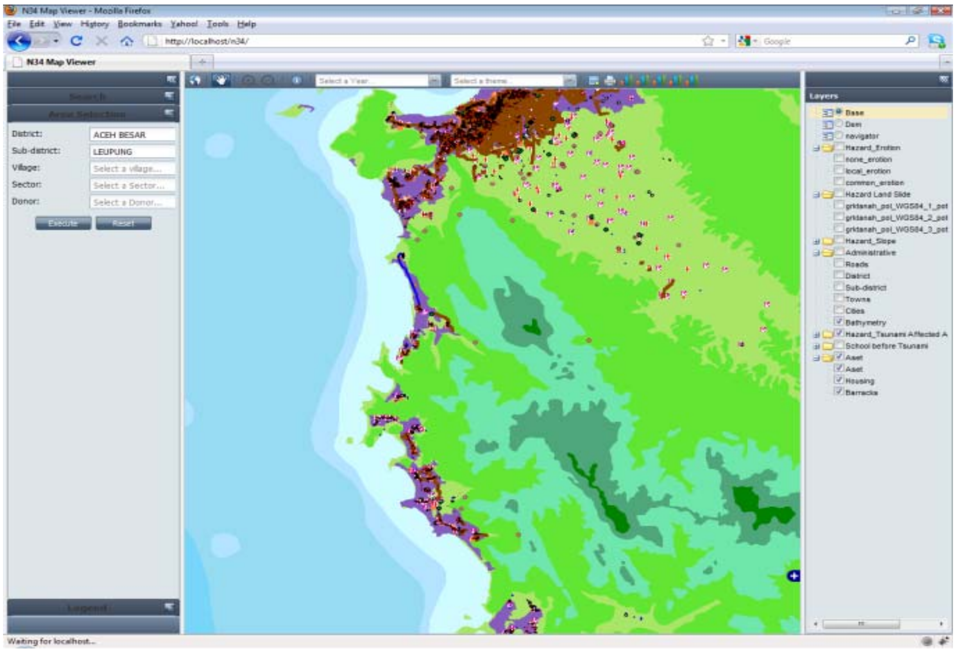


Figure 5.5 The result of map navigation based on the Aceh Besar district and the Leupung sub-district

5.3.2 Asset map with district and sub-district selection

A map showing the distribution of all asset, housing and barrack data is automatically generated when the application starts. Users can then specify the distribution of asset data based on several selections such as district, sub-district, village, donor and year. **Figure 5.6** shows the distribution of asset data in Aceh Besar district area and health sector, which are selected. In generating a map of the distribution of asset data based on district area, I implemented the Java Script function that call get_asset_map(location_code, sector_code, donor_code, year)

```
{
// Query data based on user selection from PostGIS
// Call WMS asset_layer by including a dynamic value of Layer's DATA in Mapfile
 asset_layer = new OpenLayers.Layer.WMS("Asset","http://localhost/cgi-bin/mapserv.exe?MAP=C:/ms4w/Apache/htdocs/ICGG/maps/asset.map&sentquery=the_geom FROM "+ query+ ") …
// Add Map Layer to OpenLayers
  map.addLayers([asset_layer]);
}
```

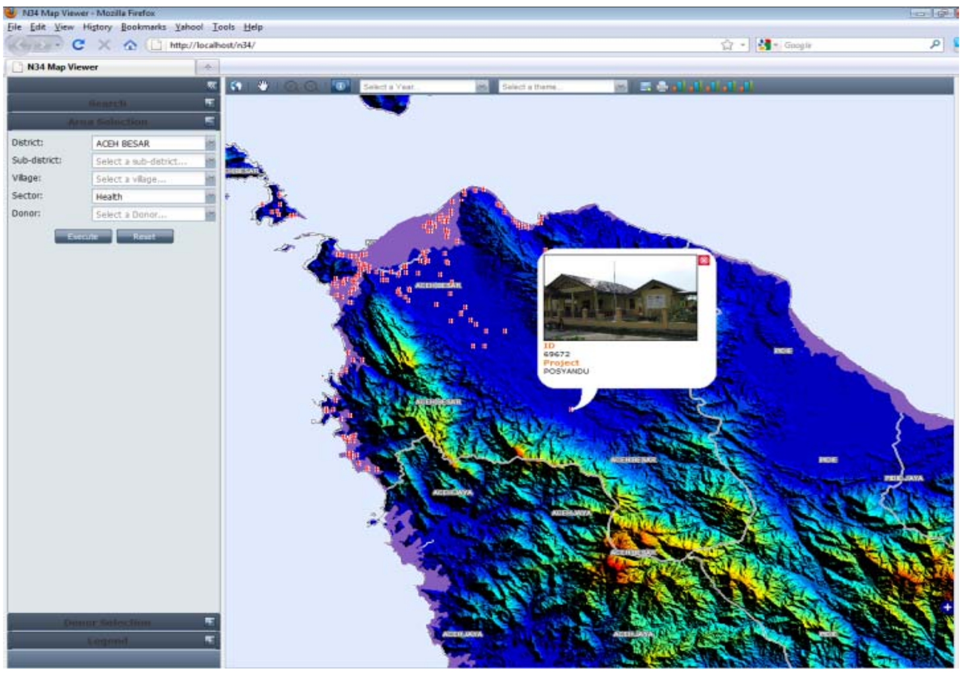


Figure 5.6 Asset data on Aceh Besar district within health sector

User request based on user selection in dropdown menu is processed. Its value is assigned as criteria for querying data from the PostGIS database. The query result will be utilized for processing the outputs. It will also be used for providing list of next level of dropdown menu, and so on. **Figure 5.7** shows a list of donors that have contributed to the rehabilitation and reconstruction project in the Banda Aceh district, Jaya Baru sub-district, and in the health sector

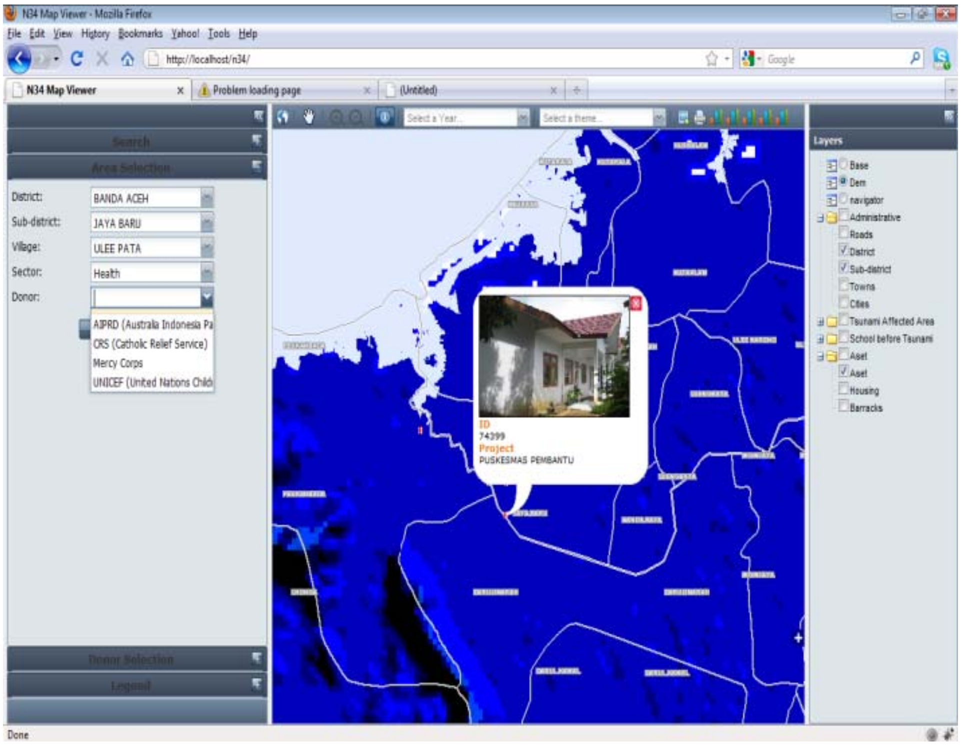


Figure 5.7 Tool tip showing a list of donors that have contributed to the health sector in the specific location

5.3.3 Asset map searching tool

This application also has a free text searching facility. Users can type any text in the search textbox. This is important for users who want to search and play around to look at their preferred keywords as shown in **Figure 5.8**

5.3.4 Asset map overlaid with other layers

This application can also be used to show the government of Indonesia policies during the rehabilitation and reconstruction by querying asset, selecting location, and overlaying the asset map with other layers.

For example, from the scale of devastation in the education sector, it was clear that it would not be enough to simply replace the school infrastructure in the tsunami-affected area. The rehabilitation and reconstruction program would need to develop a new policy for rebuilding every facility and infrastructure that supports the education sector. The rehabilitation program was not only carried out in the tsunami affected area but also in every district or sub district to make sure that the education facilities were at least equal to the education system in the areas being built.

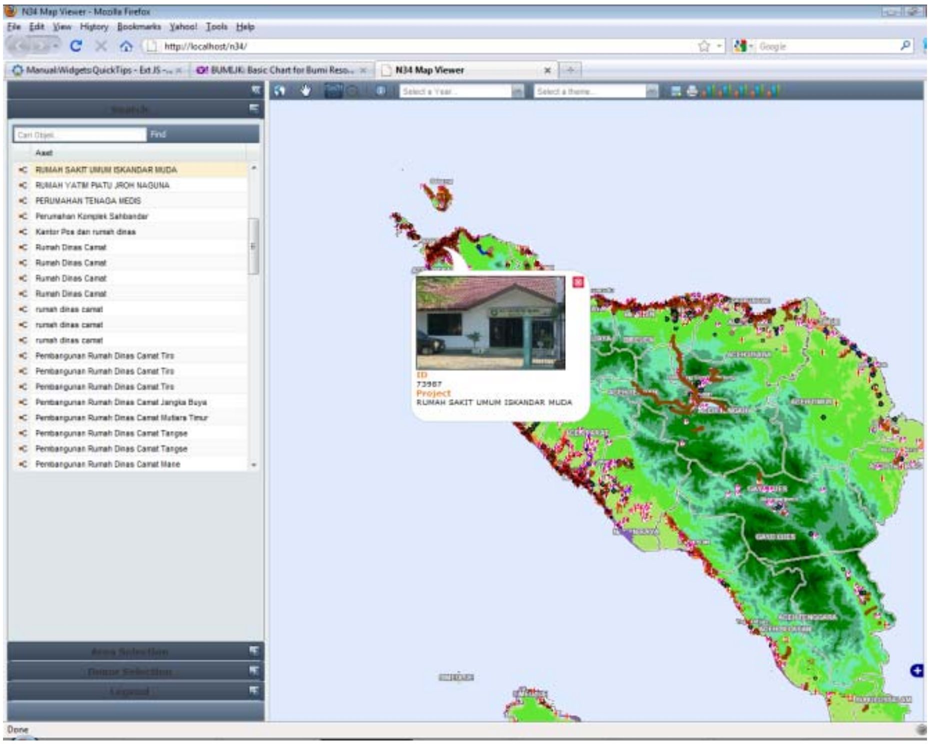


Figure 5.8 Assets free text-searching tool

The government of Indonesia also gave high priority to support the new education system in poor, disadvantaged and remote areas, such as Central Aceh, Gayo Lues and Aceh Singkil district, far from the central capital. The government of Indonesia clearly planned to comprehensively rebuild the education sector in Aceh shown from the distribution of rehabilitation and reconstruction in the education sector in **Figure 5.9**. On the map in **Figure 5.9**, we can also see the purple polygons represent the tsunami-affected area, the brown points are education facilities before the tsunami struck Aceh province, and the red symbols represent the rehabilitation and reconstruction programs in the education sector.

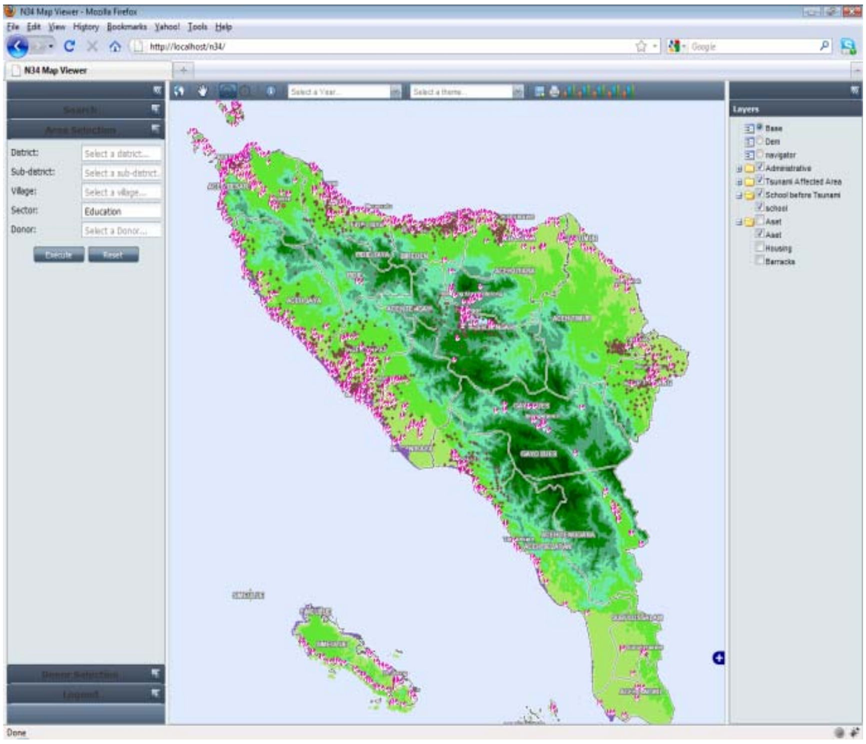


Figure 5.9 Overlay of the distribution of education sector before and after the rehabilitation with the tsunami affected area

5.3.5 Chart showing rehabilitation data

I added a number of charts to show the rehabilitation and reconstruction process and to give a simple overview of the total amount of money in each sector and the total number of projects in a specific district or sub-district. I implemented an open source add-on from open-flash-chart [102] to generate a chart of rehabilitation and reconstruction data retrieved from the PostGIS database. The entire chart is shown by opening new windows using ExtJS's Ext.Window with the "xtype: 'openchart'" item.

Figure 5.10 and **5.11** shows bar and pie charts of the total the amount of money in each sector for Aceh province and Aceh Barat district. **Figure 5.12** shows the total number of projects in each district of Aceh province.

