UNIVERSITY OF NAIROBI

V¥ Semantic Web Geoportal: A case study of Ontology Driven Kenya National Spatial Data Infrastructure (KNSDI) / /

By

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A Project submitted to the Department of Geospatial arid Space Technology in Partial Fulfillment of the Requirements of the Degree of:

Master of Science in Geographic Information Systems

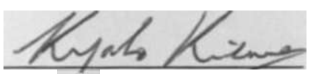
DECLARATION

This project is mv original work and has not been submitted ior a aeeree in anv University.

Signature Date

Edward Mayaka

This project has been submitted for examination with our approval as University Supervisors.



Signilfure ^ ^ Date

Dr..-Ing. J.B.K Kiema

Signature Date

D.N. Siriba

DEDICATION

To my family

Acknowledgements

I would like to express my sincere gratitude to the Government of Kenya, for the opportunity to pursue a Master of Science degree in GIS at the University of Nairobi. I am very grateful to my supervisors Dr.-lng. J.B.K. Kiema and D.N Siriba. for their guidance and valuable advice.

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To my Heavenly Father, God Almighty, who gave me the ability and opportunity to study.

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LIST OF ACRONYMS:

XML	Extensible Markup Language
RDF	Resource Description Framework
RDF-S	Resource Description Framework Schema
OWL	Ontology Web language
URI	Uniform Resource Identifier
WWW	World Wide Web
W3C	World Wide Web Consortium
SDI	Spatial Data Infrastructure
GSDI	Global Spatial Data Infrastructure
HTML	Hypertext Markup language
GIS	Geographic Information System
UDDI	Universal Description Discovery and Integration
SOAP	Simple Object Access Protocol
HTTP	Hyper Text Transfer Protocol
AI	Artificial Intelligence
KR	Knowledge Representation
DL	Description Logic
OGC	Open Geospatial Consortium
CORBA	Common Object Request Broker Architecture
TCP	Transport Control Protocol
SOA	System Oriented Architecture
SMTP	Simple Mail Transfer Protocol
ORB	Object Request Architecture
GIOP	General Inter ORB Protocol
HOP	Internet Inter ORB Protocol
DCOM	Distributed Component Object Model
XSD	XML Schema Specification

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ABSTRACT

This research has dealt with one of the geospatial data sharing problems namely, semantic interoperability. The motivation of this research is the current Kenya National Spatial Data Infrastructure (KNSDI) that is being implemented and which require open and interoperable systems.

The last few decades have shown a major shift in computing from stand-alone software systems to networked ones. There is an increasing need for organizations to perform on demand geo-processing tasks by integrating and reusing geo-information and geo-services from within and outside the organization. These services are best perfomed within a Spatial Data Infrastructure (SDI)

The current state-of-art technology for sharing geospatial information is Geospatial Web Services. Effective use of geo-information requires easy access to metadata that describes the geospatial data and services. However, current descriptions of data and services advanced by KNSDI do not provide the semantics or meaning of the data content and therefore are not sufficient to allow semantic interoperability. For KNSDI to be effective overcoming semantic interoperability problem is an issue that requires a solution.

To address this problem, the research deals with developing an ontology, entailing a common vocabulary for concepts and the relationships between them in an SDI. Using protege ontology editor the concepts are mapped as classes and their properties and facets specified. Lastly, instances which are the actual metadata in an SDI are keyed into the prototype. From the prototype it is possible to query for different properties of the metadata.

From this research it can be concluded that ontologies can be used in organizing metadata in software application to support interoperable machine to machine interaction over a network. It is recommended that the proposed KNSDI makes use of ontologies in presenting its data and metadata.

KEYWORDS Ontology, Semantics, Spatial Data Infrastructure, GIS and metadata

1 INTRODUCTION

1.1 Background to the Study

One of the major challenges in the new millennium is how to manage the world's environment and its resources. As human population grows the pressure on resources also grows with it. Human activities have also increased impacts on the climate, which has become major development challenges for most developing countries. As these problems persist, governments, industry and conservationists try to plan and manage resources in a sustainable way (GSDI, 2004). The sustainable development efforts require complex decision making which involves the consideration of environmental, social and economic effects on the use of resources. Such decision making in turn requires ready access by decision makers and stakeholders to up-to-date and reliable information.

In recent years, geo-information has become very important as the means for communicating and describing real world situations. Consequently, vast databases have been created and are being handled by many organizations to provide an inventory of natural resources and to support planning and decision making.

One of the problems in the development of Geographic Information Systems (GIS) is the volume of data that need to be gathered. Currently, large and valuable datasets are used in some organizations. Others without knowing the existence of the datasets in these organizations, or with lack of access and data sharing mechanisms, duplicate the effort to create the datasets which already exist. In addition, with the increasing data acquisition by modern remote sensing and Global Positioning Systems (GPS) based technologies, the size of GIS databases become more difficult to maintain.

During the last decade, technological developments have facilitated access to geo-information and have made it easier to manipulate, reducing the effort and skills required to exploit it effectively. As a result, the use of geo-information is expanding beyond the traditional users (government), to include new user communities such as industries, and the private sector. As there are more users that require geo-information for different applications and their needs are becoming service oriented, developers and data providers have to deal with a great diversity of user needs.

In recent years, the problem related with geo-spatial information such as duplication of efforts, non-standardized approaches, lack of awareness have been analyzed and understood by most organizations. Geo-information providers have realized that satisfying today's geo-information needs goes beyond the capacity of 'single' organizations. Therefore, these organizations should seek mechanisms that enable them to work together to share their data and resources. A major initiative towards data sharing is the Spatial Data Infrastructure (SDI). SDI has evolved since the earlier nineties, where the proposed development of national geospatial data infrastructure in Canada received acceptance from stakeholders. The first international conference on "Emerging Global Geospatial Data Infrastructure" which was held in Bonn in September 1996 brought together diverse communities to share ideas in building a Global geospatial data infrastructure (Groot and McLaughlin, 2003). And subsequent conferences, gave rise to awareness about SDI for a larger information community.

SDI has been defined by different bodies and researchers at different times. The United States Federal Geographic Data Community (FGDC) defines SDI as the technologies, policies, and people necessary to promote sharing of geospatial data throughout all levels of government, the private and non-profit sectors, and the academic community (FGDC, **2006).**

According to (Groot and McLaughlin. 2003) Geospatial Data Infrastructure encompasses the networked geospatial databases and data handling facilities, the complex of institutional, organizational, technological, human, and economic resources which interacts with one another and underpin the design, implementation, and maintenance of mechanisms facilitating the sharing, access to, and responsible use of geospatial data at an affordable cost for a specific application domain or enterprise. SDI has become very important in determining the way in which spatial data are used throughout an organization, state, nation and the world.

As the information technology is changing, the concept of SDI is also evolving and adapting to the new technology to meet the changing needs. One of the technologies facilitating the growth of SDI is the internet. Since its popularization in the early 1990's the Internet has had tremendous and far-reaching impact on the accessibility of GIS data (Longley et. al., 2004).

Different countries have adopted different strategies in the development of their National Geospatial Data Infrastructure (NGDI). Naturally, different countries have gone through different experiences and achieved different levels of success. Today, it can be generalized that most developed countries have developed GDIs with varying functional capabilities. On the other hand, most developing countries are still grappling with the challenge of establishing NGDI prototypes.

Like many other developing countries that are striving to set up an NGDI, Kenya is still in the infancy stage of establishing an NSDI. The survey of Kenya, which is the national mapping authority in Kenya, is in the process of digitizing its fundamental data sets. According to a survey conducted to gauge Kenya's readness for GDI (Mulaku et al., 2007) out of 115 data sets identified in the survey, 52% of foundation data sets are suitable and 43% are unsuitable, while for framework data sets, 46% are suitable and 54% are unsuitable. According to the study it was observed that the biggest challenge to realization of KNSDI is Kenya's policy situation. The policy of geospatial information should guide the realization of GDI. However, a comparison of Kenya with other countries like South Africa and Tanzania supports the observation that Kenya's current policy lacks a single vision that is imperative in harmonizing the efforts of the public and private sectors, civil societies and communities (ibid).

1.2 Statement of the Problem

Effective communication and smooth interaction between different sources of geodata require a method of sharing and integrating information from different sources. However, interoperability in sharing of geospatial data is a major challenge. Interoperability aims at the development of mechanisms to resolve any incompatibility and heterogeneity and to ensure access to data from multiple sources. The dynamic interaction of different applications requires not only the technical support for the exchange of data, but the preservation of the underlying semantics as well. However, although, the technical aspect of data exchange is developed due to advances in information technology, issues related to the semantic aspect need further examination.

Sharing geospatial data is difficult due to diverse conceptual schemata and semantics. Indeed, different interpretations of geospatial data encoded in different databases cause heterogeneities between them. Heterogeneities between different databases can be classified according to three major categories (Bishr, 1998):

- Syntactic Heterogeneity is caused by different logical data models (e.g relational Vs object oriented) or due to different geometric representations (raster vs vector)
- Schematic Heterogeneity occurs because of different conceptual data models (e.g objects in one database considered as properties in another, different generalization hierarchies).
- Semantic Heterogeneity raises most information integration problems. It occurs because of differences in meaning, interpretation or usage of the same or related data. Semantic heterogeneity is divided into:
    - Naming heterogeneity (homonyms and synonyms), and
    - Cognitive heterogeneity: different conceptualizations e.g class definitions or geometric descriptions.

To highlight these issues let us consider a simple search for 'vegetation metadata' using Google Search engine. Figure 1 shows that the search returns 225,000 search results; it will take such a long time to go through the search results. In this case the searcher intended to find vegetation metadata. However, the first search result is a report which obviously is not metadata the searcher intended to find. The second search result returns a web page for downloading software; again it is obvious that search does not return the result expected by the searcher.

The above example has demonstrated the shortcomings of keyword based information search and retrival. More intelligent searches for example 'Which theodolite stockist nearest to the University of Nairobi that sells at the lowest price possible?' will be impossible to return the required results using the current information models in the web.