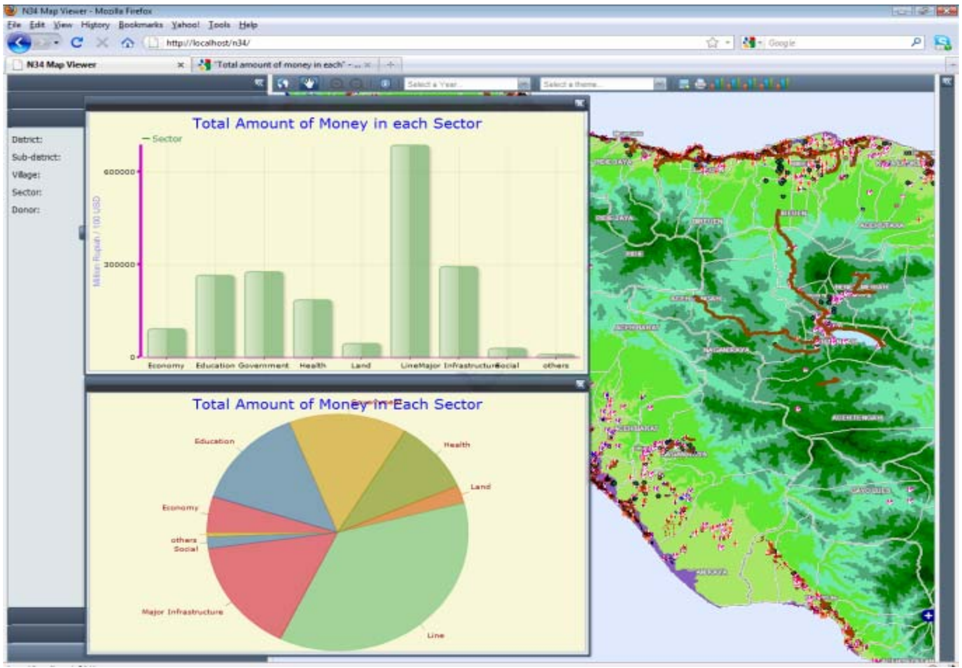


Figure 5.10 Bar and pie chart of the total amount of the money in each sector in Aceh province

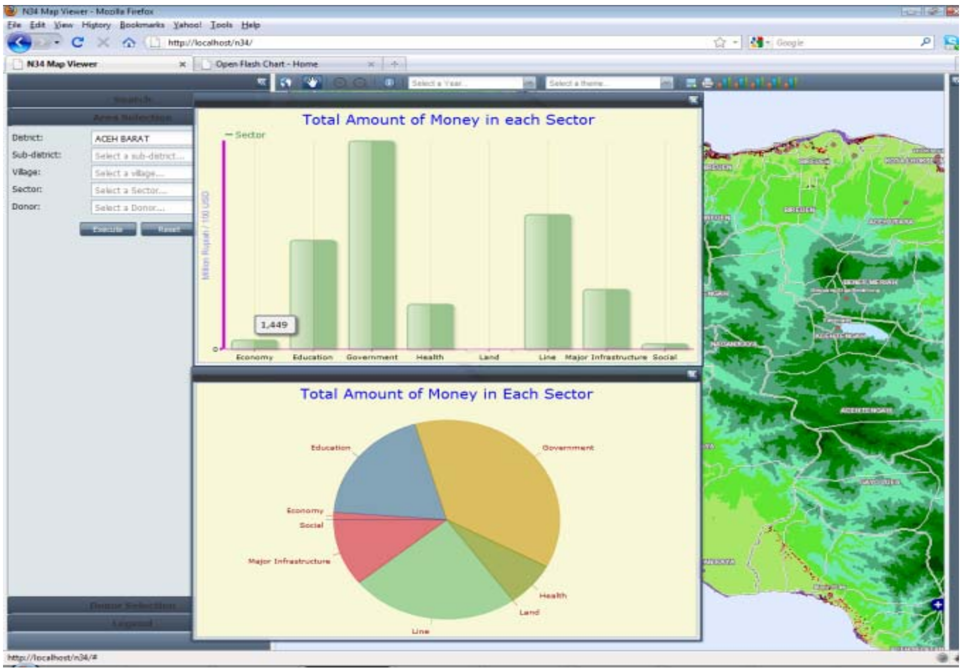


Figure 5.11 Bar and pie chart of the total amount of money in each sector in Aceh Barat district

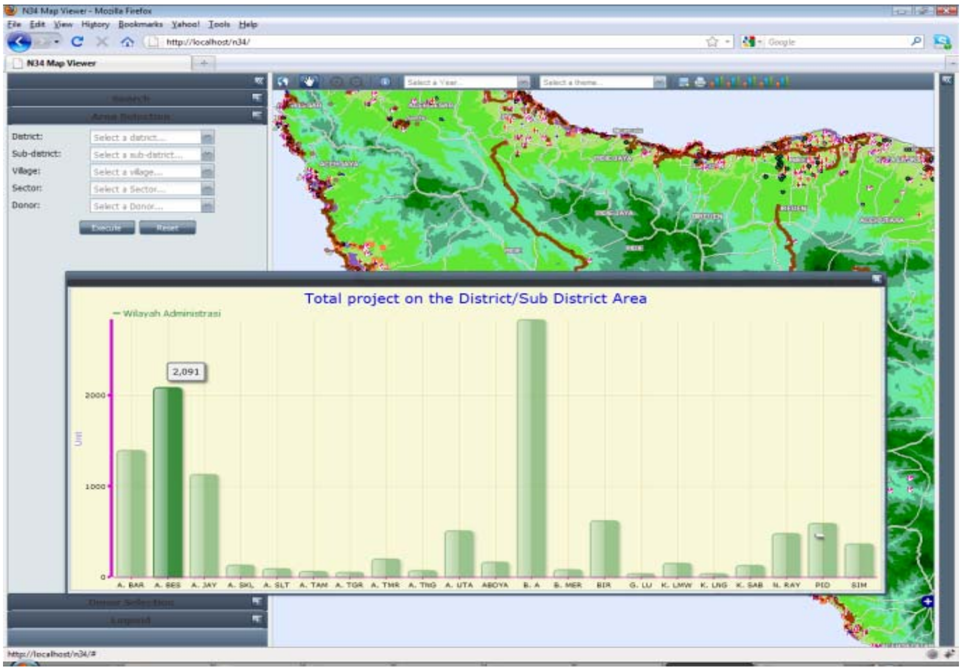


Figure 5.12 The total number of projects in each district of Aceh province

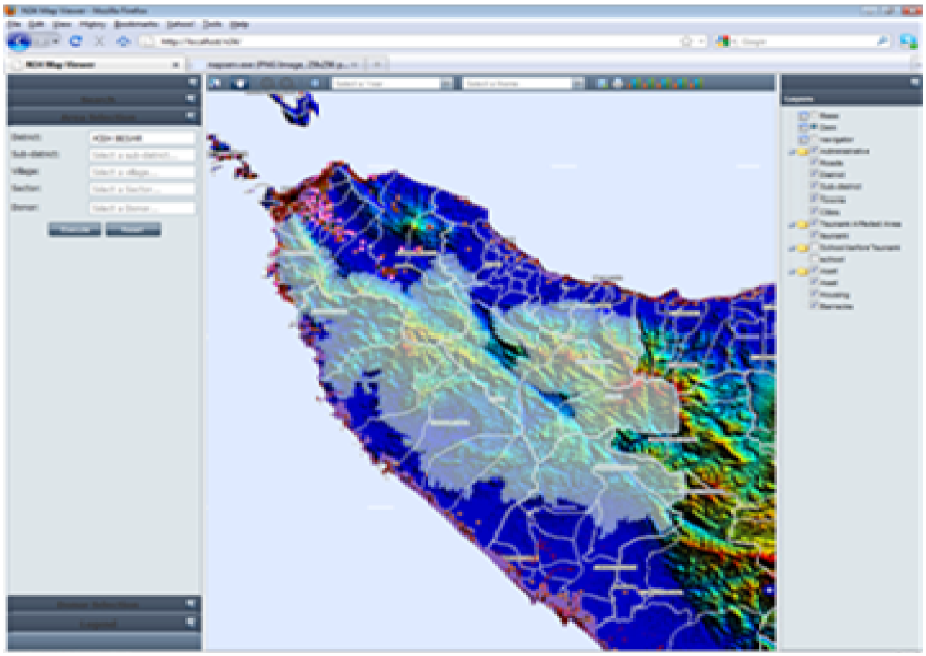


Figure 5.13 The tool for adding the WMS and the Ulue Masen forest called from WMS

5.3.6 Adding WMS functionality

I provided an ADD_WMS function to provide additional layers from a number of different resources to the user. Users can add WMS layers published from another MapServer. Users just need to enter the URL of WMS and a list of layers will automatically appear in the drop down menu. These WMS layers are overlaid with current layers.

In obtaining service-level metadata, I implemented the Open GIS Consortium (OGC) GetCapabilities specification version 1.1.1 to deal with WMS. After getting the URL and list of layers from the user selection, I implemented OpenLayers.Layer.WMS to add WMS and to overlay it with the other layers. **Figure 5.13** shows the tool for adding the ADD_WMS and the Ulue Masen protected Forrest added from the WMS of protected forest of Aceh province.

5.4 Conclusion for the Web-based application

I have developed a web-based application for visualization of the four-year spatial data from the rehabilitation and reconstruction process in Aceh-Nias. Utilizing the MapFish Framework supported with JavaScript and PHP coding will enabled us to handle and manage spatial data stored in PostGIS, and enable it to be viewed in Openlayers. I produced an interactive map in the browser by combining several WMS layers generated by MapServer and Mapfiles, based on user requests on the asset data and user selections.

The Government of Indonesia under the Ministry of Finance is doing a final inspection of all assets and housings. From the total 17,831 projects that I received data from, I have 5,066 complete records of asset data, including budget, location etc., and from 140,300 houses that had been built I received 110,008 records of housing data. .

At this time, I have just finished implementing searching and querying of the asset data in the application to create an interactive Web based application for the reconstruction process. After the Indonesian Government finishes the final inspection project, I will integrate and more specifically classify all data for the searching facility. I hope this application will be used by ACDC as a tool for archiving and showing the rehabilitation and reconstruction process in an interactive way.

Chapter 6
A prototype for an integrated information system for geographic information produced during the rehabilitation and reconstruction process following the earthquakes and tsunami disasters in Aceh province, Indonesia

6.1 Overview

The objective of this study is to develop the prototype for an integrated information system for managing, disseminating and sharing huge amounts of geographic information generated during the tsunami recovery process in Aceh province. I have investigated applications used during RR-process and the issues relating to GIS use in chapter 3. The disadvantages of the existing system will be clearly explained in section 6.2.

I have collected, analyzed, and classified a huge amount of geographic information and prepared it to be used in the integrated system for this study, as shown in section 6.5. I developed the integrated information system for the three types of user, i.e. AGDC staff, local government decision-makers or ordinary end users, and application developers for the Aceh province.

The main functionalities for three types of users are as follows:

(a) system functionalities for AGDC staff (including for storing and accessing geographic data in ArcSDE Geodatabase, providing geographic information services, and creating and publishing metadata documents, and creating Web mapping application),

(b) system facilities for decision makers and end users (including for finding geographic information through Metadata Service with ArcCatalog, finding geographic information in Metadata Explorer, direct accessing to GI services through ArcCatalog and ArcMap for analysis),

(c) system facilities for application developers.

The detailed explanation about system functionalities will be explained in section 6.6.

This study also shows four examples of analyses that can be performed using the integrated system, the collected geographic information (GI) and GI services. The examples of analyses are shown in section 6.7

6.2 The problems of the existing application at AGDC

Although AGDC received several applications mentioned in section 3.5.1, only AGDC Geoportal has been accessible through the Web since 2007. The possible reasons for the inaccessibility of other applications are license issues, the lack of maintenance staff, and compatibility among operating systems, database servers, and application platforms. Currently, AGDC does not have an integrated information system that can be used to efficiently and effectively manage and provide services around their huge store of geographic information. AGDC has only dealt with two separate main applications: a metadata catalog application and a Web mapping application [93] supported with PostgreSQL/PostGIS and MapServer [40] serving OGC-WMS. 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 format. GeoNetwork Opensource XML metadata tool has been used to publish the xml metadata file. However, AGDC staff cannot directly publish the created metadata document to the metadata catalog service from ArcCatalog Tree by dragging and dropping it into the metadata catalog service.

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

c) AGDC staff cannot directly and easily utilize many ArcMap Documents received during the RR process as an input when creating and publishing Map Services. This is because MapServer (Server GIS) that is being used by AGDC uses a Mapfile to create WMS.

d) The existing work process of using PostgreSQL/PostGIS does not allow AGDC staff to directly store geospatial data to geodatabase from ArcCatalog. Therefore, users also cannot directly and easily access the published geodatabase with ESRI server/desktop GIS and other desktop GIS.

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

6.3 System design and construction

6.3.1 System requirements

In chapter 1 and 3, I analyzed problem and issues at AGDC and in Aceh province. I have also explained the disadvantages of the existing applications in section 6.2. There are three target users of integrated information system, i.e. AGDC staff, local government decision-makers or ordinary end users, and application developers. Based on the analysis, the system requirements for an integrated information system are as follows:

a) AGDC staff needs an integrated information system that can be used to easily manage and provide services relating to their huge store of geographic information containing ArcMap Documents. These include several applications:
   - Geodatabase management system, used to manage the geodatabase for the fundamental dataset and other geospatial data,
   - Server GIS, used to manage and publish map services, especially Server GIS that can easily and directly utilize ArcMap Document when providing map service. The fact that AGDC has received many ArcMap Documents from RR-process and has also been working with and producing ArcMap Documents in routine work when creating or producing map using ArcCatalog
   - Metadata catalog server, service and application, used to store metadata document and manage the published metadata documents for various types of geographic information,
   - Web mapping application manager, used to create simple or advanced Web mapping applications,
   - Applications that can be used to handle ArcMap Documents for opening and making map or providing map services and to handle metadata document for opening and creating metadata and publishing metadata documents.

b) Local government decision-makers or ordinary end users need the following services:
   - Metadata catalog service and metadata catalog application, used to browse and search content metadata services of geographic information,
   - Live data and maps services, obtained from metadata search results, which can be directly added as layers in the GIS Desktop software,
   - Geodatabase services, Image Service and Feature Service, which can be directly

accessed in the GIS Desktop software,

c) An application developer needs geodatabase services, mapping services including ArcMap Image Services, ArcIMS Image Services, ArcIMS Feature Services, ArcGIS Server Map Services, WMSs and WFSs, used in the developer's custom Web mapping application.

6.3.2 System architecture

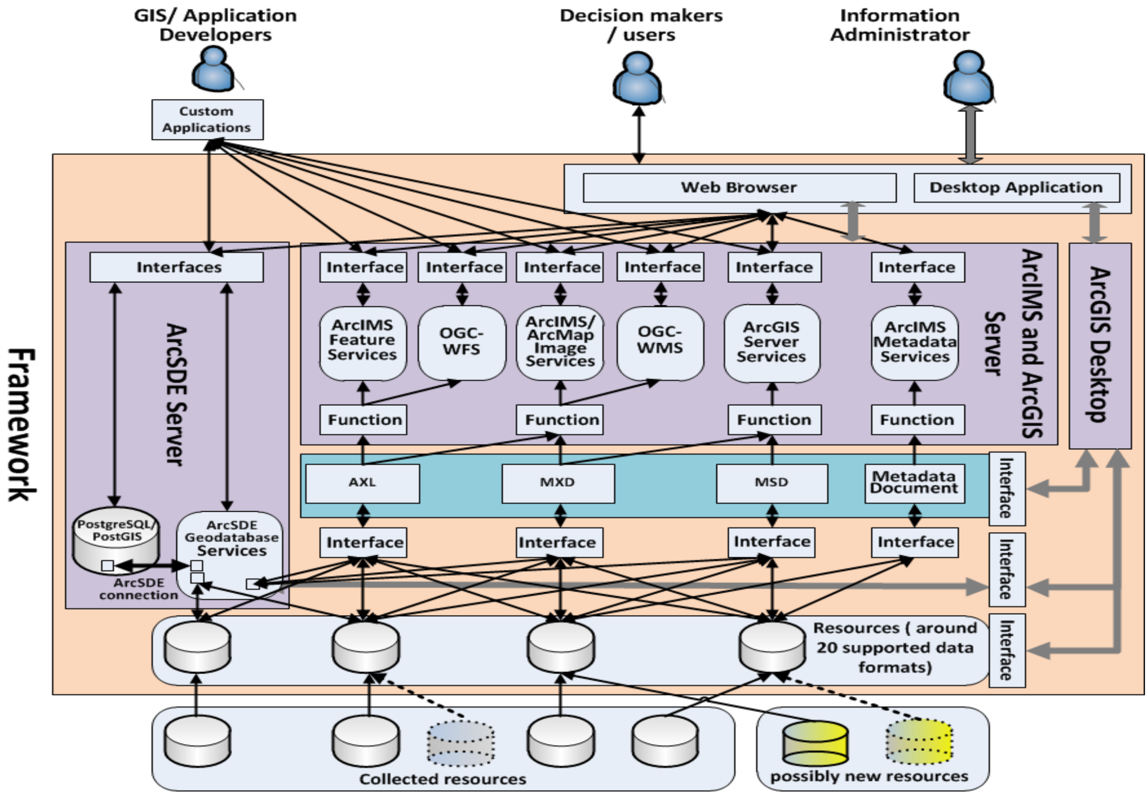


Figure 6.1 The implementation of integrated environment for heterogeneous GI

In order to meet system requirements, I adopted model of an integrated environment for heterogeneous GI as shown in **Figure 6.1** and selected ArcIMS Feature Services, OGC-WFS, ArcIMS/ArcMap Images Services, OGC-WMS, ArcGIS Server Services because their high acceptability of various data formats of resources as shown in **Table 2.5**. MXD is the highest acceptability of various data format of sources for creating ArcIMS ArcMap Image Service and OGC-WMS through ESRI ArcIMS Server, and AGDC has many MDX documents.

The integrated environment has also ability to accept the possibly new resources. If data format of the possibly new resource is available in the accepted data formats in the environment, then new resources can be directly utilized by information administrator while creating or publishing GI services. If the possibly new resource is not available in the environment, a converter or data interoperability tool is needed, as explained in section 2.4.4 and 2.4.5.