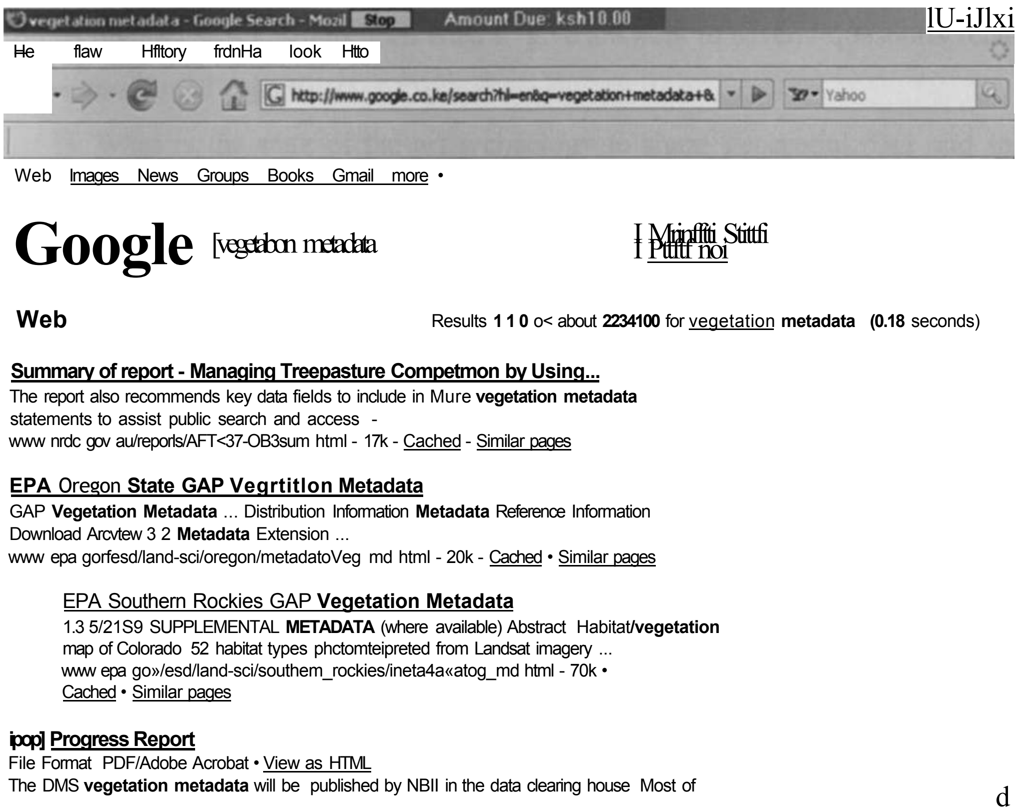

Fig 1.1: Vegetation metadata search (Google, 2007)

Ontologies have emerged over the last ten years as a core technology and fundamental data model for Knowledge Systems. They enable various advanced functions (e.g., smart search) and are the foundation of the (emerging) Semantic Web. This reseach uses Ontology Web Language (OWL) in describing metadata in an SDL

U Objectives of the Study

The main aim of this research is to solve semantic problems to facilitate the sharing of geospatial data. To achieve this aim the following objectives have been identified:

- Definition of ontologies for Geospatial Information metadata.
- Development of prototype ontologies for discovery of metadata in a Spatial Data Infrastructure

1.4 Research Questions

In this research work, it has been tried to give answers to several questions related to the above mentioned objectives:

1) What is the state of the art technology to share geospatial data and service for users?
2) What are the problems in using the state of the art technology for sharing geospatial data and service?
3) How can Geographic Information metadata be presented in a way that can be processable by software applications?
4) What are the requirements to describe metadata in order to facilitate data discovery

1.5 Research Scope

The scope of this research is ontology development for metadata in a SDI, i.e ontology editing, ontology visualization, static generation of content, content analysis (validation) and ontology analysis.The research does not address ontology markup, dynamic generation of ontologies and Application Programming Interface (API).

1.6 Organization of the Report

Chapter two gives definitions of Web Services and discusses the current state of the art technology for data sets and Web Services and the techniques involved in the deployment of the web service architecture. Chapter three focuses on the concept of ontologies. Description Logic (DL) as knowledge representation. It provides the knowledge representation languages used to develop ontologies. Then it introduces the syntax and basic constructors used in DL to build knowledge bases. Chapter four reports the implementation of the research in building the concepts of ontology in a SDI. then using Protege ontology editor the knowledge base is modeled. Chapter five presents the results of the prototype which includes queries from the prototype. Chapter six gives conclusions and recommendations.

2 WEB-GEOPORTAL DATA SETS AND SERVICE

2.1 Web Sen ice

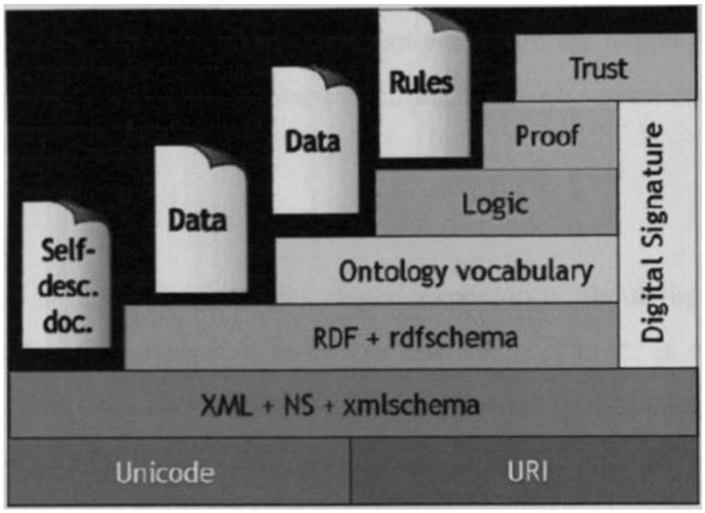

Fig 2.1: Web Service Architecture (Berners-Lee, 2000b)

The Semantic Web architecture Fig 2.1 (Berners-Lee, 2000) grounds itself on available standards for referring to entities,viz. Uniform Resource Identifier (URI), and encoding of character symbols, i.e Unicode (Unicode Consortium. 2003). XML. RDF and ontology will be discussed in subsequent sections. The top layer provides proof and trust. According to (Berners-Lee, 1999), the ability to check the validity of statements made in the (Semantic) Web is important. Therefore the creators of statements should be able to provide proof of correctness of the statements which is verifiable by a machine.

A Web service is a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format specifically Web Service Description Language (WSDL). Other systems interact with the Web service in a manner prescribed by its description using Simple Object Access Protocol (SOAP) messages, typically conveyed using Hyper Text Transfer Protocol (HTTP) with an Extensible Markup Language (XML) serialization in conjunction with other web-related standards.

A Web service is an abstract notion that must be implemented by a concrete agent. The agent is the concrete piece of software or hardware that sends and receives messages, while the service is the resource characterized by the abstract set of functionality that is provided. To illustrate this distinction, one might implement a particular Web service using one agent one day (perhaps written in one programming language), and a different agent the next day (perhaps written in a different programming language) with the same functionality. Although the agent may have changed, the Web service remains essentially the same.

2.1.1 Semantics

The semantics of a Web service is the shared expectation about the behavior of the service, in particular in response to messages that are sent to it. In effect, this is the "contract" between the requester entity and the provider entity regarding the purpose and consequences of the interaction. Although this contract represents the overall agreement between the requester entity and the provider entity on how and why their respective agents will interact, it is not necessarily written or explicitly negotiated. It may be explicit or implicit, oral or written, machine processable or human oriented, and it may be a legal agreement or an informal (non-legal) agreement. While the service description represents a contract governing the mechanics of interacting with a particular service, the semantics represents a contract governing the meaning and purpose of that interaction. The dividing line between these two is not necessarily rigid. As more semantically rich languages are used to describe the mechanics of the interaction, more of the essential information may migrate from the informal semantics to the service description. As this migration occurs, more of the work required to achieve successful interaction can be automated.

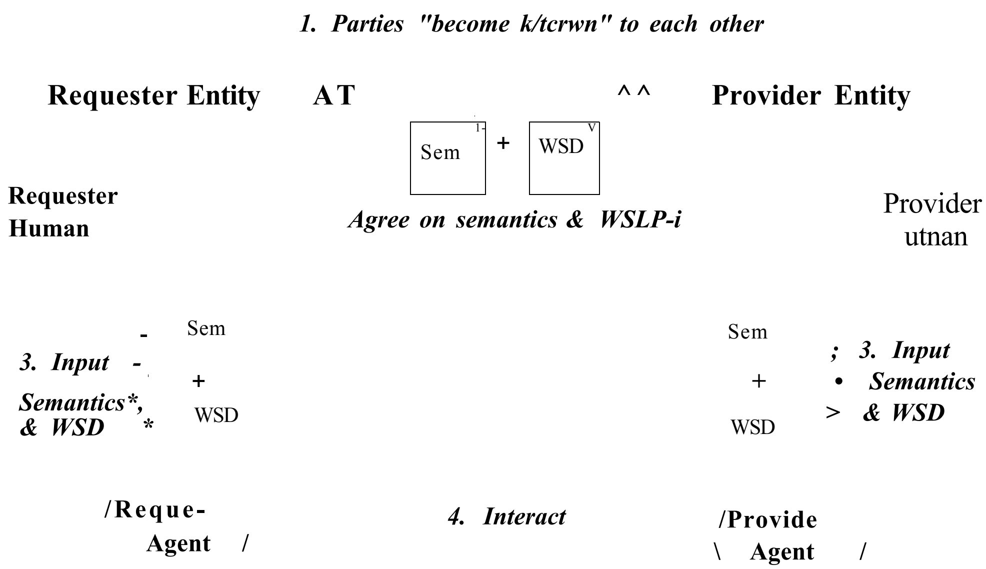

Fig 2.2: General Process of Engaging a Web Service (Wikipedia, 2007a)

There are many ways that a requester entity might engage and use a Web service. In general, the following broad steps are required (Austin et al., 2004), as illustrated in Fig 2.2:

(1) The requester and provider entities become known to each other (or at least one becomes know to the other);

(2) The requester and provider entities somehow agree on the service description and semantics that will govern the interaction between the requester and provider agents;

(3) The service description and semantics are realized by the requester and provider agents; and

(4) The requester and provider agents exchange messages, thus performing some task on behalf of the requester and provider entities, (i.e., the exchange of messages with the provider agent represents the concrete manifestation of interacting with the provider entity's Web service). Some of these steps may be automated, others may be performed manually.

2.1.2 Simple Object Access Protocol (SOAP)

SOAP makes use of an Internet application layer protocol as a transport protocol (Gudgin et al., 2003). Critics have argued that this is an abuse of such protocols, as it is not their intended purpose and therefore not a role they fulfill well. Backers of SOAP have drawn analogies to successful uses of protocols at various levels for tunneling other protocols.