The integrated environment accommodates three types of user with functions and facilities assigned based on the needs for each type of users. Three types of users, framework (server GIS, desktop GIS, GI services, functions, and interface), and resources (collected and possibly new resources) are shown in **Figure 6.1**. To accommodate the requirements of the three types of users, I have selected/implemented the following components:

(a) To support AGDC staff' needs,

1. To provide Geodatabase management system then ArcSDE Geodatabase and PostgresSQL/PostGIS are selected.
2. To provide server GIS that can be used to easily manage and publish GI services, and then ArcIMS Server and ArcGIS Server are selected. Both server GIS has ability to directly utilizes ArcMap Document, while publishing GI Services. This ability will help AGDC staff to easily publish and manage GI services.
2. To provide Metadata catalog server, service and application then ArcIMS Server, which has metadata service called ArcIMS Metadata Services, are selected. ArcIMS Metadata Explorer has been deployed to provide Metadata catalog application.
4 To provide Web mapping application manager, ArcIMS and ArcGIS Server Manager are selected.
5. To provide applications that can be used handle GI containing many ArcMap Documents, Metadata, GI Services and Geodatabase, then ArcGIS desktop has been selected.

(b) To support decision makers' needs,

1. To provide facilities that can be used to browse and search GI in Metadata Service, then ArcIMS Metadata Services and Metadata Explorer are selected.
2. To provide direct access to live data or Map Services that are obtained from Matadata Explorer, then ArcIMS ArcIMS Feature/Image/ArcMap Image Services and ArcGIS Server REST API are provided.
3. To provide Geodatabase service that can be accessed from any desktop GIS then both ArcSDE geodatabase services and PostgreSQL/PosGIS are served. To provide Image service and Feature Services, which can be accessed from any desktop GIS, then

ArcIMS Feature/Image/ArcMap Image Services and OGC WMS/WFS through ESRI Server are served.

(c) To provide application developers' needs,

To provide GI services that can be used by application developers in their custom application, then ArcSDE geodatabase services and PostgreSQL, ArcIMS Feature/Image/Arcmap Image Services and OGC WMS/WFS through ESRI Servers are served.

To realize this architecture I have implemented the following ESRI products, including ArcIMS Server, ArcGIS Server, and ArcSDE Geodatabase, and I have also implemented PostgreSQL/PostGIS.

The system architecture shown in **Figure 6.2** consists of the following three layers:

{1} Data layer:
- (a) Geospatial data, (b) ESRI ArcSDE Geodatabase [37], (c) PostgreSQL/PostGIS spatial database,

{2} Server layer:
ArcIMS Server [103] [32], ArcGIS Server [104] 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 [105],
  - (iii) QuantumGIS (QGIS) [23], etc,
- (b) ArcIMS Administrator [106],
- (c) Web applications:
  - (i) ArcGIS Server Manager,
  - (ii) ArcIMS Metadata Explorer [107][49],
  - (iii) ArcGIS Server REST API [108],
  - (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).

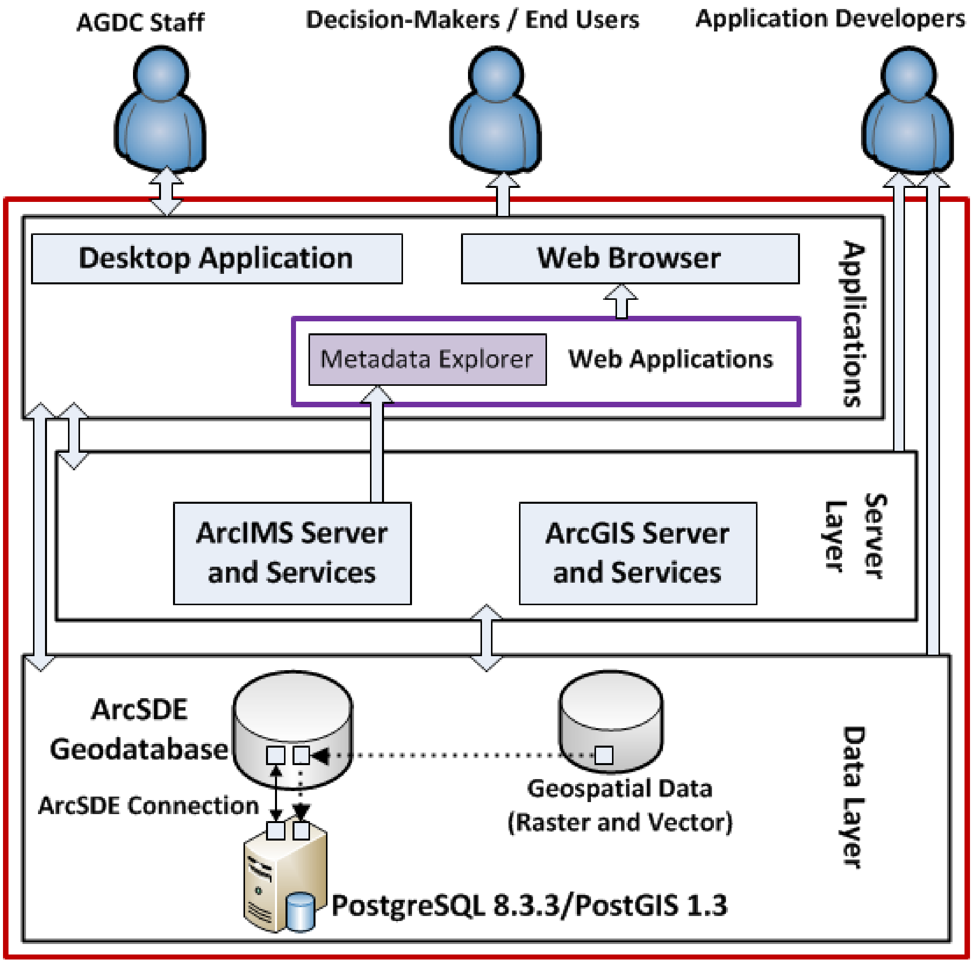


Figure 6.2 The architecture of the integrated GIS and its users

6.3.3 System construction

In developing the system prototype, there are several options to choose between when it comes to the implementation of operating system, Web Server, Servlet Engine, Database Server and application platform. Here, I have chosen Microsoft Windows Server 2008 as the operating system. I used both .NET Framework and Java Platform technologies. I implemented Microsoft Internet Information Service (IIS) 7 for ArcGIS Server and the combination of IIS 7 as Web Server with Tomcat 6 as Servlet Engine to support ArcIMS server applications. I configured both ArcIMS 9.3.1 Server for Windows and ArcGIS Server 9.3.1 for the Microsoft .NET Framework to create, publish and serve map services. I used ArcIMS Web ADF for the Java Platform that has features to facilitate the development of Web mapping applications including web controls, java connector and Metadata Explorer. In implementing ArcSDE, there are five options of spatial databases (i.e. Oracle, SQL Server, IBM DB2, IBM Informix, and PostgreSQL) where ArcSDE supports the connection [60]. I utilized ArcSDE connection for PosgreSQL 8.3 and PostGIS 1.3.6. **Figure 6.2** shows a prototype of the integrated information system.

I used Visual Studio.Net 2008 for developing the Web mapping application for consuming service from ArcGIS and ArcIMS Server. I also implemented Java Server Page (JSP) for handling the Metadata explorer application.

In developing the integrated information system, I used a Dell Power Edge Server T410 Intel Xeon E5506 with two 2.13 GHz processors and 8 GB RAM.

6.3.3.1 ArcSDE connection for PostgreSQL/PostGIS

In constructing ArcSDE Geodatabase, I implemented an ArcSDE 9.3.1 connection for PostgreSQL. I chose PostgreSQL 8.3.8/ PostGIS 1.3.6 as a spatial database server. ArcSDE 9.3.1 for PostgreSQL supports either ST_Geometry or PG_Geometry as geometry storage type [109]. I chose PG_Geometry because it allows geospatial data to be stored in the PostGIS geometry type in ArcSDE Geodatabase. As the result of choosing the PG_Geometry, user can directly access ArcSDE Geodatabase through the open source desktop GIS.

6.3.3.2 ArcIMS Server 9.3.1

In constructing the ArcIMS Server, I combined both IIS 7 as Web server with Tomcat 6 as Servlet engine. I utilized ArcIMS 9.3.1 for Windows and chose

(1) ArcIMS Server applications, including:
    (a) Map creation and Administration tool,
    (b) Server component,
    (c) Metadata solution and OGC interoperability, and
(2) ArcIMS Web Manager and Application Developer Framework (ADF) for Java Platform, including:
    (a) Web ADF used to develop the Metadata Explorer Web application,
    (b) ArcIMS Web Manager, and (c) Java Connector.

6.3.3.3 ArcGIS Server 9.3.1

In constructing the ArcGIS Server, I implemented IIS 7 as a Web server. I utilized ArcGIS server for the Microsoft .NET framework and chose

(1) GIS server applications, including:

  (a) Server Object Manager (SOM) and

  (b) Server Object Container (SOC),

(2) Web application manager, and

(3) Web ADF for Microsoft Visual Studio.NET 2008.

6.3.3.4 Building, Configuring and Deploying a Metadata Explorer

Metadata Explorer included in ArcIMS Web ADF for the Java Platform is a Web-based Metadata catalog application [110] that allows users to search and browse the content of Metadata Service from a web browser. Before configuring, building and deploying Metadata explorer, I created a Metadata Service, in which I stored metadata documents of geographic information, and two other optional services, namely Gazetteer Metadata Service and Search Map Image Service.

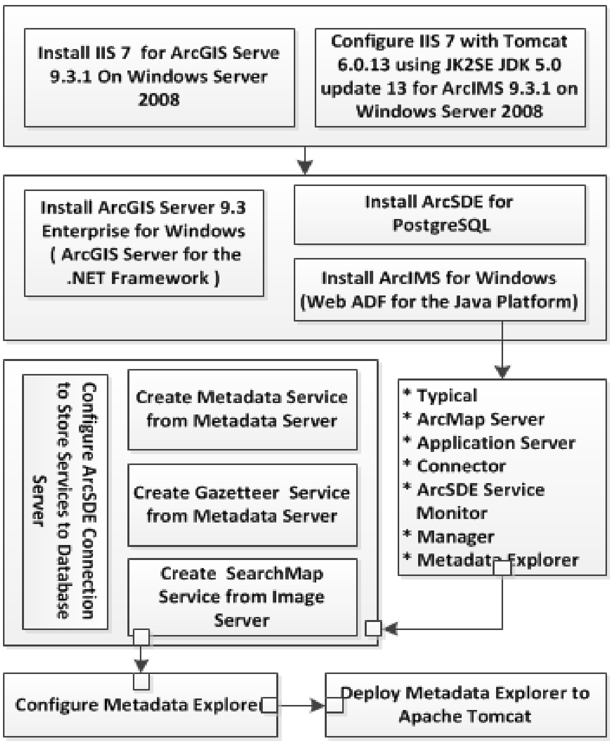


Figure 6.3 Installation processes of ArcGIS Server, ArcIMS Server and Metadata Explorer

Metadata Service is one of the ArcIMS services that can be used for publishing and sharing metadata documents [49]. I used ArcIMS Administrator and ArcXML configuration file (axl) to configure and construct Metadata Service that is stored in ArcSDE Geodatabase.

The Gazetteer Metadata Service allows user to search using place names that associated with location [111]. I also created an ArcIMS image Service named "SearchMap" that will be used for map orientation in the search box on the metadata explorer. The Search map allows user to draw a box to narrow a search in the specific location.

In order to create Metadata Explorer Web application, I installed ArcIMS Web ADF for Java Platform and then configured, built and deployed the Metadata Explorer Web application to Apache Tomcat. The flowchart of the installation and deployment process of the Metadata Explorer Web application is shown in **Figure 6.3**.

6.4 Software Component

The system consists of the following software components:

6.4.1 ArcIMS Server

ArcIMS Server is made up of several components, such as ArcIMS Management consisting of (a) AcrIMS Administrator, (b) Author and (c) Designer, and ArcIMS Server components, etc [33]. ArcIMS Administrator is used to create and publish ArcIMS services and to manage the published ArcIMS services in ArcIMS Server. ArcIMS Author [112] is used to create an AXL [113] file (ArcXML based map configuration file). The AXL file can also be created or edited with a text editor. ArcIMS Designer [83] is used to generate and customize the Web mapping application.

6.4.2 ArcGIS Server

ArcGIS Server, implemented as a server GIS, is used here to provide ArcGIS Server Services. In addition, ArcGIS Server Manager is used to create ArcGIS Server Map Services and to develop and customize the Web mapping application based on the Microsoft .NET framework. ArcGIS Sever offers a Representational State Transfer (REST) Application Programming Interface (API). REST [114] is a simple and open method to access distributed hypermedia systems. It is useful in Web application development. All ArcGIS Server Services exposed by the REST API [108] can be accessed through a hierarchy of endpoints or URLs. The ArcGIS Server REST API allows several applications, such as ArcMap, ArcGIS Explorer, ArcGIS JavaScript and Google Earth, to directly access ArcGIS Server services.

6.4.3 ArcCatalog

ArcCatalog is used here to (a) access, store, and manage geospatial data and ArcSDE Geodatabase, (b) create metadata documents, (c) publish metadata documents into ArcIMS Metadata Service, (d) publish ArcGIS Server Map Service into ArcGIS Server, etc.

6.4.4 ArcMap

ArcMap is used here to create ArcMap Documents and a MSD (Map Service Definition) file, to visualize geographic information, to publish the ArcGIS Server Map Service into ArcGIS Server, etc.

6.4.5 ArcSDE Geodatabase

ArcSDE Geodatabase consists of an ArcSDE connection to the PostgreSQL/PostGIS. PostgreSQL/PostGIS spatial database server to which users can directly connect is also available in the ArcSDE geodatabase.

6.5 Preparing Geographic Information

6.5.1 The published services

ArcIMS Server provides GI services through ArcMap Image Service, ArcIMS Image Service and ArcIMS Feature Service. These published GI services are created from GI in the data layer. The input of ArcMap Image Service is the ArcMap Document. The AXLfile is an input for ArcIMS Image Service and ArcIMS Feature Service (See **Table 2.5**).

ArcGIS Server provides GI services through ArcGIS Server Map Services. These published GI services are also created from geographic information in the data layer. Either MSD (Map Service Definition) file or ArcMap Document is the input of ArcGIS Server Map Service.

I collected geographic information from the various projects and centers in the RR phase in Aceh province in order to utilize them for the system as shown in **Table 6.1**. 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, geo-referenced raster images, e.g. aerial orthophotos, satellite images, scanned maps, etc. I further emphasized using all geospatial data from the “Thematic atlas of Aceh province project [97]” (see item No. 4 of **Table 6.1**), in which I took part as a cartography editor. Information from many different Indonesian national departments were compiled into the thematic atlas, and it covers almost all thematic data in the entire Aceh province.

The collected geographic information is stored in ArcSDE geodatabase and geospatial data in data layer as shown in **Figure 6.2**. How to create and publish services will be described in section 6.6.1 and 6.6.2.

Table 6.1 Selected list of collected geographic information and published services in the system

Item No	Name of geospatial data and 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 1.3**
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 [97] project	52	50	29	160	-	
5	NORAD orthophoto Aceh area imagery - Banda Aceh city area imagery - Aceh Barat district area imagery - Sigli district area imagery	39 25 14 -	36 26 10 -	1480 104 566 810	- - - -	- - - -	2
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[115][100]	20	22	337	136	1	
11	BRR housing project and its geospatial data	5	63	-	26	1	9
12	Asset mapping project and its 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 infrastructure map of Banda Aceh city compiled by BRR-GTF team	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	-	

6.5.2 The published Metadata Document

This system provides ArcIMS Metadata Service and Metadata Explorer Web application for users to search and access published services managed by ArcIMS Server and ArcGIS Server. Metadata of ArcMap Image Service, ArcIMS Image Service and ArcIMS Feature Service are compiled as metadata documents published into ArcIMS Metadata Service. Metadata of the items (except ArcIMS Images or Feature Services) consisting of the online resource relating to ArcGIS Server Map Service has also been compiled as metadata documents published into ArcIMS Metadata Service. Accessing the items' online resources is performed through ArcGIS Server REST API. Metadata of the published services are described according to ISO standard: ISO 19115:2003 [64] and FGDC (Federal Geographic Data Committee [116].

6.5.3 Geospatial information for spatial query, visualization and analysis

I have summarized and classified several items of collected geographical information used for spatial data query, visualization and analysis and listed these in **Table 6.2**. **Table 6.2** shows examples of spatial query, visualization and analysis that can be performed with the specific geospatial data in the specific location in Aceh province.

Table 6.2 Spatial data query, visualization and analysis that can be accomplished using collected GI

No	Name of geospatial data	Spatial data query, visualization (draw location, categories, quantities or charts of spatial data, or show grouped raster class) and analysis
1	Thematic atlas of Aceh province [97] project	
	a. Index, Administration boundaries and TLM, NORAD/BlOM Ortophoto and TLM and IFSAR index	- querying map index and visualizing map index
	b. Topography map	
	- Elevation contour (page 8)	- draw categories of contour type (range (m))
	- Bathymetry (page 9)	- draw categories of bathymetry depth type (range (m))
	- Slope (page 10)	- draw categories of slope type (range (%))
	- Watershed (page 11)	- draw categories of watershed name and calculating area
	c. Infrastructure Map	
	- Electricity system	- visualize main electrical substation (location, name, capacity) and main transmission network
	d. Hazard Map / Disaster-prone map	
	- Ground motion area	- draw categories of ground motion potential type
	- Landslide (page 24)	- define query of and draw landslide location
	- Flood-prone area (page 25)	- draw categories of drainage system type (condition)
	- Tsunami affected area (page 27)	- visualizing tsunami affected area
	- Erosion-prone area (page 28)	- draw categories of erosion-prone level type
	- Illegal logging area (page 29)	- draw location of illegal logging activities

	e. Conservation and Natural Resources area - Land cover area (page 30) - Forest estate area (page 31) - Land system area (page 32) - Agriculture and plantation mainstay - Aquaculture mainstay map - Lithology map - Aquifer productivities area - Salinity area (page 38) - Mineral distribution area (page 39) - Wildlife conservation (page 40) - Protected forest area (page 42) - Geology map (page 43) - Vegetation of land use (page 48) - Geothermal potential	 - draw categories of land cover type (feature code or name) - draw categories of forest estate type (code) - draw categories of land system type (code and name) - draw categories of lithology type (code or description) - draw categories of aquifer type (code and description) - draw categories of a dissolved salt content class (mmhos/cm) - draw categories of mineral type - visualizing elephant, rhino and orangutan area, - draw categories of forest type (code and description), calculating protected forest area - draw categories of rock type - draw categories of land use vegetation type (code and description) - draw location of geothermal potential
2	Aceh spatial planning project by SIM-C	- draw categories of soil type (code and description), draw categories of national or provincial strategic area, soil type (code and description),
3	Prospect area of natural resources in Aceh	- draw the prospect area of mining and plantation holders
4	BRR housing geospatial data	- define query of damage houses - define query of reconstructed houses based on several attributes (donor, year, district, sub-district and village, etc) - draw quantities of reconstructed house at specific district, villages
5	Asset mapping geospatial data	- define query of reconstructed houses based on several attributes (donor, sector, year, district, sub-district and village, etc)
6	JICA –ARRIS geospatial data for Banda Aceh [19] 1. Case study for micro land use Case study for land use plan in sub-district 2. City plan - Post-tsunami land use area - Post-tsunami vacancies area - Banda Aceh city plan concept - Land use plan - Estimated population increase (by village) 3. Disaster assessment - Maximum tsunami water height (DA-001) - Tsunami water flow (DA-001) - Damaged buildings - Damaged electricity supply, drainage	 - draw categories of land use plan type (description) - draw categories of land use type (feature code, description) post-tsunami - draw categories of suitable and unsuitable land for re-settlement post-tsunami - draw categories of city plan type (description) - draw categories of land use plan type (spatial plan) - draw quantities of missing and dead by village area, draw chart of pre-post tsunami population and estimated population (2005-2009) by village area - draw quantities of maximum tsunami water height class (range) measured at the spot damage check point - draw categories of tsunami water direction type measured spot damage check point (code, symbol) - draw categories of houses/buildings damage type (code, description) based on 100 m-grid - draw categories of electricity, drainage, telephone

	and telephone services	damage type (code, description) measured at the spot damage check point
	- Damaged roads	- draw categories of road damage type (code, description), and define query of damaged road by sub-district and village code and name.
	- Damaged bridges,	- draw location of damaged bridges
	4. Disaster management	
	- Disaster management resource plan and evacuation/relief plan from 2005 to 2009	- draw emergency or disaster risk management center location, draw shortest evacuation route for village, draw categories of road network plan type, draw categories of escape building type, draw categories of evacuation base area type.
	5. Education	
	- Tsunami damage map for elementary, Junior High, and senior high School	- draw categories of school damage type (description) or school type, or visualizing school location and name
	- Map for elementary and Junior high school plan	- draw categories of school plan type (description)
	6. Hazard and risk management	
	- Hazard potential area (earthquake (liquefaction), tsunami (inundation), flood (drainage), fire spreading, escaping activity, topographic zoning Map)	- draw quantities of earthquake, tsunami, flood, fire spreading, escape activities potentials class (range, description) by village area
	7. Health	
	- Map for health center and sub-health center plan	- draw categories of rehabilitation/reconstruction health center (plan or existing) type (code, description) by location
	8. Transportation	
	- Road classification (TR-0001)	- draw categories of road type by a definition query on village name.
	- Number of road lanes (TR-0002)	- draw categories of number of road lanes type
	- Width of roads (TR-0003)	- draw categories of width of road type (code, width rank)
	- Damage rate of city roads by district	- draw quantities of damage rate class (range (%)) by district
	9. Water supply	
	- Improved water distribution network based on water demand in 2009	- draw quantities of water supply demand class (range (m/day)) by village area or by a definition query of sub-district name - draw categories of pipe type distribution (code, range (m))

6.6 System functionalities

6.6.1 System functionalities for AGDC staff

The integrated information system consists of software components as shown in **Figure 6.4.** The system allows AGDC staff to perform the following tasks:

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 Image Service, ArcIMS Image Service, and 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 to an ArcIMS Metadata Service.
This task is performed using only ArcCatalog.

4) To develop Web mapping applications:

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.

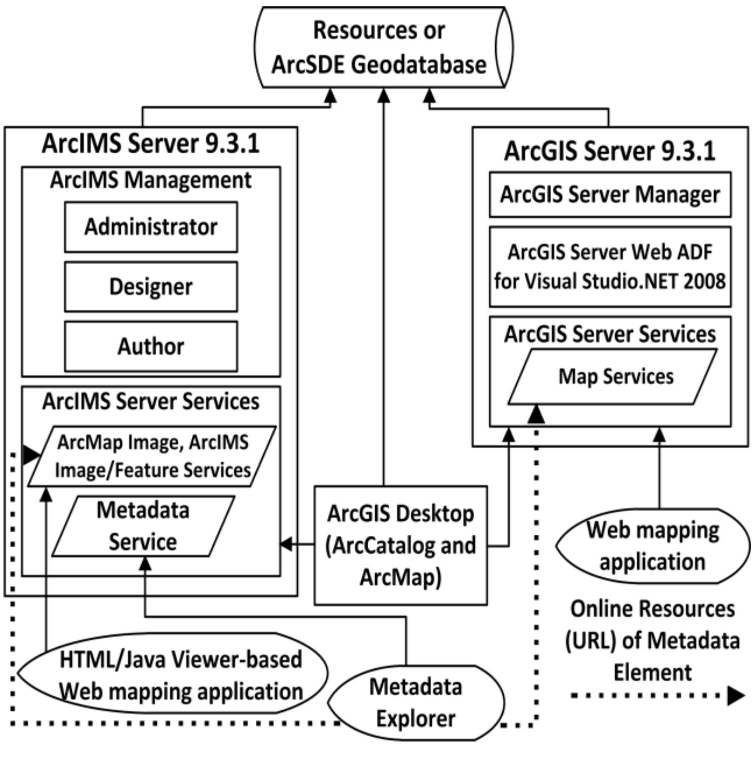


Figure 6.4 Software components, service and data access in the integrated system

The implementations of the integrated information system supporting the work of AGDC are described in detail bellow.

6.6.1.1 Storing and accessing geographic data in ArcSDE Geodatabase

The system allows AGDC staff to easily store geospatial data in ArcSDE Geodatabase and to access and manage ArcSDE Geodatabase using ArcCatalog. The system also allows users, who use non-ESRI desktop GIS software such as QGIS and uDig [26], to directly access, query and visualize the geodatabase from PostgreSQL/PostGIS. This is due to the fact that I have enabled the use of PostGIS geometry types in ArcSDE Geodatabase as mentioned in section 6.3.3.1.

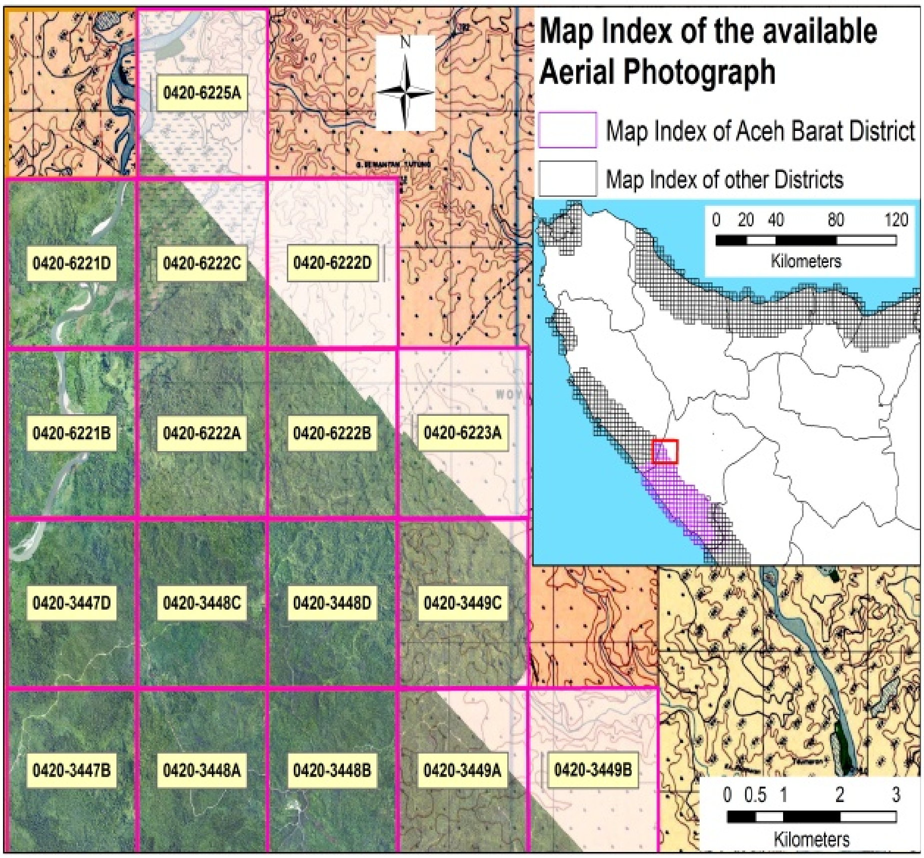


Figure 6.5 The map consisting of ArcMap Image Service of aerial photograph and ArcIMS Image Service of scanned old topographic map

6.6.1.2 Providing geographic information services

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

The system allows AGDC staff to create and publish ArcMap/ArcIMS Image Service and ArcIMS Feature Service [117]. AGDC staff can select which service is most convenient depending on the availability of GI types at AGDC. The huge MXD files available at AGDC can be directly used as an input to ArcIMS Administrator for creating an ArcMap Image Service. AXL file, created using ArcIMS Author or an MXD to AXL converter [81], is used as input for creating ArcIMS Image/ Feature Service. Georeferenced raster images, such as scanned maps and maps products, can be published as ArcMap/ArcIMS Image Service. **Figure 6.5** shows tiles from several ArcMap Image Services of high-resolution aerial photographs combined with ArcIMS Image Services of scanned old topographic maps. The aerial photographs are only available in the tsunami-affected area as shown by the map index in the overview map in **Figure 6.5.**

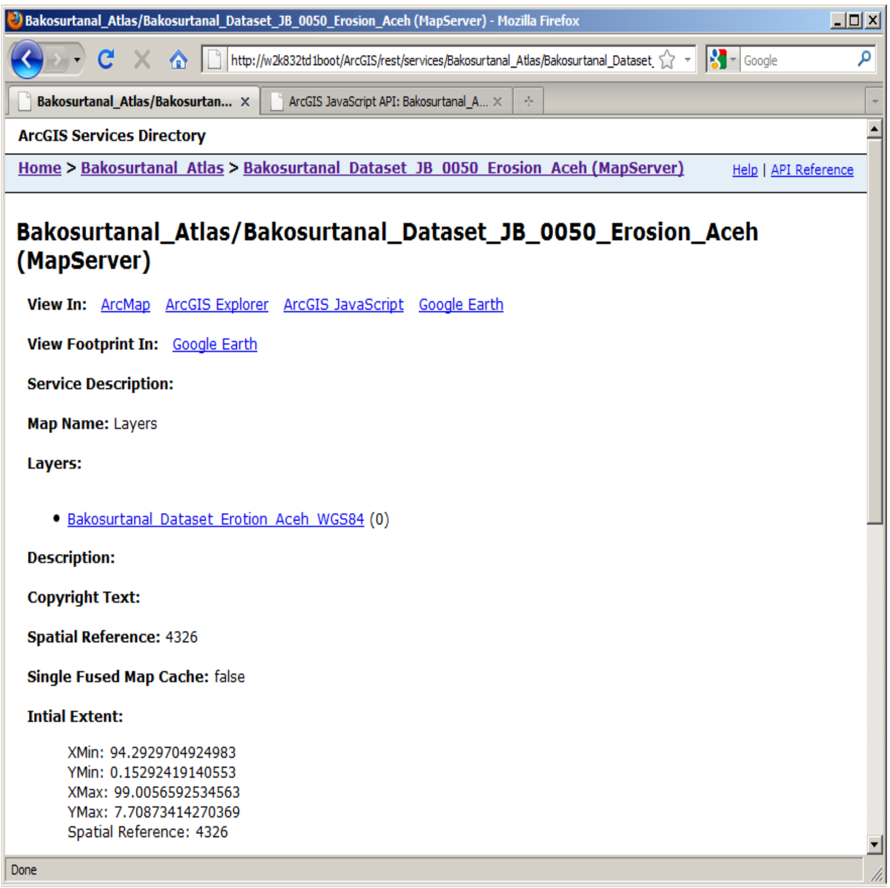


Figure 6.6 ArcGIS Server REST API for displaying ArcGIS Server Map Service

6.6.1.2.2 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. ArcMap from version 9.3.1 has the "Map Service Publishing" toolbar, which is used to (a) analyze and preview map before publishing the ArcGIS Server Map Service, (b) directly publish Map Services from ArcMap and (c) create a MSD file. ArcGIS Server Manager 9.3.1 or ArcCatalog 9.3.1 uses the MSD file as an input to publish high performance ArcGIS Server

Map Services [118]. ArcGIS Server Manager or ArcCatalog 9.3.1 also uses a MXD file to publish ArcGIS Server Map Service.

In this system, ArcGIS Server Map Service is utilized to provide additional external links (online linkages/resources or URLs) in the metadata element. I only provided online resources or URLs in the metadata document when I directly published a metadata document of a geospatial data into ArcIMS Metadata Service without creating any prior ArcMap Image Service, ArcIMS Image or Feature Service for this geospatial data. I implemented ArcGIS Server because of the following advantages:

(a) It produces high performance ArcGIS Server Map Service [118].

(b) It provides several options of application for directly displaying ArcGIS Server Map Service to users, such as ArcMap, ArcGIS Explorer, ArcGIS JavaScript, and Google Earth as shown in **Figure 6.6**.

(c) It allows AGDC staff to easily publish ArcGIS Server Map Services from ArcGIS Desktop.