Both Simple Mail Transfer Protocol (SMTP) and HTTP are valid application layer protocols used as Transport for SOAP, but HTTP has gained wider acceptance as it works well with today's Internet infrastructure; specifically, SOAP works well with network firewalls. SOAP may also be used over HTTP (since it is the same protocol as HTTP at the application level, but using an encrypted transport protocol underneath) in either simple or mutual authentication; this is the advocated WS-I method to provide web service security as stated in the Web Service (WS)-I Basic Profile. This is a major advantage over other distributed protocols like General Inter ORB Protocol (GIOP)/ Internet Inter-ORB Protocol (HOP) or Distributed Component Object Model (DCOM) which are normally filtered by firewalls. XML was chosen as the standard message format because of its widespread use by major corporations and open source development efforts. Additionally, a wide variety of freely available tools significantly ease the transition to a SOAP-based implementation (W3C, 2003).

The somewhat lengthy syntax of XML can be both a benefit and a drawback. Its format is possible for humans to read, but can be complex and can have slow processing times. For example Common Object Request Architecture (CORBA) use much shorter, binary message formats. On the other hand, hardware appliances are available to accelerate processing of XML messages. Binary XML is also being explored as a means for streamlining the throughput requirements of XML.

Advantages

- Using SOAP over HTTP allows for easier communication behind proxies and firewalls than previous remote execution technology.
- SOAP is versatile enough to allow for the use of different transport protocols. The standard stacks use HTTP as a transport protocol, but other protocols are also usable.

Weaknesses

- Because of the verbose XML format, SOAP can be considerably slower than competing middleware technologies such as CORBA. This may not be an issue when only small messages are sent. On the other side, SOAP has Message Transmission Optimization Mechanism.
- When relying on HTTP as a transport protocol and not using WS-Addressing or an Enterprise Resource Server (ESB), the roles of the interacting parties are fixed. Only one party (the client) can use the services of the other. Developers must use polling instead of notification in these common cases.
- Many SOAP implementations limit the amount of data that can be sent.
- Most uses of HTTP as a transport protocol are done in ignorance of how the operation would be modelled in HTTP. This agnosticism is by design (with analogy to how different protocols sit on top of each other in the Internet Protocol (IP) stack but the analogy is imperfect (because the application protocols used as transport protocols are not really transport protocols). Because of this there is no way to know if the method used is appropriate to the operation. This makes good analysis of the operation at the application-protocol level problematic at best with results that are at least sub-optimal (if the POST-based binding is used for an application which in HTTP would be more naturally modelled as a GET operation (Ibid).

2.13 Universal Description Discovery and Integration

Universal Description, Discovery and Integration (UDD1) is a platform-independent. XML-based registry for businesses worldwide to list themselves on the Internet. UDDI is an open industry initiative, sponsored by Organization for the Advancement of Structured Information Standards (OASIS), enabling businesses to publish service listings and discover each other and define how the services or software applications interact over the Internet. A UDDI business registration consists of three components (Ibid):

- White Pages — address, contact, and known identifiers;
- Yellow Pages — industrial categorizations based on standard taxonomies;
- Green Pages — technical information about services exposed by the business.

UDDI is one of the core Web services standards. It is designed to be interrogated by SOAP messages and to provide access to Web Services Description Language documents describing the protocol bindings and message formats required to interact with the web services listed in its directory.

The UDDI was integrated into the Web Services Interoperability (WS-I) standard as a central pillar of web services infrastructure. By the end of 2005, it was on the agenda for use by more than seventy percent of the Fortune 500 companies in either a public or private implementation, and particularly among those enterprises that seek to optimize software or service reuse. Many of these enterprises subscribe to some form of Service-Oriented Architecture (SOA), server programs or database software licensed by some of the professed founders of the UDDl.org (Ibid).

UDDI Data Types

- **husinessEntity:** The top level structure, describing a business or other entity for which information is being registered
- **businessService:** Description of a set of services which may contain one or more bindingTemplates.

- **bindingTemplate.** Information necessary to invoke specific services which may encompass bindings to one or more protocols, such as HTTP or SMTP.
- **tModel:** Technical "finger print" for a given service which may also function as namespace to identify other entities, including other tModels.

2.1.4 Web Service Description Language (WSDL)

WSDL is a service description on how to communicate using web services. The WSDL defines services as collections of network endpoints, or ports. WSDL specification provides an XML format for documents for this purpose.

The abstract definition of ports and messages is separated from their concrete use or instance, allowing the reuse of these definitions. A port is defined by associating a network address with a reusable binding, and a collection of ports define a service. Messages are abstract descriptions of the data being exchanged, and port types are abstract collections of supported operations. The concrete protocol and data format specifications for a particular port type constitutes a reusable binding, where the messages and operations are then bound to a concrete network protocol and message format. In this way. WSDL describes the public interface to the web service.

WSDL is often used in combination with SOAP and XML Schema to provide web services over the Internet. A client program connecting to a web service can read the WSDL to determine what functions are available on the server. Any special datatypes used are embedded in the WSDL file in the form of XML Schema. The client can then use SOAP to actually call one of the functions listed in the WSDL.

XLang is an extension of the WSDL such that "an XLANG service description is a WSDL service description with an extension element that describes the behavior of the service as a part of a business process" Resources or services are exposed using WSDL by both Web Services Interoperability (WS-I Basic Profile) and WSRF framework.

A WSDL document defines services as collections of network endpoints, or ports. In WSDL, the abstract definition of endpoints and messages is separated from their concrete network deployment or data format bindings. This allows the reuse of abstract definitions: messages, which are abstract descriptions of the data being exchanged, and port types which are abstract collections of operations. The concrete protocol and data format specifications for a particular port type constitute a reusable binding. A port is defined by associating a network address with a reusable binding, and a collection of ports define a service. Hence, a WSDL document uses the following elements in the definition of network services (W3C, 2003):

- **Types-** a container for data type definitions using some type system (such as **XSD).**
- **Message-** an abstract, typed definition of the data being communicated.
- **Operation-** an abstract description of an action supported by the service.
- **Port Type**-an abstract set of operations supported by one or more endpoints.
- **Binding-** a concrete protocol and data format specification for a particular port type.
- Port- a single endpoint defined as a combination of a binding and a network address.
- **Service-** a collection of related endpoints.

It is important to observe that WSDL does not introduce a new type definition language. WSDL recognizes the need for rich type systems for describing message formats, and supports the XML Schemas specification (XSD) as its canonical type system. However, since it is unreasonable to expect a single type system grammar to be used to describe all message formats present and future. WSDL allows using other type definition languages via extensibility.

In addition, WSDL defines a common binding mechanism. This is used to attach a specific protocol or data format or structure to an abstract message, operation, or endpoint. It allows the reuse of abstract definitions.

2.2 Geospatial Web Service

The focus of this research is the description of geographic web services and the data sets where these services operate on. According to W3C, a description is the act of mentioning the essential characteristics associated with a thing. A common procedure associated with the description of a thing, is its classification into certain class. The fact of belonging to certain class implies that this thing possesses the characteristics associated with that specific class. In this section the classification schemas for services provided by Open Geospatial consortium (OGC) is reviewed. The OGC provides a set of geographic information standards through the ISO 19101, which provides a set of different ways to consider the web service architecture, based on different viewpoints (ISO 19101, 2002):

- The enterprise viewpoint
- The computational viewpoint
- The information viewpoint
- The engineering viewpoint
- The technology viewpoint

This research will concentrate with the information viewpoint, which deals with the semantics of information and information processing. The information viewpoint, considers, five categories for the web services:

- Human interaction services
- Model/Information management services
- Workflow/Task services
- Processing services
- System management services

The services that deal with geospatial data sets are the processing services. These kind of services, partially modify the attributes of the data sets. The processing services can be classified into four categories:

a) Geographic processing services-Spatial

Example: coordinate conversion, coordinate transformation, coverage/vector conversion, route determination.

b) Geographic processing services-Thematic

Example: Geoparameter calculation and feature generalization.

c) **Geographic processing services-Temporal**

Example: subsetting service and sampling service.

d) Geographic processing services-Metadata

Example: statistical calculation service, geographic annotation services etc

Currently OGC prescibes geographic web services to describe themselves through the 'getcapability' operation. The result of the operation is an **XML**-encoded document called 'capability document'. The capability document contains a high level description of the service instance and its provider.

3 KNOWLEDGE REPRESENTATION

Knowledge representation is an issue that arises in both cognitive science and artificial intelligence. In cognitive science, it is concerned with how people store and process information. In artificial intelligence (AI), the primary aim is to store knowledge so that programs can process it and achieve the verisimilitude of human intelligence. AI researchers have borrowed representation theories from cognitive science. Thus there are representation techniques such as frames, rules and semantic networks which have originated from theories of human information processing. Since knowledge is used to achieve intelligent behavior, the fundamental goal of knowledge representation is to represent knowledge in a manner as to facilitate inferencing i.e. drawing conclusions from knowledge.

Some issues that arise in knowledge representation rrom an ai DersDeccv- (Wikipedia, 2007b):

- How do people represent knowledge?
- What is the nature of knowledge and how do we represent it?
- Should a representation scheme deal with a particular domain or should it be general purpose?
- How expressive is a representation scheme?
- Should the scheme be declarative or procedural?

There has been very little top-down discussion of the Knowledge Representation (KR) issues and research in this area is a well aged quiltwork. There are well known problems such as "spreading activation" (this is a problem in navigating a network of nodes), "subsumption" (this is concerned with selective inheritance; e.g. an ATV can be thought of as a specialization of a car but it inherits only particular characteristics) and "classification." For example, a tomato could be classified both as a fruit and a vegetable.

In the field of artificial intelligence, problem solving can be simplified by an appropriate choice of knowledge representation. Representing the knowledge using a given technique may enable the domain to be represented. For example Mycin, a diagnostic expert system used a rule based representation scheme. An incorrect choice would defeat the representation endeavor, the analogy is to make computations in Hindu-Arabic numerals or in Roman numerals; long division is simpler in one and harder in the other. Likewise, there is no representation that can serve all purposes or make every problem equally approachable. Knowledge Representation (KR) is most commonly used to refer to representations intended for processing by modern computers, and in particular, for representations consisting of explicit objects (the class of all elephants, or Clyde a certain individual), and of assertions or claims about them (Heflin et al.. 2002).

In the 1980s formal computer knowledge representation languages and systems arose. Major projects attempted to encode wide bodies of general knowledge. For example, the "Cyc" project went through a large encyclopedia, encoding not the information itself, but the information a reader would need in order to understand the encyclopedia: naive physics; notions of time, causality, motivation; commonplace objects and classes of objects.

Through such work, the difficulty of KR came to be better appreciated. In computational linguistics, meanwhile, much larger databases of language information were being built, and these, along with great increases in computer speed and capacity, made deeper KR more feasible.