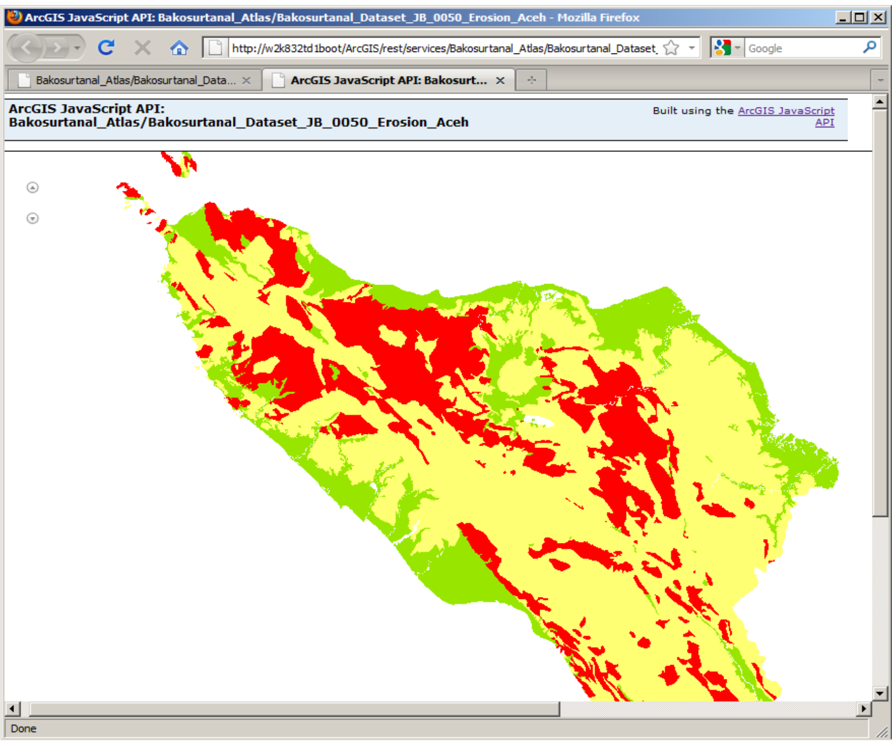


Figure 6.7 ArcGIS Server Map Service of BAKOSURTANAL's erosion map [97] of Aceh province built using ArcGIS JavaScript API

Figure 6.7 shows the published ArcGIS Server Map Service generated form a MSD file from BAKOSURTANAL's erosion map [97] in Aceh province. The map is shown in the browser using ArcGIS JavaScript API. The erosion map shows three categories of erosion area in Aceh province: common erosion (red), local erosion (yellow) and no erosion (green)

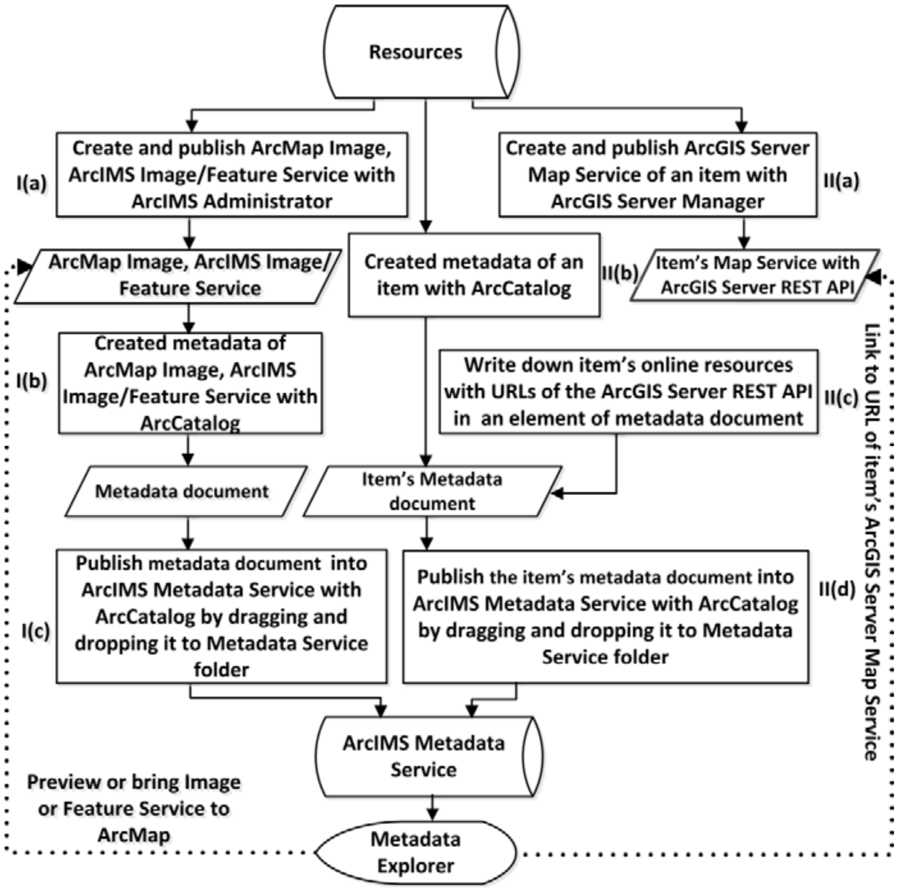


Figure 6.8 Two ways to create and publish metadata documents

6.6.1.3 Creating and publishing metadata documents

In order to allow a user to directly bring geographic information retrieved from Metadata Explorer; this integrated system provides two ways of creating and publishing the metadata of various geographic information. The first way (way I) has 3 steps: I(a), I(b), and I(c) as shown in **Figure 6.8**. As a 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 as shown in **Figure 6.9**, 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 **Figure 6.8**. Way II is only used when publishing any item's metadata (except the metadata of 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 a result of way II, users can view a metadata document found in the Metadata Explorer in full HTML or XML mode. Then, users can access the URLs of ArcGIS Server services (REST-API) to preview geographic information with ArcGIS JavaScript on the Web browser as shown in **Figure 6.6 and Figure 6.7**. Finally, users can directly bring/add ArcGIS Server Map Services to their ArcMap, ArcGIS Explorer and Google Earth application as shown in **Figure 6.6**.

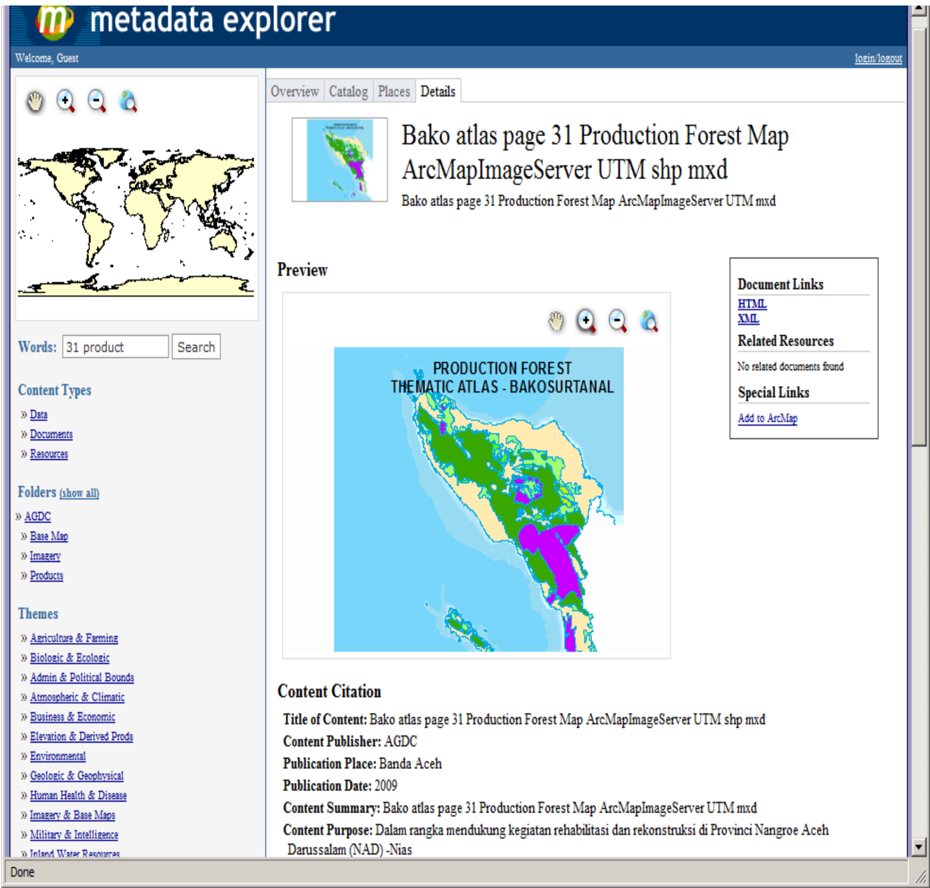


Figure 6.9 Detail Tab of metadata document on the Metadata Explorer consisting of Map Preview and a special links Add to ArcMap

Publishing Metadata using ArcCatalog

AGDC's staff or users who have full administrator access can easily create, edit and publish metadata of geographic information and map services and manage the published metadata onto the Metadata Service using ArcCatalog's "catalog tree". Creating metadata document can be done using ArcCatalog's Metadata Editor for ISO or FGDC standard. Some information of metadata element must be defined before the metadata can be published. This information is title, publisher, spatial extent, theme, and content type. After preparing the metadata, AGDC's staff or users just need either to copy and paste or drag and drop the metadata item onto the Metadata service in ArcCatalog's "catalog tree". **Figure 6.10** shows the ArcCatalog displaying catalog tree, Metadata Service (metadataserverpg) and Metadata document (Metadata items) in the specific directories.

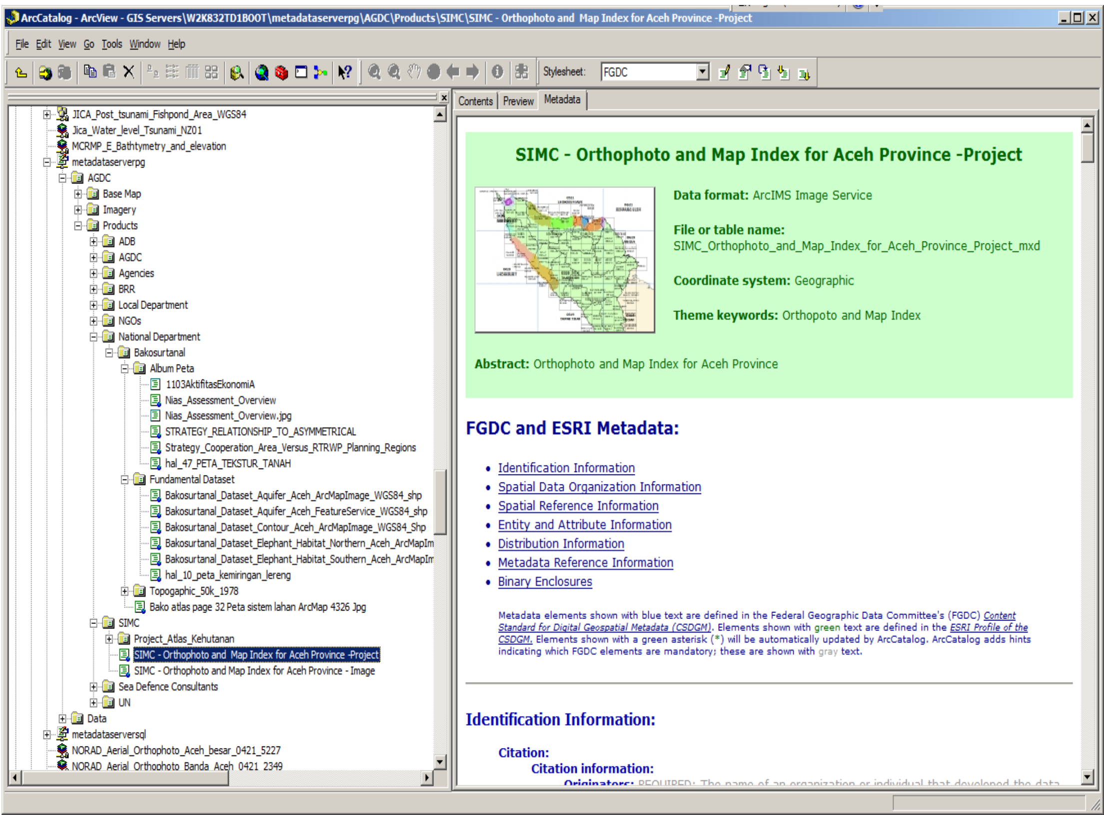


Figure 6.10 ArcCatalog's "catalog tree" showing Metadata Service called "metadataserverpg", including several of the metadata items, and a metadata document

6.6.1.4 Web mapping application

6.6.1.4.1 Creating the Web mapping application using ArcIMS Designer

ArcIMS Designer is used to generate and customize a HTML Viewer- or Java Viewer-based Web mapping application [83] with several functionalities, such as map display area, toolbar, overview map, scale bar, North arrow, and layer list on the right side. Toolbar includes zoom and pan, query, etc.

AGDC staff can easily utilize the ArcIMS Designer, choose ArcMap/ArcIMS Image and ArcIMS Feature Service, and customize several map functionalities, explained in the ESRI ArcIMS manual [32] for creating Web mapping applications as shown in **Figure 6.11**.

The HTML Viewer-based Web mapping application shown in **Figure 6.11** displays main roads and land use areas described in several colors (the red are settlement areas, the purple are homogeneous plantation areas, the yellow are rice-fields and upland areas, the green are secondary forest (or second-growth forest) areas and the dark green are primary forest (or old-growth forest) areas.

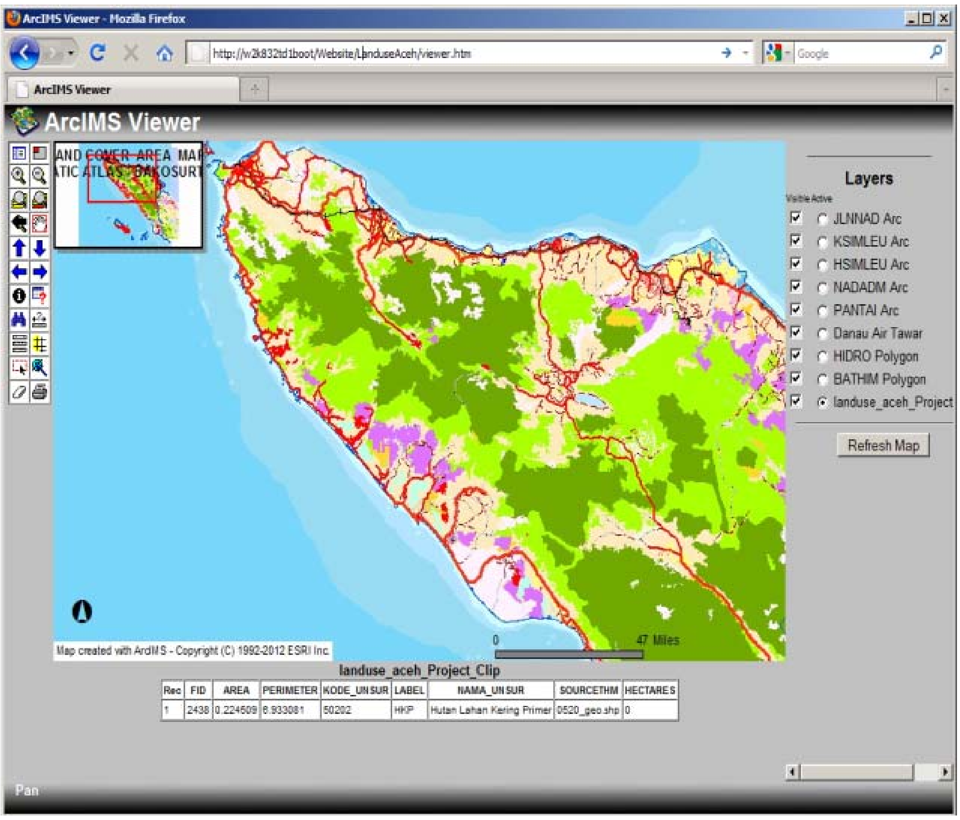


Figure 6.11 The HTML Viewer-based Web mapping application generated using ArcIMS Designer

6.6.1.4.2 Developing a Web mapping application using ArcGIS Server Manager

I have implemented both ArcGIS Server Web Application Manager 9.3.1 and Web ADF [38] 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 **Figure 6.12**, choose ArcGIS Server Map Services, and ArcMap/ArcIMS Image and ArcIMS Feature Service, and customize several map functionalities for creating the ASP.NET based ESRI Web mapping application. The process of developing the Web mapping application [84] can be done without writing any code. However, when utilizing Visual Studio.NET 2008 shown in **Figure 6.13**, AGDC staff needs to have some .NET coding ability.

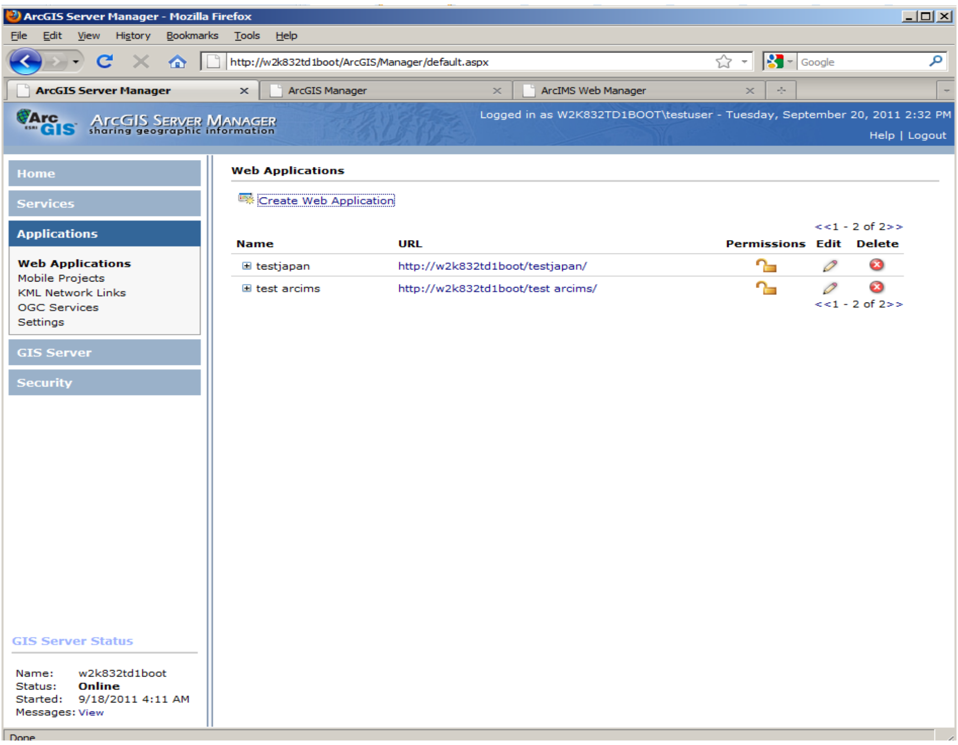


Figure 6.12 ArcGIS Server web manager wizard interface for creating Web mapping application

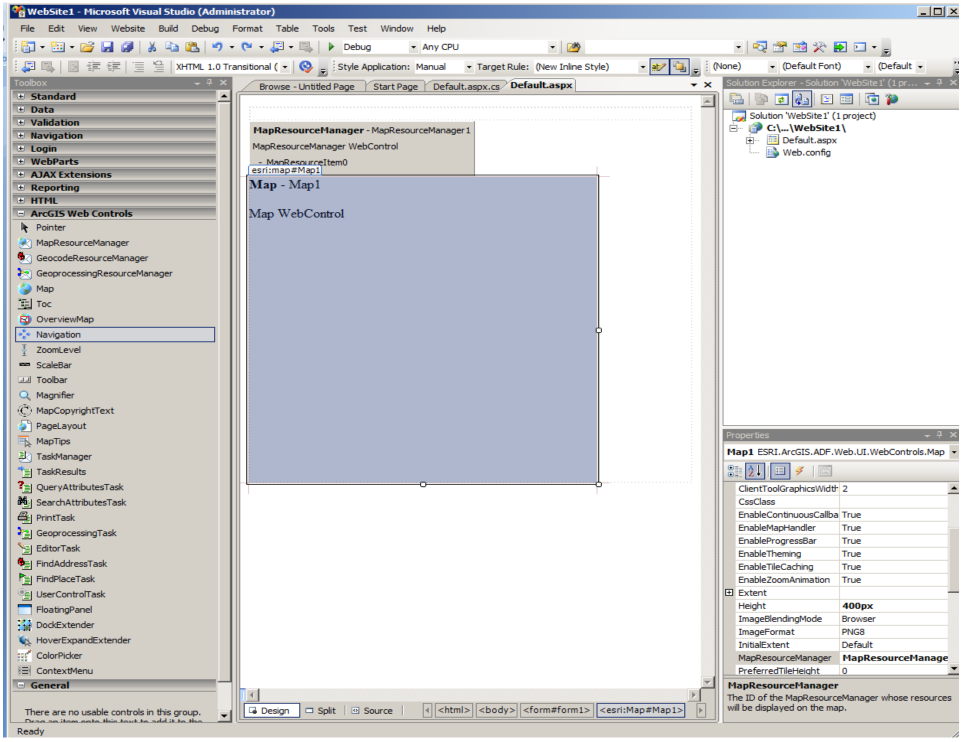


Figure 6.13 ArcGIS integration Web control in Visual Studio .NET 2008

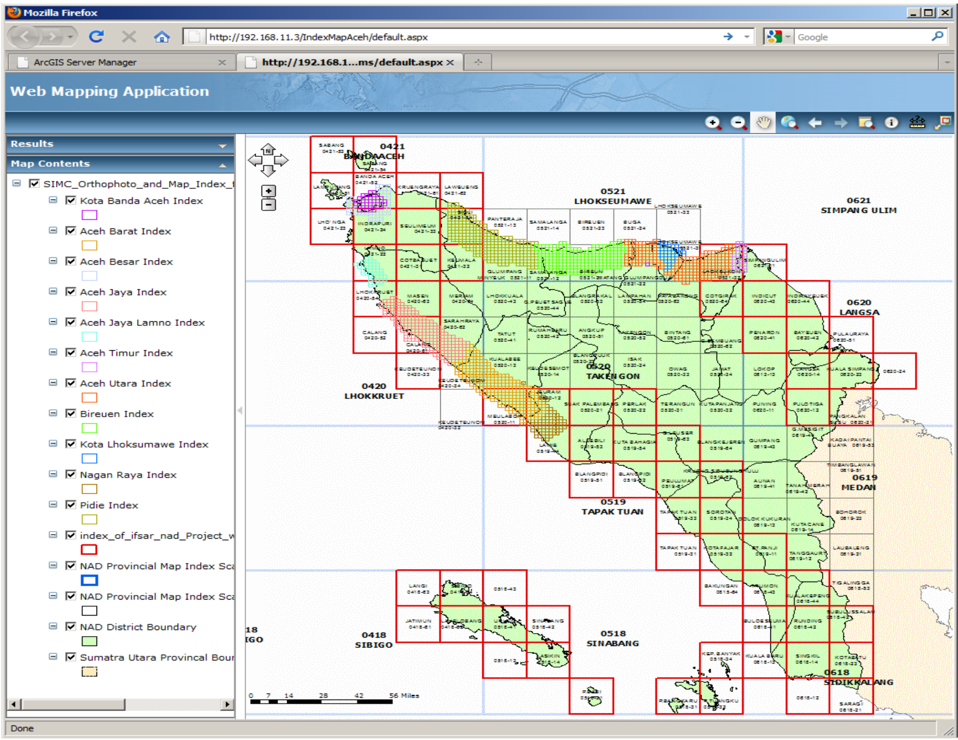


Figure 6.14 The Web mapping application generated using the ArcGIS Server Web Application Manager

Figure 6.14 shows the Web mapping application generated using the ArcGIS Server Web Application Manager. It utilized ArcGIS Server Map Services of all the map indexes that are available in Aceh province.

6.6.2 System facilities for decision makers and end users

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

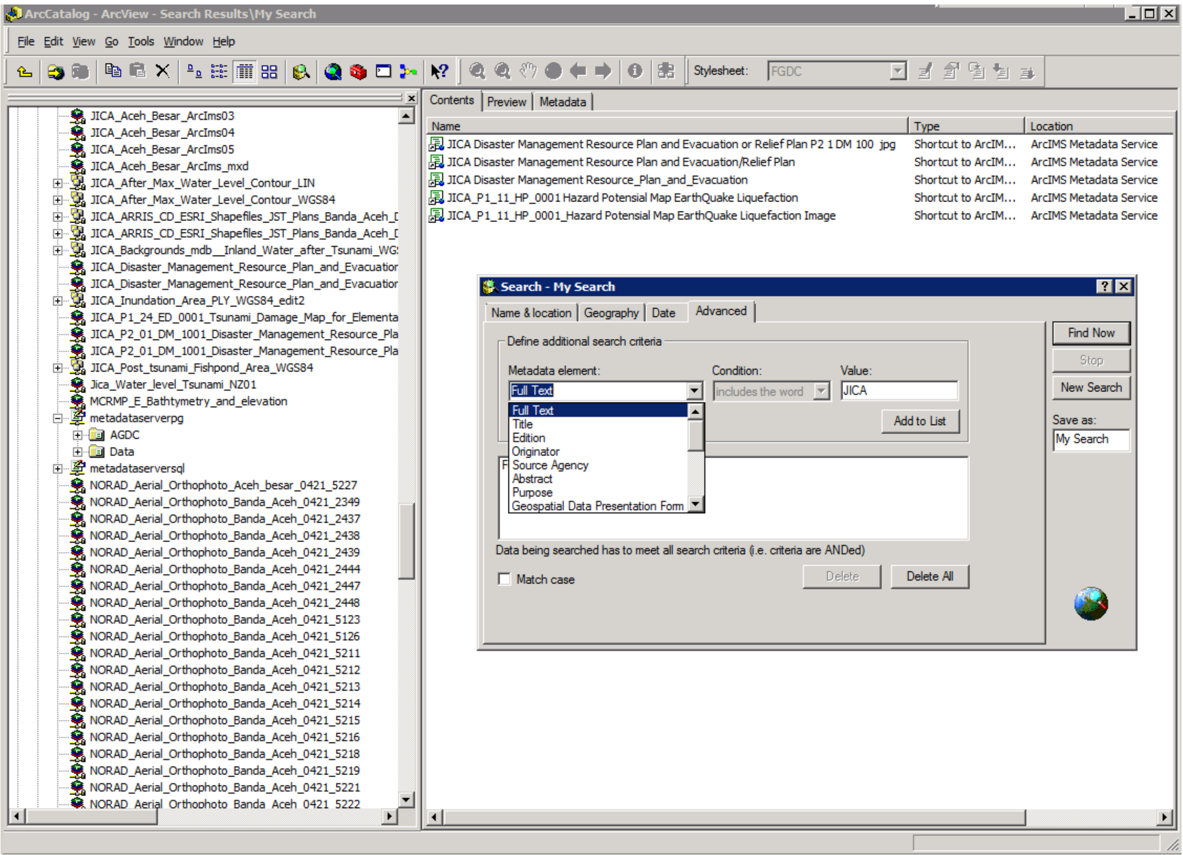


Figure 6.15 Searching Metadata document and its content using ArcCatalog

6.6.2.1 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 [49]. After adding and establishing a connection to ArcIMS Server in ArcCatalog, a user can first search for geographic information shown in **Figure 6.15** and then directly utilize ArcMap/ArcIMS Image Service or ArcIMS Feature Services from the result as shown **Figure 6.16** by dragging and dropping from ArcCatalog Catalog Tree to ArcMap.

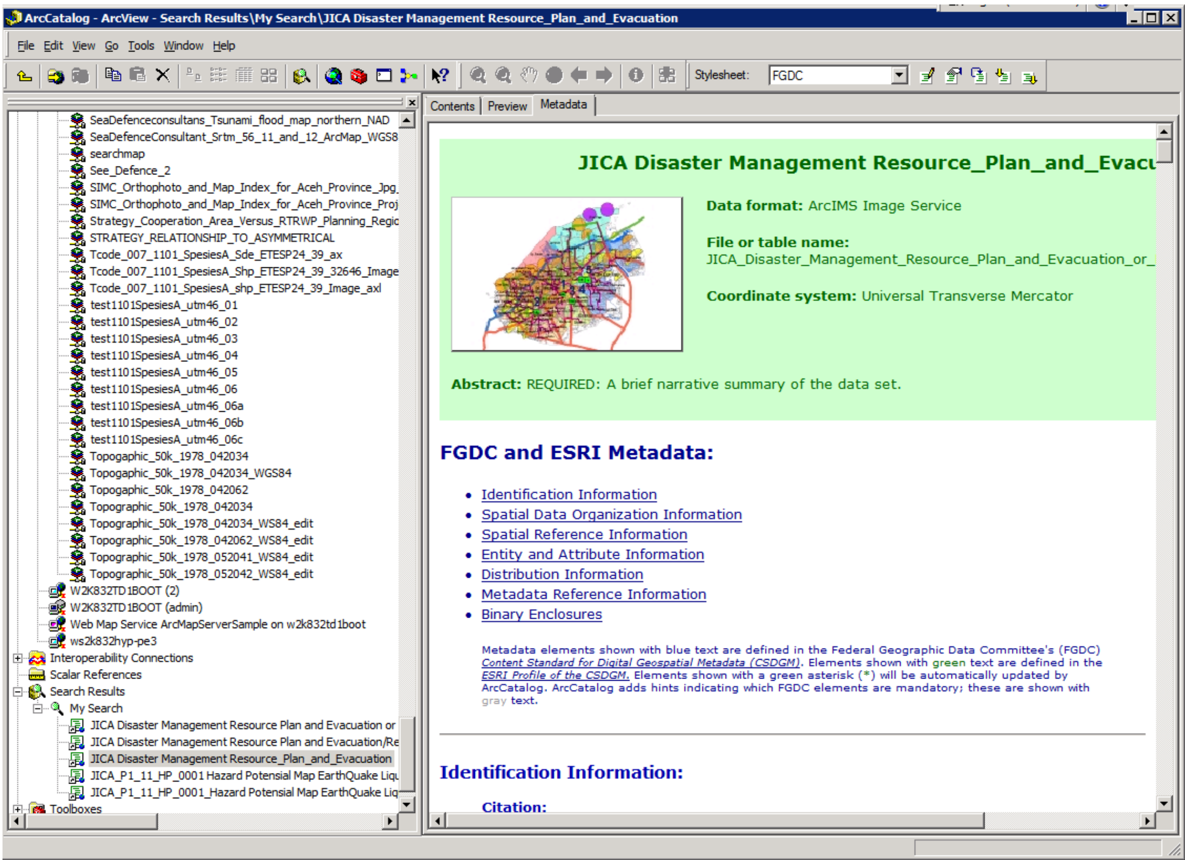


Figure 6.16 Result of searching metadata document

6.6.2.2 Finding geographic information in Metadata Explorer

Metadata Explorer shown in **Figure 6.17** is used to search and browse the content of ArcIMS Metadata Service through a Web browser [49]. After finding the geographic information in Metadata Explorer, users can bring/add an ArcMap/ArcIMS Image Service or ArcIMS Feature Service into their ArcMap by clicking a special link called "Add to ArcMap" as shown in **Figure 6.9.**

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 **Figure 6.17**. In **Figure 6.17**, 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”.

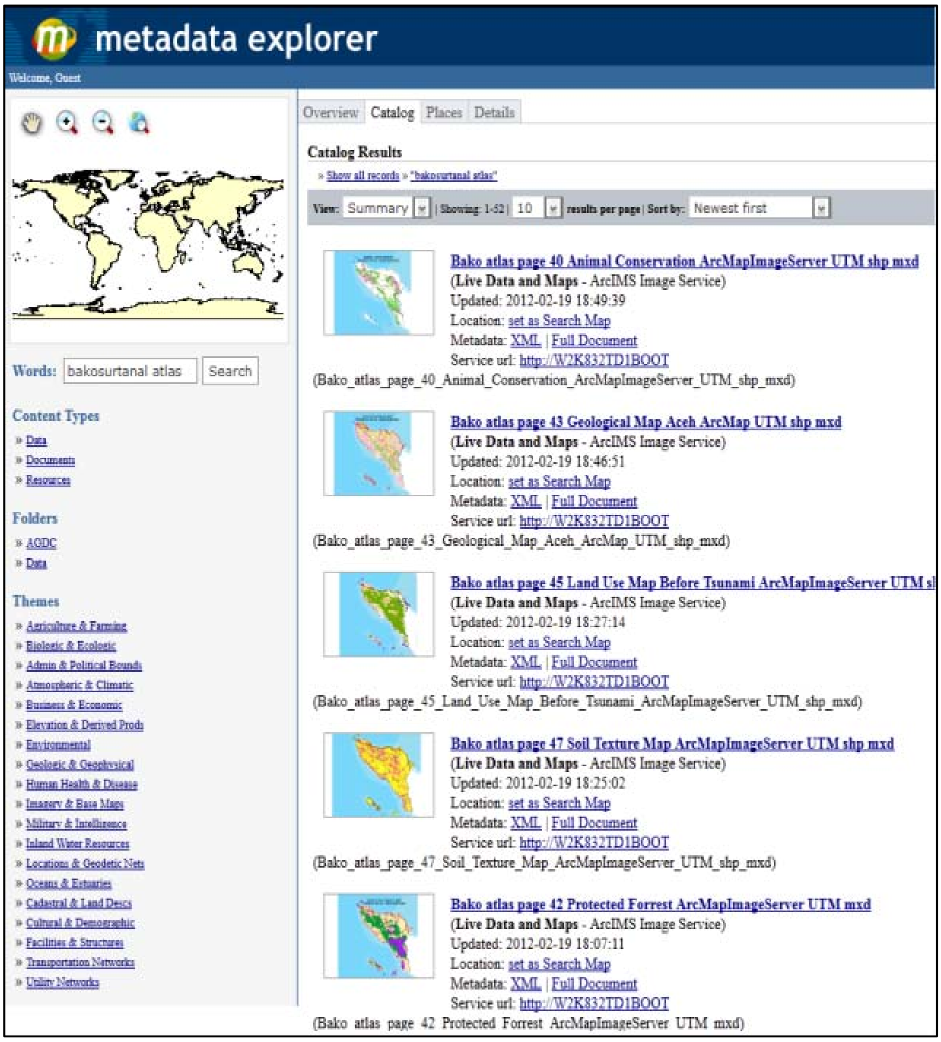


Figure 6.17 The Metadata Explorer Catalog tab shows the list of metadata document

6.6.3 System Facilities for application developers

The system allows an application developer who wants to develop custom Web mapping applications, and to utilize geographic information services available at the AGDC. If the developers utilize ESRI technology, including ArcGIS Web ADF [84] or ArcGIS API for JavaScript [89], Silverlight.NET [90] and Flex [91], 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 [84], 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[119] [120]. The Web mapping developers who utilize OpenLayers and MapServer [40] can also visualize the geodatabase directly from the PostgreSQL/PostGIS using MapServer connection for PostgreSQL in Mapfile. We have used this method in my previous study when visualizing the assets and the housing geospatial database [80].