Several programming languages have been developed that are oriented to KR. Prolog developed in 1972 (http://www.aaai.0rg/AIT0pics/bbhist.html#m0d). but popularized much later, represents propositions and basic logic, and can derive conclusions from known premises. KL-ONE (1980s) is more specifically aimed at knowledge representation itself.

In the electronic document world, languages were being developed to represent the structure of documents more explicitly, such as HTML and later XML. These facilitated information retrieval and data mining efforts, which have in recent years begun to relate to KR. The Web community is now especially interested in the Semantic Web, in which

XML-based KR languages such as RDF, Topic Maps, and others can be used to make KR information available to Web systems.

3.1 Description logics

Description logics (DL) are a family of knowledge representation languages which can be used to represent the terminological knowledge of an application domain in a structured and formally well-understood way. The name *description logic* refers, on the one hand, to concept descriptions used to describe a domain and. on the other hand, to the logic-based semantics which can be given by a translation into first-order predicate logic. Description logic was designed as an extension to frames and semantic networks, which were not equipped with formal logic-based semantics.

Description logic was given its current name in the 1980s. Previous to this it was called (chronologically): *terminological systems*, and *concept languages.* Today description logic has become a cornerstone of the Semantic Web for its use in the design of ontologies. The OWL-DL and OWL-Lite sub-languages of the W3C-endorsed Web Ontology Language (OWL) are based on description logic.

3.1.1 Basic Syntax

Syntax of description logics consists of

- A set of unary predicate symbols that are used to denote *concept names',*
- A set of binary relations that are used to denote *role names;*
- A recursive definition for defining concept terms from concept names and role names using constructors.

In description logics, concept names are regarded as atomic concepts, role names are regarded as atomic roles. In general, a concept denotes the set of individuals that belongs to it. and a role denotes a relationship between concepts.

The syntax of a member of the description logic family is characterized by its recursive definition, in which the constructors that can be used to form concept terms are stated.

Some common constructors include logical constructors in first-order logic such as *intersection* or *conjunction* of concepts, *union* or *disjunction* of concepts, *negation* or *complement* of concepts, *value restriction (universal restriction), existential restriction,* etc. Other constructors may also include restrictions on roles which are usual for binary relations, for example, inverse, transitivity, functionality, etc. Especially for intersection and union, description logics use the symbols ⊓ and ⊔ to distinguish them from the first-order logic *and* and *or.*

3.1.2 Description Logic Semantics

The semantics of description logics is defined by interpreting concepts as sets of individuals and roles as sets of pairs of individuals. Those individuals are typically assumed from a given domain. The semantics of non atomic concepts and roles is then defined in terms of atomic concepts and roles. This is done by using a recursive definition similar to the syntax.

For example, given a set as the domain, an interpretation of AL-concepts is defined first over atomic concepts and roles as follows:

- An atomic concept is interpreted as a set of individuals that is a subset of the domain.
- An atomic role is interpreted as a set of pairs of individuals from the domain, i.e., a binary relation over the domain. In this case, if an individual *x* is related to *y* via a role R, then *y* is called an ***R*-successor of *x*.**

Next, this interpretation is extended to non atomic concept and role according to the constructors. This is done in the following.

- The top concept is interpreted as the whole domain.
- The bottom concept is interpreted as the empty set.
- The interpretation of ~*C* is the set of all individuals in the domain which does *not* belong to the interpretation of C.

- Intersection of two concepts C and D is interpreted as set-intersection, i.e., the set of all individuals in the domain that belongs to both the interpretation of C and the interpretation of D.
- The value restriction DR.C is interpreted as the set of all individuals in the domain whose all /f-successor (if any) belong to the interpretation of C.
- The limited existential restriction ***3R.T*** is interpreted as the set of all individuals in the domain which has at least one /?-successor.

Thus, according to the way concepts and roles interpreted above, if P is interpreted as the set of all persons and F is interpreted as the set of all female, then the set of all persons that are not female can be expressed by the concept

P H i F

3.1.3 Reasoning

In DLs, a distinction is drawn between the so-called TBox (terminological box) and the ABox (assertional box). In general, the TBox contains sentences describing concept hierarchies (i.e., relations between concepts) while the ABox contains "ground" sentences stating where in the hierarchy individuals belong (i.e., relations between individuals and concepts). For example, the statement:

(1) Every employee is a person belongs in the TBox, while the statement:

(2) Bob is an employee belongs in the ABox. Note that the TBox/ABox distinction is not significant, in the same sense that the two "kinds" of sentences are not treated differently in first-order logic (which subsumes most DLs). When translated into first-order logic, a subsumption axiom like (1) is simply a conditional restriction to unary predicates (concepts) with only variables appearing in it. Clearly, a sentence of this form is not privileged or special over sentences in which only constants ("grounded" values) appear like.

So why was the distinction introduced? The primary reason is that the separation can be useful when describing and formulating decision-procedures for various DLs. For example, a reasoner might process the TBox and ABox separately, in part because certain key inference problems are tied to one but not the other one ('classification' is related to the TBox, 'instance checking' to the ABox). Another example is that the complexity of the TBox can greatly affect the performance of a given decision-procedure for a certain DL, independent of the ABox. Thus, it is useful to have a way to talk about that specific part of the knowledge base.

The secondary reason is that the distinction can make sense from the knowledge base modeller's perspective. It is plausible to distinguish between our conception of terms/concepts in the world (class axioms in the TBox) and particular manifestations of those terms/concepts (instance assertions in the ABox.)

3.1.4 Concepts

A concept is expected to have some correspondence with any realizations of the architecture. For example, the message concept identifies a class of object (not to be confused with Objects and Classes as are found in Object Oriented Programming languages) that we expect to be able to identify in any Web services context. The precise form of a message may be different in different realizations, but the message concept tells us what to look for in a given concrete system rather than prescribing its precise form.

Not all concepts will have a realization in terms of data objects or structures occurring in computers or communications devices; for example the person or organization refers to people and human organizations. Other concepts are more abstract still; for example, message reliability denotes a property of the message transport service — a property that cannot be touched but nonetheless is important to Web services.

Each concept is presented in a regular, stylized way consisting of a short definition, an enumeration of the relationships with other concepts, and a slightly longer explanatory description. For example, the concept of agent includes as relating concepts the fact that an agent is a computational resource, has an identifier and an owner. The description part of the agent explains in more detail why agents are important to the architecture.

3.1.5 Relationships

Relationships denote associations between concepts. Grammatically, relationships are verbs; or more accurately, predicates. A statement of a relationship typically takes the form: concept predicate concept. For example, in agent, we state that:

An agent is a computational resource

This statement makes an assertion, in this case about the nature of agents. Many such statements are descriptive, others are definitive:

A message has a message sender

Such a statement makes an assertion about valid instances of the architecture: we expect to be able to identify the message sender in any realization of the architecture. Conversely, any system for which we cannot identify the sender of a message is not conformant to the architecture. Even if a service is used anonymously, the sender has an identifier but it is not possible to associate this identifier with an actual person or organization illustrates how they relate to each other. It should be stressed however that these diagrams are primarily navigational aids; the written text is the definitive source.

3.2 Data Layer

3.2.1 XML

XML (Fig 2.1) solves a key technology requirement that appears in many places. By offering a standard, flexible and inherently extensible data format, XML significantly reduces the burden of deploying the many technologies needed to ensure the success of Web services.

The important aspects of XML. for the purposes of this Architecture, are the core syntax itself, the concepts of the XML Infoset (XML Infoset), XML Schema and XML Namespaces.

XML Infoset is not a data format per se, but a formal set of information items and their associated properties that comprise an abstract description of an XML document [XML 1.0]. The XML Infoset specification provides for a consistent and rigorous set of definitions for use in other specifications that need to refer to the information in a well-formed XML document.

Serialization of the XML Infoset definitions of information may be expressed using XML 1.0. However, this is not an inherent requirement of the architecture. The flexibility in choice of serialization format(s) allows for broader interoperability between agents in the system, suitable replacement for the textual serialization. Such a binary encoding may be more efficient and more suitable for machine-to-machine interactions.

3.2.2. Resource Description Framework (RDF)

The Resource Description Framework (RDF), (Fig 2.1), (Klyne & Carroll, 2003) tries to improve data interoperability on the Web by specializing the XML data model.

3.2.3 Data Model

In essence, RDF allows to syntactically encode labeled directed graphs using a dedicated XML syntax. In RDF, the term graph is used synonymously with the term model. Vertex types In an RDF graph several types of vertices are distinguished:

• Resource: Resources are vertices which represent object identifiers. Resources are usually represented by an URI.

• Literal: Literals are vertices which denote data values. Each literal can be associated with an XML Schema datatype.

• Property: Properties are those resources, which are used as labels of graph edges.

Anonymous resources are used extensively when RDF is used as a syntax carrier for another language. For example, the existential restriction constructor in a Description Logic can be represented by means of three statements, which are stating that some object is of type restriction and restricts a certain property (e.g. forEvent) to a certain class (e.g. Birthday). Obviously, the subject of these statements is only used to hold the statements together, therefore it is usually omitted. Anonymous resources are also used to encode non-binary relations (Klyne & Carroll, 2003).

3.2.4. RDF Schema (RDF-S)

The RDF vocabulary description language (RDF Schema [RDF-S]) (Brickley & Guha. 2003), Fig 2.1, defines a simple modeling language on top of RDF. RDF-S is intended to provide the primitives that are required to describe the vocabulary used in particular RDF models. This description is achieved by expressing set membership of objects in property and class extensions. Therefore RDF-S uses classes, subsumption relationships on both classes and properties and global domain and range restrictions for properties as modeling primitives. When compared to typical object-oriented modeling languages. RDF-S exposes a peculiar notion of object orientation:

1. RDFS treats properties as first class citizens, viz. they can exist independently of classes.
2. Global domain and range restrictions on properties are entailment rules, i.e. they assert that the subject (object) of a statement where the property occurs is a member of the classes stated in the domain (range) restriction. This departs from the usual constraint interpretation, which most object-oriented formalisms take for class attributes and associations.
3. Multiple domains and range restrictions can be defined on properties. If the domain or range of a property is not defined, the instantiation of its domain or range may occur to any resource-value pair.
4. RDFS allows cycles in its subsumption hierarchies. Cycles can be used to express the equivalence of classes or properties.
5. RDFS allows objects to instantiate multiple classes simultaneously, which is typically disallowed in object-oriented languages.
6. The RDFS language has a cyclical metamodel. The language elements itself are part of the vocabulary. For example, the resource rdfs:Class is an instance of itself and thereby always included in the extension of a class. Similarly rdfiResource is an instance of rdfs:Class, while it subsumes rdfs:Class.

3J Ontology Layer

Ontologies feature prominently in the emerging Semantic Web as a way of representing the semantics of documents and enabling the semantics to be used by web applications and intelligent agents (Heflin et al., 2002).

Ontologies are models that represent an abstraction of a domain in a formal way, (Fig 2.1), such that several parties are able to agree on the abstraction and reuse the model in their own (Web) applications. The definition of ontology is not bound to a particular formalism but to the aspect of sharing a model. However, the latter aspect requires that ontologies are represented in some formal language, such that detailed, accurate, consistent, sound and meaningful distinctions can be made (Heflin et al., 2002).

33.1. Web Ontology Language (OWL)

For example, the RDF vocabulary description language (RDF Schema) already provides a simple language for describing the vocabulary of RDF data. However, "more complex relationships between entities including: means to limit the properties of classes with respect to number and type, means to infer that items with various properties are members of a particular class, a well-defined model of property inheritance, and similar semantic extensions" (W3C, 2003) were identified to be required for a modeling language for the Semantic Web. To come forward with Ontology Layer such a language, several research projects and subsequently W3C standardization, chose Description Logics as a logical basis for an expressive ontology language. The recently proposed Web Ontology Language (OWL) can be considered as a particular Description Logic.

3.3.2 Syntax

OWL is syntactically layered on RDF. Therefore, the official syntax of OWL is the syntax of RDF. However, OWL extends RDF with additional vocabulary that can be interpreted as OWL ontologies when used to form particular RDF graphs.

3.33 **Language Species**

OWL provides three increasingly expressive sublanguages designed for use by specific communities of implementers and users (W3C, 2004)

OWL Lite

OWL-Lite is the syntactically simplest sub-language. It is intended to be used in situations where only a simple class hierarchy and simple constraints are needed. For example, while it supports cardinality constraints, it only permits cardinality values of 0 or 1.

OWL DL

Supports those users who want the maximum expressiveness while retaining computational completeness (all conclusions are guranteed to be computable) and decidability (all computations will finish in finite time)

OWL Full

Is meant for users who want maximum expressiveness and the syntactic freedom of RDF with no computational guarantees. For example in OWL Full a class can be treated simultaneously as a collection of insivisuals and as an individual in its own right.

4.0 METHODOLOGY

4.1 Test Case

This research focuses on semantic description of geospatial web portal based on the meaning of concepts developed in ontologies. It aims at providing user access to this semantic web through geospatial portals to facilitate data sharing, and solving semantic problems. To achieve this, an ontology is developed for describing Geospatial Information Metadata in the proposed Kenya National Spatial Data Infrastructure (KNSDI).

4.2 Tools used

4.2.1 Protege core and OWL Plug-in

Protege (Asuncion et al., 2003) is the latest version of the protege line of tools, created by the Stanford Medical Informatics (SMI) group at Stanford University. The aim of protege is to simplify the knowledge acquisition process for expert system. Protege-2000 is oriented to the task of ontology and knowledge-base development. It is freely available for downloading under the Mozilla open source license. The version used is 3.3.1.

Protege-2000 is a java-based standalone application to be installed and run in a local computer. The core of its application is the ontology editor. It has an extensible architecture for creating and easily integrating new extensions.

4.2.2 Reasoning through Description Logic Implementation Croup (DIG)

Protege can be connected through a reasoner through the DIG interface, which is a standardized XML interface to Description Logic (DL) (Horridge et al., 2004). Protege has several commands it can send to DIG interface.

4.23 Pellet 1.5.0 Plug-in

Pellet started as a proof of concept system to help meet the W3C's implementation experience requirements for the Web Ontology Language (OWL). It has since become a practical and popular tool for working with OWL. Pellet has been the first reasoner to support all of OWL-DL.

43 Development of Ontology

Using methontology method for building ontologies (Asuncion et al., 2003), an ontology for Kenya National Spatial Data Infrastructure (KNSDI) metadata was developed according to the following step:

4.3.1 Building the Glossary of Terms

A glossary of terms that includes all relevant terms of the domain of KNSDI was identified as shown in Table **4.1:**

Table 4.1: **Glossary of Terms in KNSDI (Wordnet, 2007)**

iName	Acronyms	Description	Type
Core Data		A data set that is necessary for optimal use of many other GIS application, i.e that provides a sufficient spatial reference for most geo-located data	Concept
Coverages		Feature that acts as a function to return one or more feature attribute values for any direct position within its spatio-temporal domain	Concept
Elevation		Distance of something above a reference point (such as sealevel)	Concept
Fundamental Data		A dataset for which several government agencies, regional groups and/or industry groups require a comparable national coverage in order to achieve their corporate objectives and responsibilities	Concept
Geodetic Control		A set of points on the surface of the Earth, the position of which have been accurately determined using surveying and computing techniques that take into account the Earth's curvature, topography, gravity field and atmosphere	Concept
Geodetic Coordinates		Coordinate system in which position is specified by geodetic latitude, geodetic longitude and (in the three dimensional case)ellipsoidal height	Attribute
Geographic Information	Gl	Information concerning phenomena implicitly associated with a location relative to the Earth	Concept
Geographic Information System	GIS	A computer system capable of assembling, storing, manipulating, and displaying geographically referenced information	Concept
geology		A science that deals with the history of the earth as recorded in rocks	Concept
Global Positioning System	GPS	a network of satellites that interact with special receivers to position the receiver relative to the	Concept

		Earth.	
hydrology		The branch of geology that studies water on the earth and in the atmosphere: its distribution and uses and conservation	Concept
Identification Information			Attribute
International Livestock Research Institute	ILRI	Dataset provider	Concept
Map Projection		Coordinate conversion from geodetic coordinate to a plane	Attribute
Metadata		A formalized set of descriptive properties which is shared by a community to include guidance on expected structures, definitions, repeatability, and conditionality of elements	Concept
Metereology		The study of weather in some location	Concept
Orthoimagery		Aerial photography from which distortion and ground relief has been removed so that ground features are displayed in their true planimetric positions	Concept
Polygon		A plane figure bounded by a number of straight sides	Relation
Population		A collection of people or organisms of a particular species living in a given geographic area	Concept
Temporal		Of or relating to time	Concept
Transportation		A facility consisting of the means and equipment necessary for the movement of passengers or goods	Concept
Utilities		The service (electric power, water, transportation) provided to the public	Concept
Wetlands		A low area where the land is saturated with water	Concept
Food and Agricultural Association	FAO	Dataset provider	Concept

4.3.2 Building Concept Taxonomies

At this stage concept taxonomies to define the concept hierarchy was done using a top-down strategy in which the most abstract concepts were identified first, and then specialized into more specific concepts (Fig 4.1 and 4.2) :

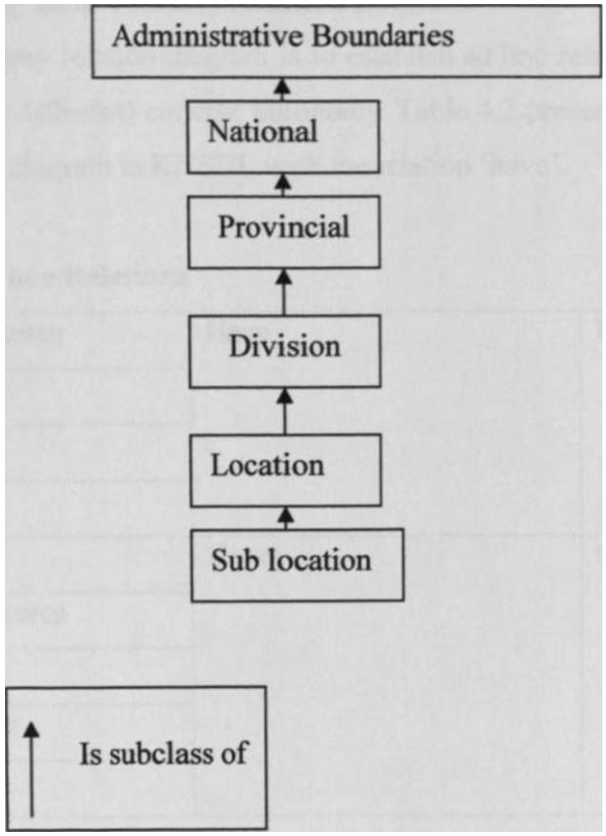

Fig 4.1: Taxonomy for Administrative Boundaries

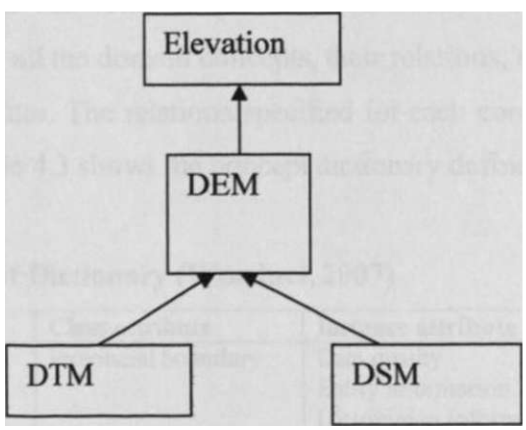

Fig 4.2: Taxonomy of Elevation

4.3.3 Building ad hoc Binary Relation Diagrams

The goal of binary relation diagram is to establish ad hoc relationships between concepts of the same (or different) concept taxonomy. Table 4.2 presents a fragment of the ad hoc binary relation diagram in K.NSDI, with the relation "have'.