6.7 Analysis using the integrated information system

The published geographic information (GI) services corresponding to the items in **Table 6.1** can be exploited for analysis to support Aceh geographic planning, assessment and asset management in Aceh province. Typical examples of GI services are as follows.

(a) Thematic atlas GI service (corresponding to item no. 4 in **Table 6.1**) 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 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. 11) for analysis of reconstructed houses,

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

A simple example of analysis using queries is shown in section 6.7.1. Typical examples of analysis using plural GI services are shown in section 6.7.2, 6.7.3 and 6.7.4. The system allows an application developer who wants to develop custom Web mapping applications, to utilize geographic information services available at the AGDC.

6.7.1 Analysis based on the education sector from Asset mapping GI services

In **Figure 6.18**, 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. This system gets the location coordinates as a results of the query of “ASSETNAME LIKE '%UNSYIAH%'” for Syiah Kuala University, whose asset name is UNSYIAH, and the query of “ASSETNAME LIKE '%IAIN%'” for Ar-Raniry State Islamic Institute, whose asset name is IAIN, from the ArcIMS Feature Service of the assets mapping GI.

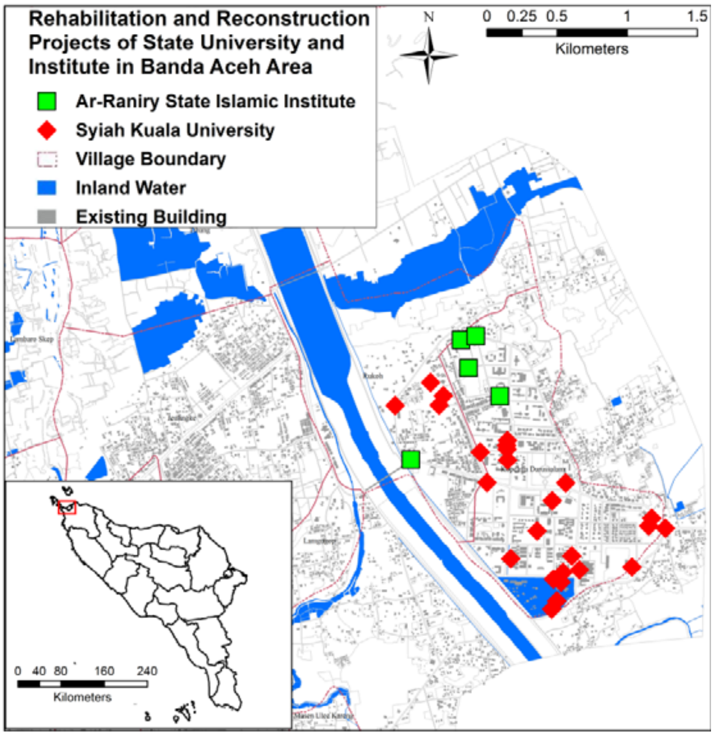


Figure 6.18 A map from ArcIMS Feature Services showing the rehabilitated or reconstructed buildings and facilities in the Syiah Kuala University and Ar-Raniry State Islamic Institute in Banda Aceh

6.7.2 Analysis of reconstructed houses in Banda Aceh

An output that overlays the layers of GI services relative to reconstructed houses is shown in **Figure 6.19**. The following facts are listed based on **Figure 6.19** and other relative outputs.

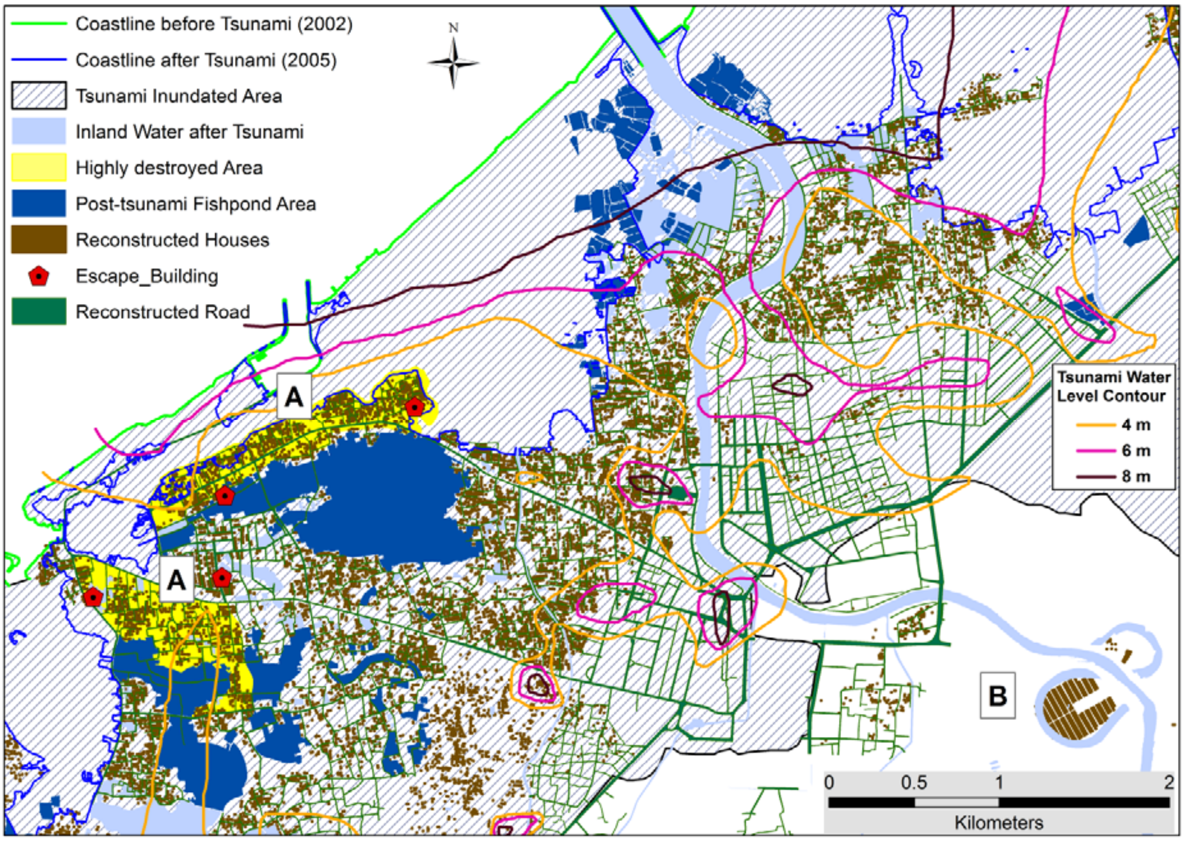


Figure 6.19 Distribution of reconstructed houses and relating issues in Banda Aceh A: Highly destroyed area, B: New domiciles

(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 the system has been used. Tsunami inundated areas and lines of tsunami water level contour are displayed using the JICA-ARRIS GI service of the system.

(2) Houses have been reconstructed not only in new relocation areas but also in some areas affected by the tsunami. The areas marked with "A" were highly damaged by the tsunami. NORAD/BLOM high-resolution images in the GI service show that almost all houses in the A areas were completely destroyed; however the images are not displayed in **Figure 6.19**, because they overlap and eclipse the other layers. The JICA-ARRIS GI service shows that a fishpond exists near to the area A. The existence of a fishpond indicates that it is necessary for persons farming fish to live near the fishpond. In the area A, houses have been reconstructed, and escape buildings have been constructed. The distribution of reconstructed houses and the location of roads are displayed using housing and asset

mapping GI service in the system. Location data for escape buildings were received from the GIS Center of Syiah Kuala University.

(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 protects the jobs of people farming fish. The planning is reasonable, and indicates a kind of sustainable development. It shows that the system has the potential to support the planning of sustainable development.

6.7.3 Analysis of reconstruction in settlement and agricultural area

The width of the tsunami-inundated area is around 7 km from the coastline as shown in **Figure 6.20**. The tsunami caused extensive damage to the region including settlement area “I” and the area of estate crop plantation marked “J” on the south west coast of Aceh province. The following facts about the reconstruction are provided by the 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 **Figure 6.20**.

(2) The location of reconstructed houses is near the location of health sector facilities. The distribution of reconstructed houses is not displayed in **Figure 6.20**, because the overlap of the distribution of houses and health sector makes the two distributions unclear. In the system, the distribution of reconstructed houses and the distribution of health sector facilities are displayed using housing the GI service and the asset mapping GI service, respectively. The locations of reconstructed houses are divided into same areas (affected by tsunami) 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 **Figure 6.20**. Land use data is displayed using thematic atlas GI service.

(3) Oil palms, coconut palms and rubber trees have been 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. The GI services from thematic atlas can display the areas of the plantation as shown in **Figure 6.20**, 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 **Figure 6.20**. 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 [121] [122], and because the trunk of the fallen palm has not been found in the images in “J” area. The images that are outside of the plantation area, i.e., the beach 2 km west of “J” area, show that all the trunks of some the fallen palms are coconut palms trunks.

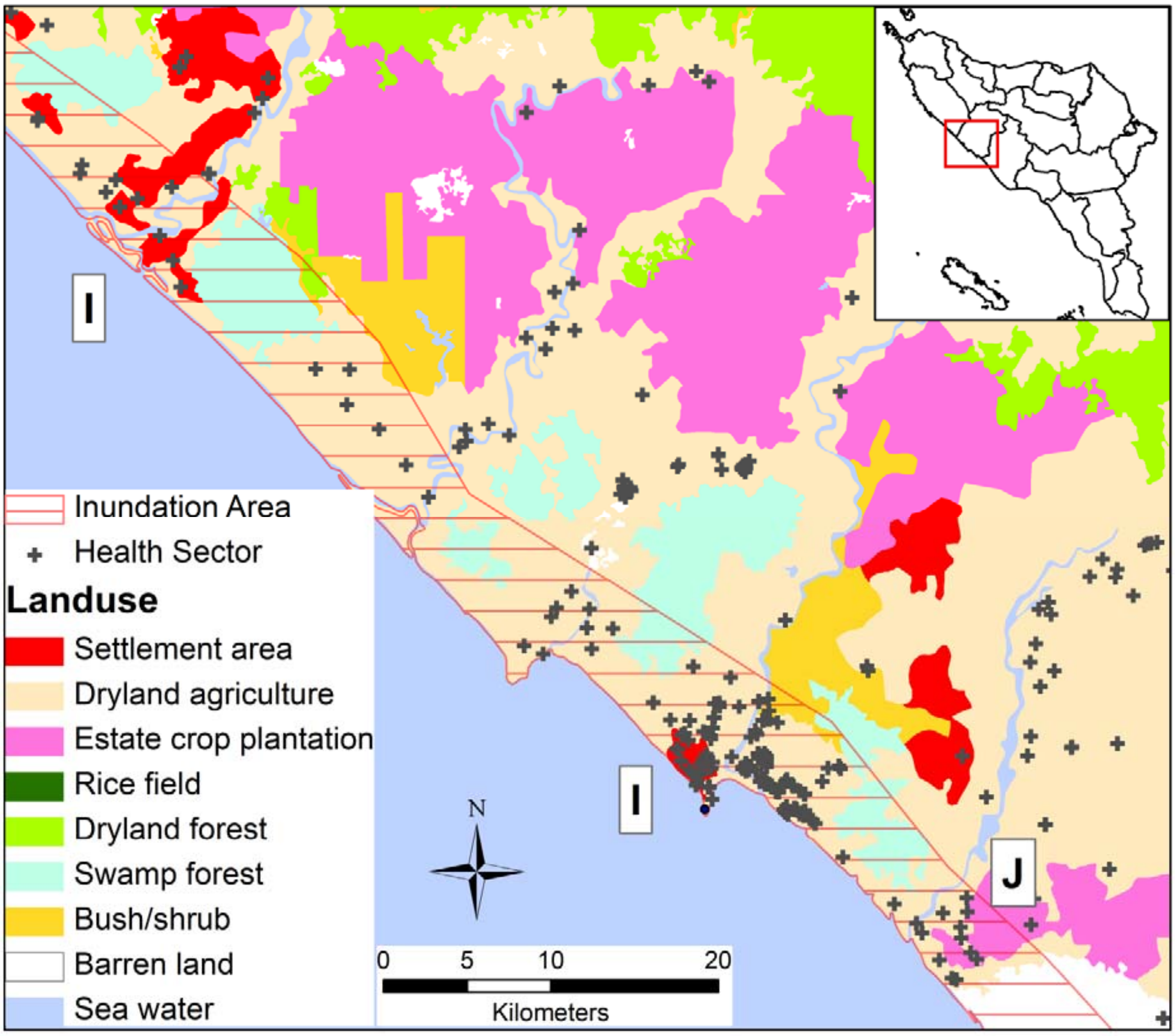


Figure 6.20 Reconstruction and related issues in agricultural regions on the south west coast I: Settlement area damaged by the tsunami; J: Area of estate crop plantation near the coast.

The planning of relocation mentioned above protects farmers' jobs in dry land agriculture areas. The system indicates a potential to support the planning of sustainable development, since the system contains land use data.