Table 4.2: Ad hoc Relations

Artificial structures	Have	Elevation
Geology		
Utilities		
Wetlands		
Wetlands	Have	Orthoimagery
Artificial structures		
Utilities		
Natural hazards		

4.3.4 Building Concept Dictionary

After generating the ad hoc binary relations, the properties and relations that describe each concept of the taxonomy in a concept dictionary were then specified. A concept dictionary contains all the domain concepts, their relations, their instances, and their class and instance attributes. The relations specified for each concept are those whose domain is the concept. Table **4.3** shows the concept dictionary defined for KNSDI

Table 4.3: Concept Dictionary (Wordnet, 2007)

Concept name	Class attribute	Instance attribute	Relations
i Administrative boundaries	Provincial boundary	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
International Livestock Research Institute	Data provider name	Originator Online linkage Contact person Address	Same data provider as

		Contact voice	
Survey of Kenya	Data provider name	Originator Online linkage Contact person Address Contact voice	Same data provider as
Food and Agricultural Organization	Data provider name	Originator Online linkage Contact person Address Contact voice	Same data provider as
Agriculture	Type of Crop	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Artificial structures	Type of building	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Elevation	DEM	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Geology	Type of Soil	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Hydrology	Type of hydrology	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Natural hazards	Type of hazard	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Orthoimagery	Type of imagery	Data quality Entity information	Same data quality as Same entity information

		Distribution information Spatial reference	as Same distribution information as Same spatial reference as
Political boundaries	Type of boundary	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Population	Type of organism	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Transportation	Type of transport	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Utilities	Type of utility	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as
Wetlands	Type of wetland	Data quality Entity information Distribution information Spatial reference	Same data quality as Same entity information as Same distribution information as Same spatial reference as

4.3.5 **Defining ad hoc Binary Relations in Detail**

Ad hoc binary relations included in the concept dictionary are described in detail; a binary relation table is made. For each ad hoc binary relation, its name, the names of the source and target concepts, its cardinality, its inverse relation and its mathematical properties are indicated. Table 4.4 shows ad hoc binary relations in KNSDI ontology

Table 4.4: Detailed Binary Relations

Relation name	Source concept	Source cardinality (Max)	Target Concept	Mathematical Properties	Inverse relations
Same data as	Administrative boundaries	N	Data	Transitive Symmetrical	Is same data as
Same data as	Agriculture	N	Data	Transitive Symmetrical	Is same data as
Same data as	Artificial structures	N	Data	Transitive Symmetrical	Is same data as
Same data as	Elevation	N	Data	Transitive Symmetrical	Is same data as
Same data as	Geology	N	Data	Transitive Symmetrical	Is same data as
Same data as	Hydrology	N	Data	Transitive Symmetrical	Is same data as
Same data as	Metereorology	N	Data	Transitive Symmetrical	Is same data as
Same data as	Natural hazards	N	Data	Transitive Symmetrical	Is same data as
Same data as	Orthoimagery	N	Data	Transitive Symmetrical	Is same data as
Same data as	Political boundaries	N	Data	Transitive Symmetrical	Is same data as
Same data as	Population	N	Data	Transitive Symmetrical	Is same data as
Same data as	Transportation	N	Data	Transitive Symmetrical	Is same data as
Same data as	Utilities	N	Data	Transitive Symmetrical	Is same data as
Same data as	Wetlands	N	Data	Transitive Symmetrical	Is same data as

4.3.6 Detailed Instance Attribute

All the instance attributes are described in detail as shown in table 4.5:

Table 4.5: Detailed Instance Attribute

Instance attribute name	Concept name	Value type	Measurement unit	Precision	Range or values	Cardinality
Accuracy		Float	Meter	0.01	0-10	Multiple
Source/Lineage		String		-		Multiple
1 Completeness		String		-		Multiple
Logical Consistency		String		-		Multiple
Coordinate system		String		-		Multiple
Datum		String		-		Multiple
Map projection		String		-		Multiple
Custodian		String		-		Multiple

-

Name	-w	String		-		Multiple
Description		String		-		Multiple
Geographic coverage		String		-		Multiple
Software Environment		String		-		Multiple
Status		String		-		Multiple
Keywords		String		-		Multiple
Formats		String		-		Multiple
Description		String		-		Multiple
Type		String		-		Multiple
Measurement units		String		-		Multiple
Domains		String		-		Multiple
Distributor		String		-		Multiple
Format		String		-		Multiple
Access procedure		String		-		Multiple

'Administrative boundaries. Agriculture, Artificial Structures, Elevation, Geology, Hydrology, Metereorology, Natural hazards, Orthoimagery, Political boundaries. Population, Transportation, Utilities, Wetlands

4.3.7 Definition of Class Attribute in Detail

Class attribute were defines as Table 4.6

Table 4.6: Detailed Class attributes

Attribute name	Defined at concept	Value type	Measurement unit	Precision	Cardinality
Data provider name	Central Bureau of Statistics	String	-	-	(1,1)
Data provider name	Department of Remote Sensing and Resource Survey	String	-	-	(1,1)
Data provider name	Geomap	String	-	-	(U)
Data provider name	International Livestock Research Institute	String	-	-	(1,1)
Data provider name	Metereorological Department of Kenya	String	-	-	(1,1)
Data provider name	Ministry of Agriculture	String	-	-	(1,1)
Data provider name	Ministry of Local Government	String	-	-	
Data provider name	Ministry of Transport	String	-	-	(1,1)
Data provider name	Ministry of Water Resources	String	-	-	(1,1)
Data provider name	Oakar Services	String	-	-	(1,1)
Data provider name	Ramani Kenya	String	-	-	(LI)
Data provider name	Regional Centre for Mapping of Resource for Development	String	-	-	(1,1)
Data provider name	Survey of Kenya	String	-	-	(1,1)
Data provider name	United Nations	String	—		(1,1)

4.3.8 Definition of Constants

Constants were defined as in Table 4.7

Table 4.7: Constant table

Name	Value Type	Value	Measurement unit
WGS 84	Float	a=6378136	Meter
WGS 84	Float	1/^=298.25	-

4.3.9 Definition of Formal Axioms

Table 4.8 Formal Axioms

Axiom name	Disjoint
Description	Class extension of a class description has no members in common with the class extension of another class description
Concepts	
Referred attributes	-
Ad hoc binary relations	-
Variables	-

'Administrative boundaries, Agriculture, Artificial Structures, Elevation, Geology, Hydrology, Metereorology, Natural hazards, Orthoimagery. Political boundaries, Population, Transportation, Utilities, Wetlands

4.3.10 Definition of Instances

Metadata for Kenya was collected from the Food and Agricultural Organization (FAO) Geoportal. These metadata has been largely published by FAO and International Livestock Research Institute (ILRI), Japan International Cooperation Agency and United Nations Environmental Programme (UNEP). The Survey of Kenya, which is the national mapping agency, has not published any metadata. The metadata got was unstructured, it was therefore structured by putting it in Microsoft Excel form. Detailed list of the metadata is in Appendix B.

4.4 Modeling of the ontology using Protege 2000

Using Protege 2000 ontology editor the defined metadata ontology in 4.2 was modeled through the following steps:

- Definition of the class and class hierarchy
- Definition of the properties (slots) of the classes
- Definition of the facets of the slots i.e slot cardinality, slot value type, domain and range of slots etc.
- Creation of instances

5 RESULTS AND ANALYSIS

5.1 Definition of Classes and Class Hierarchy

The ontology document produced by the prototype which is an OWL file serialized in RDF/XML syntax is shown in Appendix A.

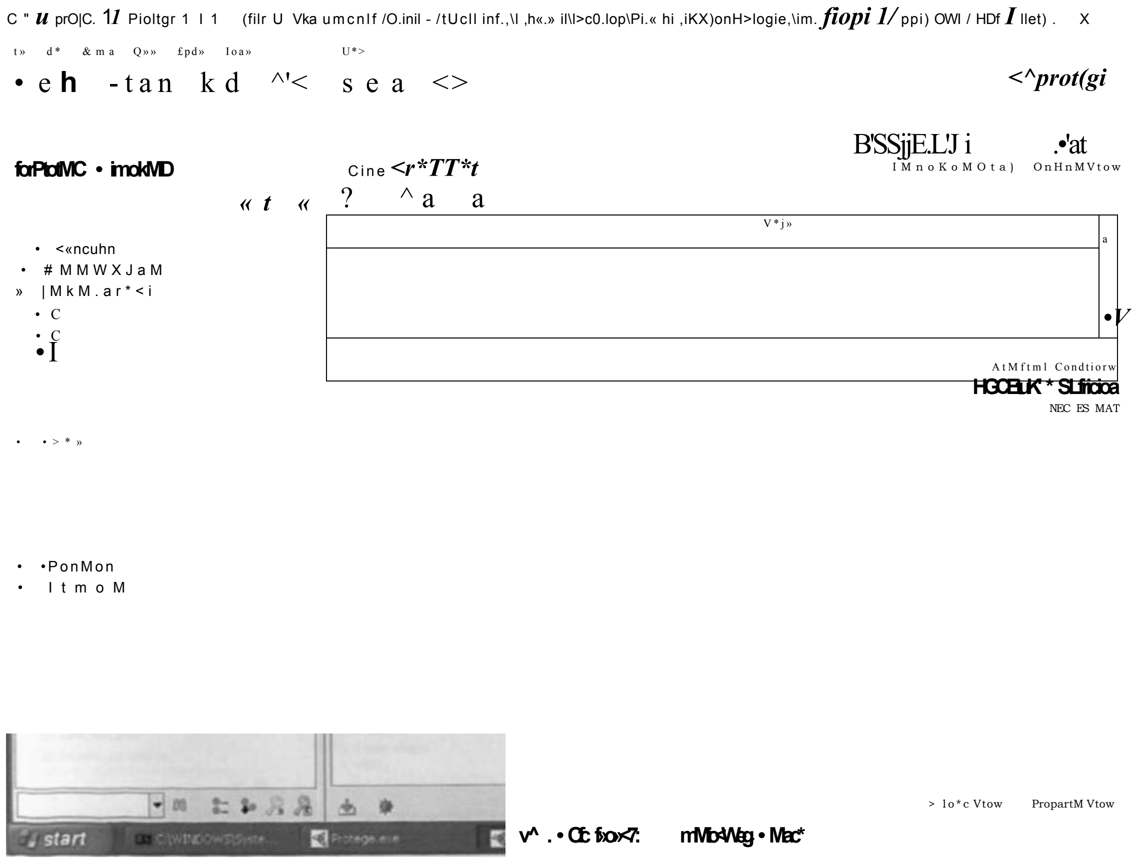

Fig 5.1: Class diagram

OWL Classes

OWL classes are interpreted as sets that contain individuals. They are described using formal (Mathematical) descriptions that state precisely the requirement for membership of the Class. Fig 5.1 shows an example of a class diagram that visualizes the fundamental datasets in an SDL The class window in the Class Relationship Pane is used to display classes and allows rearranging the class hierarchy. The classes are represented as circles, stating their names. The pointed arrow shows that the class has sub-classes under it. Due to the specialization relationships that are encoded in the hierarchy, the set of objects in a sub-class is a subset of its superclass. The set of subclasses of a class is incomplete when their union does not contain all objects of the superclass i.e the union of subclasses of road, air water and railway should contain all objects of the class transportation.