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

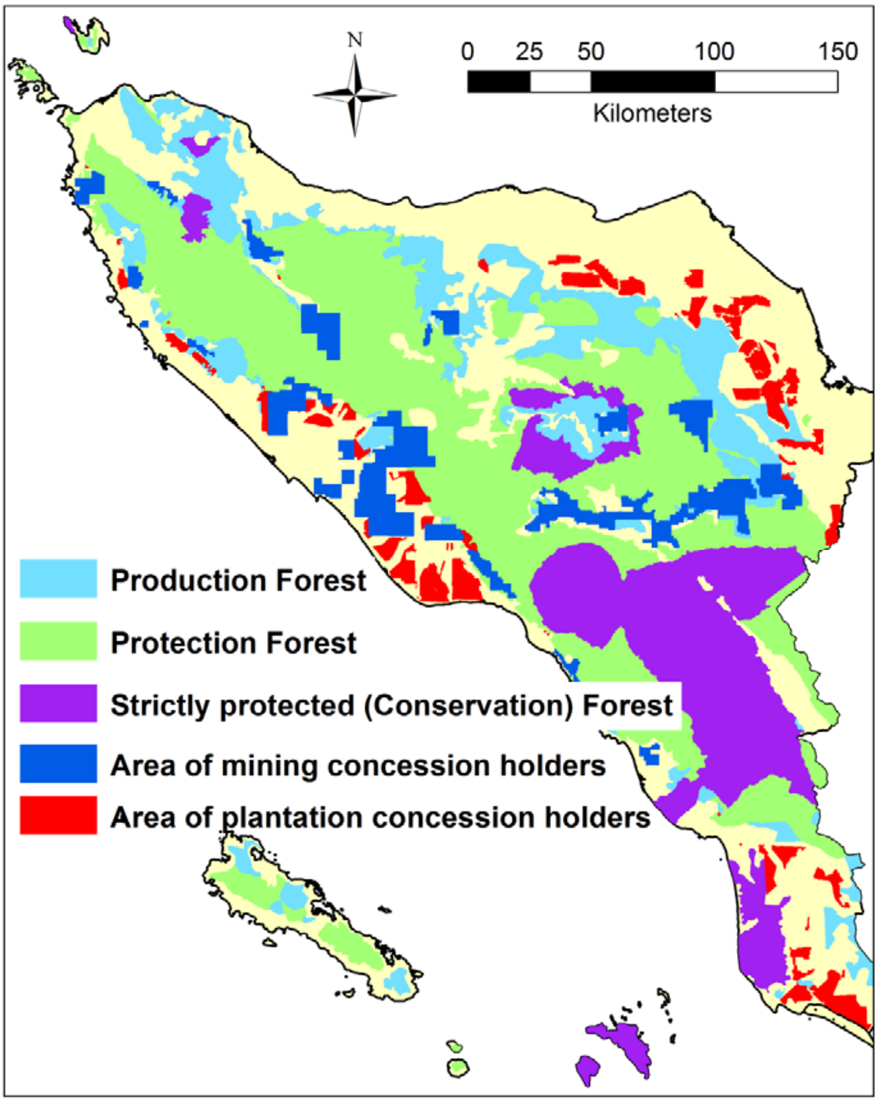


Figure 6.21 Distributions of production, protection and conservation forests and areas of mining and plantation concession holders in Aceh province

Aceh province is covered by around 3,469,450 hectares of forest, which is classified into four categories [97]: production, protection, conservation and other. Conservation forest is strictly protected forest, and includes nature reserves, national parks, wildlife sanctuaries and natural tourist objects. Distributions of production forest, protection forest and conservation forest are shown in **Figure 6.21**. Distributions of conservation forests in the system are generated with a definition query where Forest_Code LIKE ‘CF’ (CF = Conservation Forest) from ArcIMS Feature Service of forest area. The total aggregated area of conservation forests is around 838,355 hectares, whose value is calculated with the ArcMap function for the statistical data in the system. The biggest area is Mount Leuser National Park, with around 624,000 hectares.

Areas of mining concession holders in 2006 and 2007 and areas of plantation concession holders are shown in **Figure 6.21**. There are 50 areas of mining concession holders and 93 areas of plantation concession holders in Aceh province. Mining and plantation is prohibited in a conservation forest. In a protection forest, only someone holding a mining concession license can perform mining [123].

Since the 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

6.8 System evaluation made by AGDC

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

(a) The issues raised are problems that have been regularly faced by AGDC in their management of 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 does not follow the data standards defined by AGDC. This is because this collected data was 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 service.
4) The different field names in the attribute table of the spatial data also cause problems 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 made 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 six advantages, and concluded that it is suitable for implementation in Aceh province. This shows that this integrated system can efficiently and effectively support and solve AGDC's task.

The issues raised at AGDC were analyzed before I designed this system. The No. 1 issue will be resolved with the adoption of this integrated 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 geo-referencing are expected. Following this, the 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.

Chapter 7

Discussion

7.1 Overview

I discuss trade-off in versatility of a geographic information system in the concept in computer science and software engineering. I also discuss the satisfaction of SDI or GOS and the realized integrated system based on the model of an integrated environment for heterogeneous geographic information in order to show the merits of the realized system.

7.2 Trade off in versatility

As mentioned in section 2.2, in ordinary geographic information science, GISs are mostly used on a project basis, and GIS is used as a tool for geographic analysis. In this situation, a GIS is a GIS application for a specific project, and is a dedicated GIS application for the specific project.

However, in computer science and software engineering, importance is placed on the versatility of software or information systems. Adoption of an “integrated environment for heterogeneous geographic information” enhances the versatility of GIS as mentioned in section 6.3 in the following areas.

1) Versatility in providing geographic information in various data format

   Effective selection of map services is performed using map service’s acceptability of resources’ data formats, which is shown Table 2.5 in chapter 2. It is necessary to consider not only the data formats of the already collected data but also the data formats of the data that will be collected in the future as mentioned in section 6.3. Metadata service and geodatabase service are also necessary services to keep versatility.

2) Versatility in functions for a user

   To consider functions for three types of user is useful to enhance versatility in functions for a user, because necessary functions for a user is different in the types of user. To consider functions for new type of user is also useful to enhance versatility in functions, because the new type of user will appear in future.

Versatile geographic information systems or GIS applications have different target and merits or demerits. Versatile geographic information systems are suitable for geographic information center such as AGDC described in chapter 6. The system is complicated system that contains many software components, then development and maintenance of the software system becomes difficult. The target of a GIS application is a specific project. The merit of a GIS application is being a simple system that can be developed using GeoFOSS components. As mentioned in chapter 4 and 5, I also successfully developed GIS applications using GeoFOSS components.

7.3 Satisfaction of the realized integrated system

As mentioned in chapter 6, the realized integrated information system based on the integrated environment for heterogeneous geographic information prepares and provides geographic information, and supports geographic analysis. SDI also prepares and provides geographic information. Therefore, I describe satisfaction of the realized developed integrated information system with the difficulties of SDI.

SDI varies in countries, state level and local level, and is based on visions of how to make better use of scarce geographic resources as mentioned in section 3.2. However, the realized integrated information system is based on the concept of the integrated environment for heterogeneous geographic information. The purposes of the realized integrated information system are to provide various contents of geographic information for three types of user, and to support the users' geographic analysis and decision making in the planning of future development in Aceh province. I describe the following results of the implementation of the realized system to shows solutions on the 6 difficulties [20] and key factors [72] found in SDI implementation which are mentioned in section 3.2.3.

Discussion on the 6 difficulties [20]

The 1st point: There are multiple models for an SDI. In particular, the regional level of SDIs is often not simply an intermediate level from global to local, subservient to the higher administrative authority.

Result: The model for AGDC that is the target of the study is simple and clear for the following conditions:

1) AGDC only has Aceh provincial geographic information produced in the RR process in Aceh provinces.

2) Planners in the Aceh provincial government will make any plans of development in Aceh province using the integrated information system in AGDC.

The 2nd point: Adequate funding is crucial. In many SDIs this support has been lacking, in part because so many organizations are involved and all see themselves as contributors rather than taking lead responsibility.

Result: Funding of AGDC is not sufficient. However, if necessity is recognized, AGDC will have a chance to get financial support from some foundations, for example special autonomy fund that is the compensation of oil and gas from the Indonesia government.

The 3rd point: Surprisingly few professional quality assessments of the social and economic impacts of SDIs have been carried out.

Result: Usefulness of geographic information has been comprehensible throughout the tsunami recovery processes. Professional quality assessments of the social and economic impacts of the integrated information system in AGDC are remaining issues.

The 4th point: Inter- and intra-organizational conflict is inevitable in implementing an SDI. Thus successful SDIs are above all networks of people and organizations.

Result: A successful situation is expected. AGDC and related organization should show provincial solidarity because inter- and intra-organizational conflict is not good for Aceh province.

The 5th point: Since no single organization can build an SDI, the success of all SDIs is totally dependent on the quality and effectiveness of the partnerships on which they are founded.

Result: Partnerships with stakeholders are expected, because all of the stakeholders are limited to Aceh provincial people.

The 6th point: If SDI has been the big idea of the last 15 years, the landscape is now more complicated: the Open Source movement has produced a different, bottom-up model of creating content on a collaborative basis which is very different to the largely top-down, public sector-driven SDI model.

Result: The realized geographic information system based on the model of an integrated environment for heterogeneous geographic information is a solution to the 6th point for the following reasons.

1) The content of geographic information, which is used as the resources in the realized system, has been created by international temporary project teams as mentioned in section 1.6. The processes of creation of diverse and heterogeneous GI are based on a bottom-up model.

2) I collected the contents of GI comprehensively, and successfully developed the integrated geographic information system based on the model of integrated environment for heterogeneous geographic information as mentioned in chapter 6. This approach is based on a top-down model.

Discussion on the key factors [72]

Because the issues of SDI organization factors are not included in the 6 difficulties, I will discuss on the SDI organization factors: the availability of spatial data and metadata, the integration and inter-flow of datasets from different parties (this has important implications for the ownership and control of information), access networks, and multiple trusted data sources.

Result: "The availability of spatial data and metadata" is satisfied, because spatial data and metadata generated during the RR processes are handed-over to AGDC as mentioned in chapter 6.

Result: "The integration and inter-flow of datasets from different parties (this has important implications for the ownership and control of information)" are satisfied, because the datasets generated during the RR processes are handed-over with ownership to AGDC as mentioned in chapter 6, and because the integrated information system can make integration of datasets simpler and more effective than existing system in AGDC.

Result: “Access network” is available. Users can access AGDC’s Web site through Internet.

Result: “multiple trusted data sources” are satisfied in most data sources, because many important data sources were produced by international or Indonesian professionals, and because all of data sources used in RR projects coordinated by BRR have been validated by SIM-C and GTF.

Therefore, SDI organization factors are satisfied in the case of the integrated system.

Discussion on GOS portal

I also discuss GOS portal and the realized system as follows. GOS portal provides not only their own GI but also GI from other providers obtained through the internet. The realized integrated information system can contain all of necessary geographic information, therefore the main functions used in GOS portal is unnecessary in the realized system.

7.4 Extensibility of the integrated environment

The model of integrated environment offers the extensibility in system architecture of the integrated environment. When improvement of the environment is necessary, the model can be used in designing of new map services and new functions for new or existing type of users based on system requirements. Creation and publishing new map services are not difficult, because they are performed with ordinary method. If the functionality of the new map service is satisfied, it will be successfully completed. If the functionality of the new map service is not satisfied, then devise additional function.

When additional function and new function or a new set of functions are necessary, detailed design on those functions will be performed. Those functions are realized using application developing environment, such as API (Application Programming Interface), SOA (Service Oriented Architecture), etc.

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

Architecture designed with the model of integrated environment for heterogeneous geographic information can be realized as integrated information system for AGDC using not only ESRI GIS software but also geoFOSS. I realized the architecture using ESRI GIS software components because of the following reasons.

It is possible for professionals of software development to develop integrated information system for heterogeneous geographic information for AGDC 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 experiences 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 3.5, almost all application software handed-over to AGDC is inaccessible now. This fact indicates the current difficulties in software maintenance in AGDC.

(b) Huge MXD files in AGDC must be converted into files that can be used by the GeoFOSS based system. ArcMap MXD to MapServer converter is freely available from the ESRI's website [81]. 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.

7.6 Maintenance of realized integrated information system

Long-range maintenance of realized integrated information system is not easy, because lifetime of software component is limited. In the case of GIS software, map service is dependent on relating software component: server GIS software. When the software becomes unavailable, the map service supported by the software possibly becomes also unavailable. When the used map service is unavailable, a solution of the induced damage is as follows.

1) Find better or alternative map services and corresponding software component.

2) Select map service and corresponding software component.

3) Create actually the map service from resource (raw data) of GI, data retrieved from geo-database, and map configuration file using selected server GIS software. Publish the created map service in order to use it.

4) Evaluate the map service, and decide to adopt the map service or not.

The integrated environment keeps raw data as resources to use the data in the future. List of typical data formats of raw data used in the environment and relation of data format and map configuration file are shown in **Table 2.4**. The sustainability of the GI resource depends on the sustainability data format. The report [124] that discuses about sustainability of data formats states that during 1990s ESRI shapefile format soon become a de facto standard after it was introduced by ESRI. The shapefile is still widely deployed today. Relations between map configuration files and map services are shown in **Table 2.5**.

Chapter 8
Conclusion

The aims of the study described in this thesis are to devise an integrated environment for heterogeneous geographic information, and to realize an integrated environment to support future development in the Aceh province in Indonesia as an example. I devised a model for an integrated environment for heterogeneous geographic information, and successfully developed an integrated information system based on the model of the integrated environment. The integrated information system is a prototype for AGDC, and has shown 6 advantages recognized by AGDC staff. I also developed a number of GIS applications described in chapter 4 and 5.

I describe my following contributions based on the results mentioned above and comparison with related works.

1) My study shows that the model of the integrated environment for heterogeneous geographic information is useful to design an integrated information system, which has to provide map services containing various types of geographic data format, and has to service different types of user. The model is effective to keep versatility of an information system.
2) My study shows that use of the model is also a solution to the 6th point of the difficulties in SDI implementation, because the use of the integrated environment model makes design of the integrated information system independent on a bottom-up model for creating geographic content as mentioned in section 7.3.
3) The 6 difficulties in the SDI implementation described in section 7.3 have mostly been resolved by the integrated information system designed AGDC. The 3rd point: professional quality assessments of the social and economic impacts of the integrated information system of AGDC are remaining issues.
4) Rare resources are important in geographic information science. I comprehensively collected geographic data or information generated by temporary project teams in the tsunami recovery processes, because this data or information is rare and high quality, and tends to vanish when the project team (original GI providers) dissolves. Various data

types or data formats of the collected geographic data or information have also motivated the idea of integrated environment for heterogeneous geographic information.

I plan to work on extending of the integrated environment for heterogeneous geographic information based on model of the integrated environment to respond the requirements that emerge at AGCD in the future. I also plan to study the extension of new model with my students in Syiah Kuala University in the future.

Acknowledgements

I would like to express my deep and sincere gratitude to my academic supervisor, Professor Emeritus Hidehiro Ishizuka, for his guidance, encouragement and support throughout my long period of study at the University of Tsukuba in Japan. Without his great patience and expertise during advising on my research papers and PhD thesis, I would not be able to accomplish my doctoral program.

I would like to express my deep and sincere gratitude to my academic supervisor, Professor Tetsuji Satoh, for his valuable comments and encouragement during writing my PhD thesis.

I would like to express my sincere gratitude to members of the refereeing committee, Professor Makoto Matsumoto, Professor Shigeo Sugimoto, Professor Kousuke Shizume, and Professor Hiroyuki Kitagawa, for their valuable comments and suggestions for my PhD thesis.

I am very grateful to JASSO Scholarships, Indonesian government and Aceh provincial government for their financial support that allowed me to study and live in Japan. I am very grateful to Syiah Kuala University in Banda Aceh that gives me permissions to pursue my study in Japan.

I wish to express my deep gratitude for many kinds of helping to BRR, SIM-C, manager and technical staff of AGDC, Mr. Budi Hermansyah, BAKOSURTANAL, BRR-UNDP’s Team for AMIS project, and Indonesian and international agencies that worked in RR process, which have provided spatial data, valuable advice, and evaluation for system for this study.

I would like to express my gratitude to Professor Yuji Murayama and Assoc. Professor Shun Watanabe, Univ. of Tsukuba, who have advised and permitted me to use university site licensed ESRI software to support this study. I would like to thank Ms. Masayo Tsuchida, GIS Solutions Sales Group Education - ESRI Japan Corporation, who provided technical advices in constructing this system,

I am deeply indebted to my parents and all of brothers and sisters who provided support and motivation. I wish also to thank my parents-in-law. Finally, I devoted this PhD thesis to my beloved wife, Nani Sudarti with her great patience to take care our sons, M. Zhafir Adzani and M. Raza Adzani in Indonesia during my study in Japan.

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List of Published Papers

1. Refereed Journal Paper

○ Nizamuddin and Hidehiro Ishizuka, “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”, Journal of Japan Society of Information and Knowledge (情報知識学会誌), Vol.23, No.1, 2013 (accepted for publication).

2. Refereed International Conference Paper

○ Nizamuddin Djalaluddin and Hidehiro Ishizuka, “Interactive Web-based Application for Visualization of Spatial Data of the Four-Years Rehabilitation and Reconstruction Process of Tsunami and Earthquake in Aceh-Nias, Indonesia”, Proceedings of the 14th International Conference on Geometry and Graphics, Kyoto, Aug. 2010, Paper No.:123, 10p. (ISBN 987-4-9900967-1-7, DVD-ROM).

私：Nizamuddin の名前はパスポートや学生証に書いてあるとおり Nizamuddin だけですが、上の論文の国際会議では family name を書きなさいと言われたので、family name の代わりに父の名前：Djalaluddin を書きました。

4. Others

(イ) International Conference Paper (Not refereed)

(1) Nizamuddin, Hidehiro Ishizuka, and Muzaillin Affan, “The Implementation of Spatial Database Case Study: Spatial Data of Rehabilitation and Reconstruction Process in Aceh”, Proceeding of Aceh Development International Conference 2010, Malaysia, Mar. 2010, pp.605-614.

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