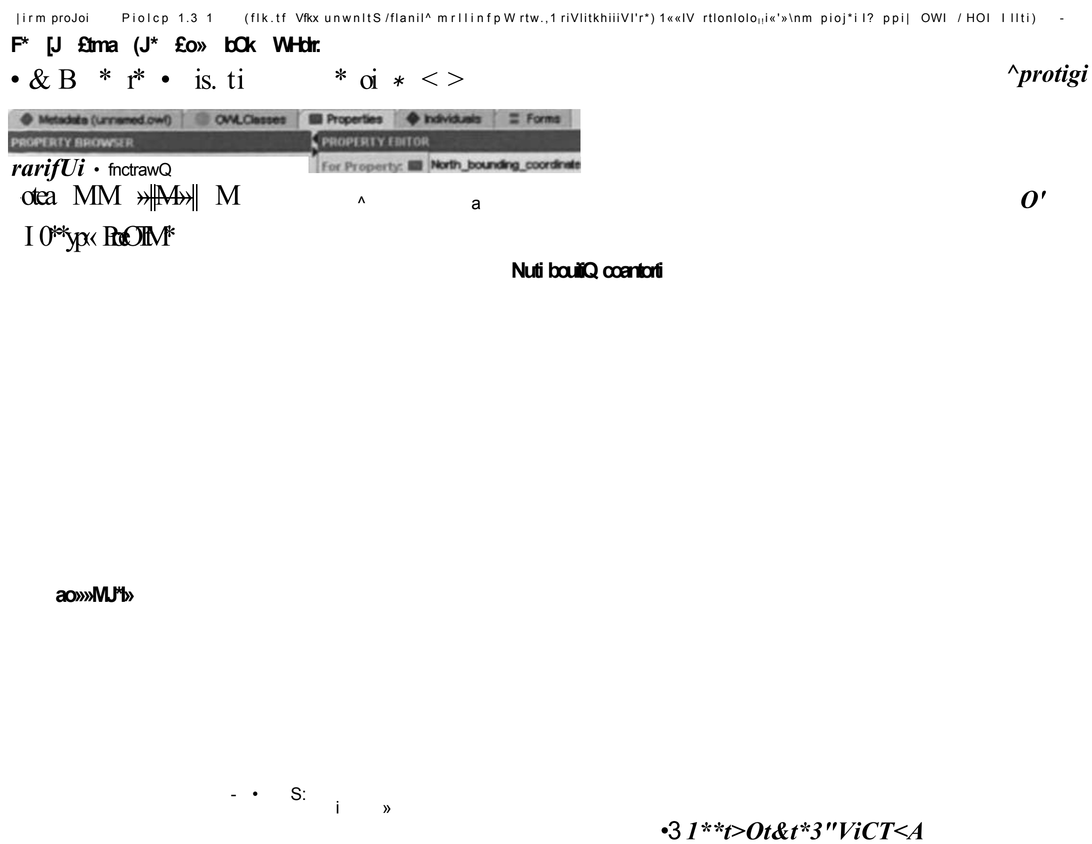

Fig 5.2: Properties Diagram

OWL Properties

OWL properties represent relationships between two individuals. There are two main types of properties, Object properties and Datatype properties. Object properties link an individual to an individual. Datatype properties link an individual to an XML Schema datatype value. Fig 5.2 shows an example of properties diagram. The left pane headed properties browser shows the properties identified in an SDI with the North Bounding Coordinate highlighted.

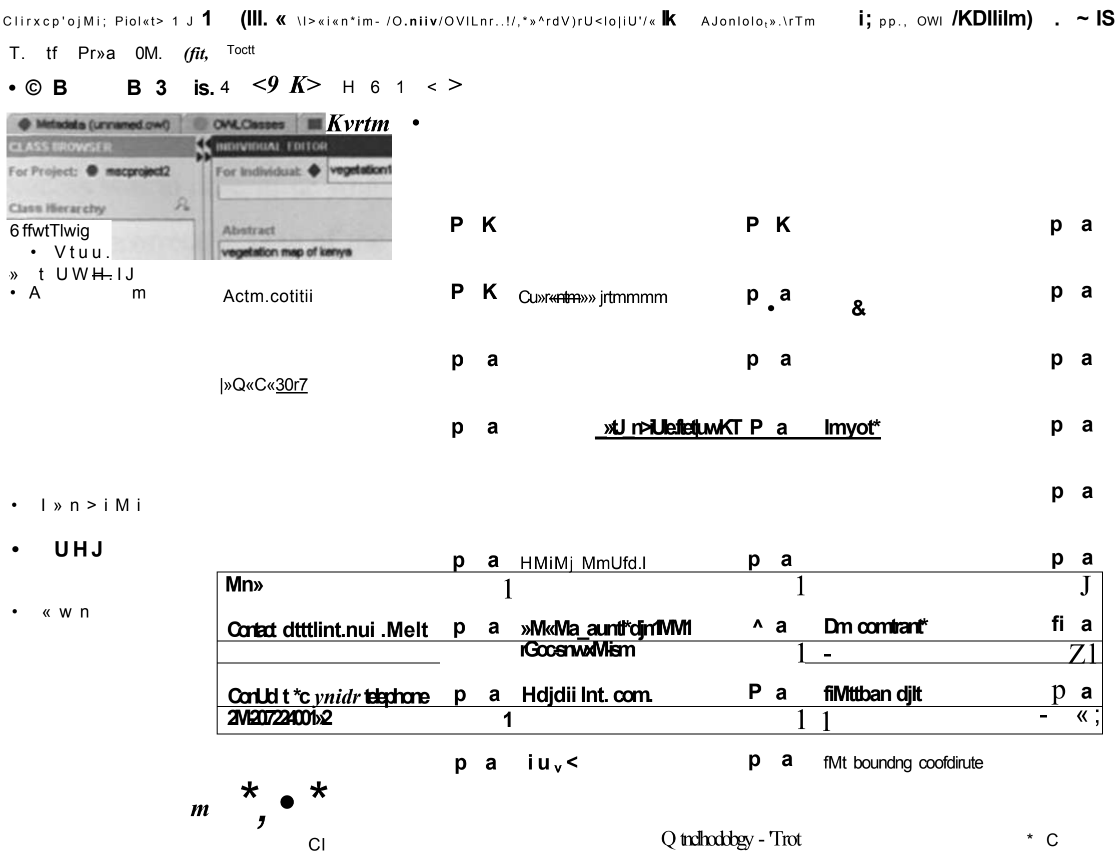

Fig 5.3: Instances Diagram

OWL Individuals

OWL individuals (or instances) are the actual data in the knowledge base. The instances are entered after defining classes and properties of the classes. Fig 5.3 shows an example of instances diagram. The left pane shows the classes while the right pane shows the individuals. The individuals shown on the right pane belong to the highlighted class on the left i.e the individuals shown are of the class vegetation.

5.2 Ontology Evaluation

As any other resource used in software applications, the content of ontologies was evaluated before using it in other ontologies or applications. The goal of the evaluation process was to determine what the ontology defines correctly, what it does not. and what it does incorrectly. One of the key features of ontologies that are described using OWL-DL is that they can be processed by a reasoner. To evaluate the content of the ontology the following criteria were identified (Austin et al., 2003): Consistency, completeness and conciseness. Pellet 1.5.0 an ontology reasoner was used.

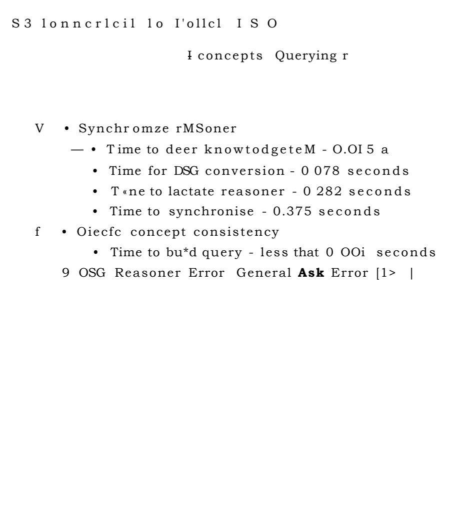

Fig 5.4a: Inconsistent ontology

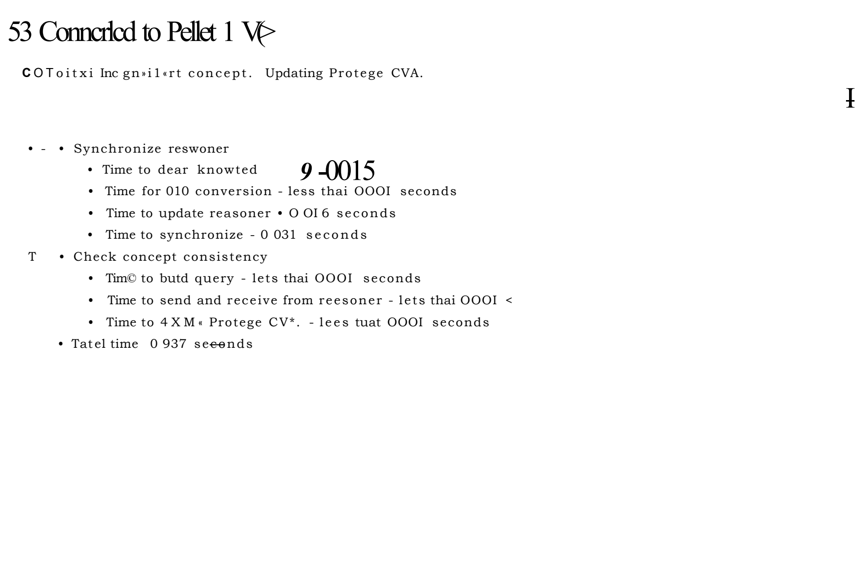

Fig 5.4b: Consistent Ontology

5.2.1 Consistency Check

Consistency refers to whether it is possible to obtain contradictory conclusions from valid input definitions. Using the reasoner the ontology was automatically computed for classification hierarchy, and also to check the logical consistency of the ontology. A given definition is consistent if and only if the individual definition is consistent and no contradictory knowledge can be inferred from other definitions and axioms. In order to demonstrate the use of a reasoner in detecting inconsistencies in the ontology a class was created that is a subclass of both hydrology and a political boundary. This strategy was used as a check to demonstrate that an ontology as been built incorrectly. Classes that are added inorder to test the integrity of the ontology are called Probe Classes. Fig 5.4a shows the results of such a check showing inconsistent ontology.

This happens because; intuitively we know that for disjoint classes something cannot at the same time be both a hydrology and a political boundary. Something should not be both an instance of hydrology and political boundaries. However, it shall be noted that the names of the classes have been chosen. As far as the reasoner is concerned names have no meaning. The reasoner cannot determine that something is inconsistent based on names. The actual reason that **ProbeInconsistentClass** has been detected to be inconsistent is because its superclasses Hydrology and Political Boundaries are disjoint from each other. Therefore, individuals that are members of the class Hydrology cannot be members of the class Political Boundaries and vice-versa. Fig 5.4b is the converse of Fig 5.4a i.e it shows the results of a consistent ontology. In this case the Probe Class is removed and the ontology is tested for consistency and a positive result is returned.

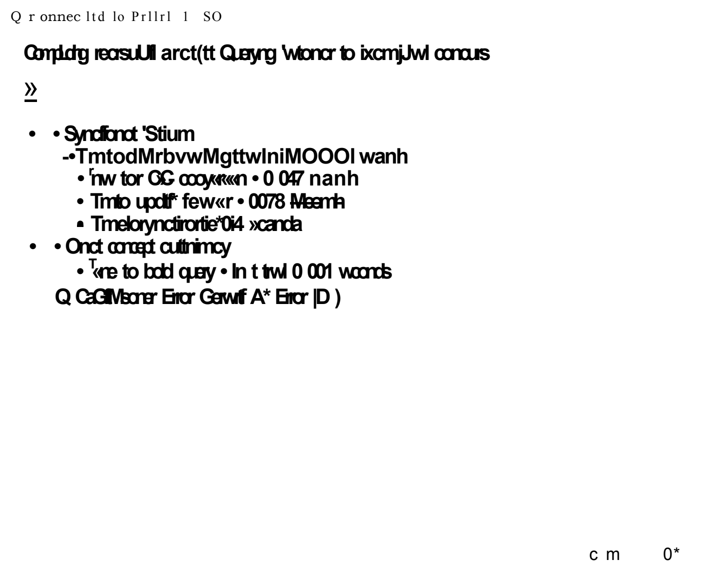

Fig 5.5a: Unclassified Ontology

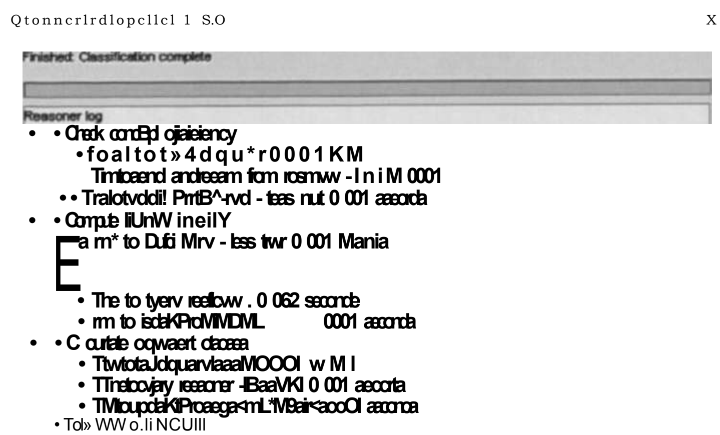

Fig 5.5b: Classified Ontology

S.2.2 Classification

The reasoner was used to automatically compute the superclass-subclass relationship (subsumption relationship) between Digital Elevation Model and Digital Terrain Model. Fig 5.5a and Fig 5.5b respectively shows negative and positive classification results. Classification can be used to automatically compute the class hierarchy. This was found to be a major benefit of building an ontology using the OWL-DL sub-language. Indeed it was found that when constructing very large ontologies the use of a reasoner to compute subclass-superclass relationships between classes becomes vital. Without a reasoner it is very difficult to keep large ontologies in a maintainable and logically correct state. Computing and maintaining multiple inheritances is the job of the reasoner. This technique which is also known as ontology normalization helps to keep the ontology in a maintainable and modular state. Not only does this promote the reuse of the ontology by other ontologies and applications, it also minimized human errors that are inherent in maintaining a multiple inheritance hierarchy.

5J Querying of Results

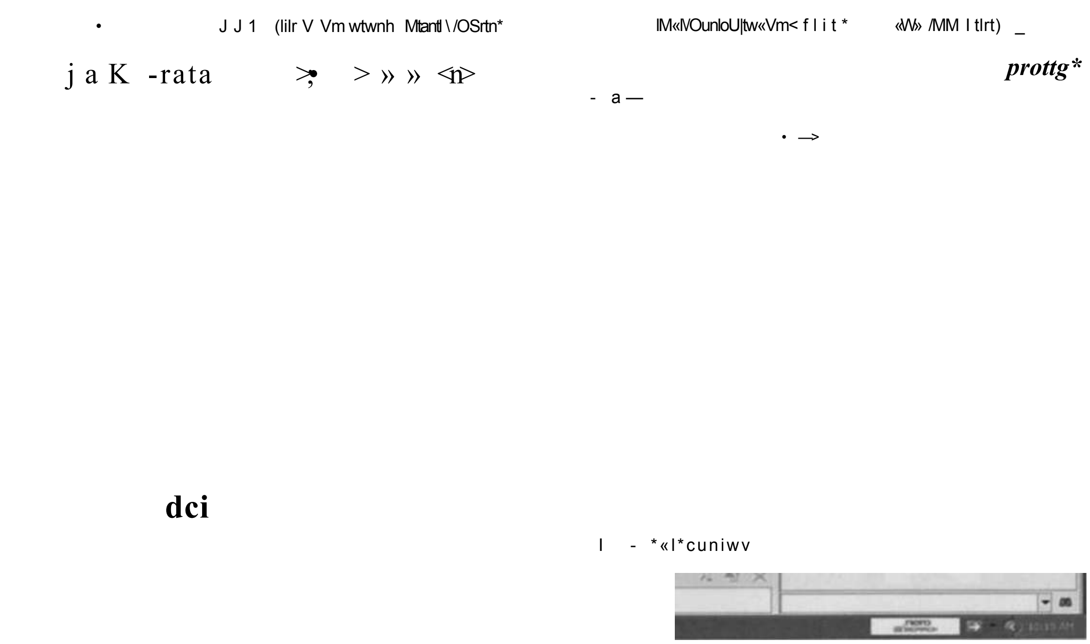

Fig 5.6: Result (shown in right pane) of querying kenya soil metadata whose publishing organization is in the city of wageningen (i.e ILRI headquartered in Wageningen but with offices in Kenya)

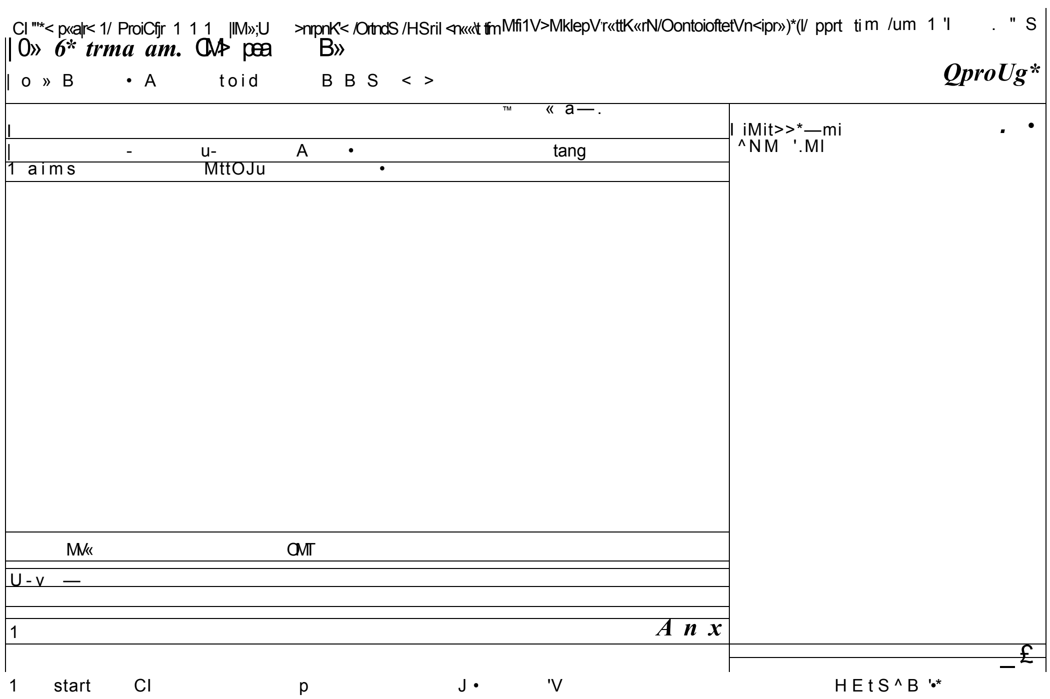

Fig 5.7: Results (shown in right pane) of querying utilities metadata whose originator is Food and Agricultural Organization

Fig 5.8: Results (shown in right pane) of querying metadata in the class vegetation whose access constraints are none (I.e vegetation data which can be accessed by anyone without any restrictions)

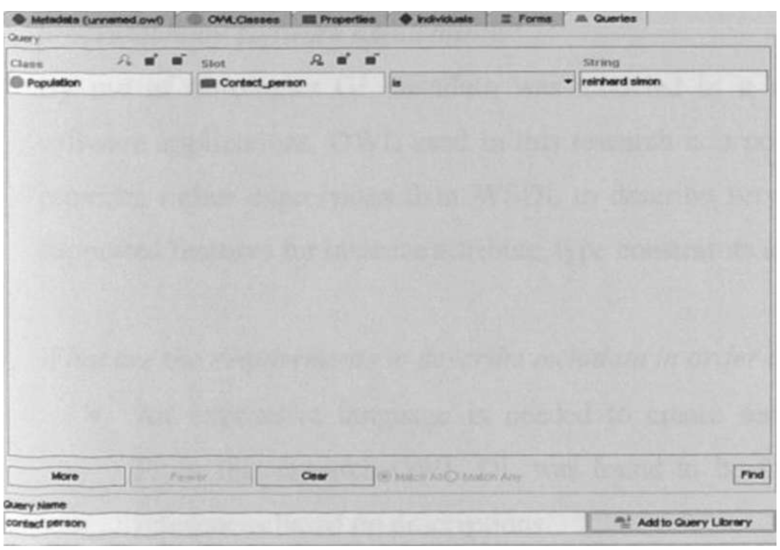

Fig 5.9: Results (shown in right pane) of querying metadata whose contact person is Reinhard Simon (I.e this is data created by ILRI Kenya office with Reinhard Simon by virtue of being the GIS manager being the contact person)

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The application of semantic web technology forms a promising approach for improving the interoperability of geo-services within and across enterprise boundaries. This research has demonstrated that geo-information models lend themselves well to translation into formal, machine accessible ontologies.

Answers to research questions

1. *What is the state of the art technology to share geospatial data/service for users?*

Traditional web portals are currently being used to share geospatial information.

2. *What are the problems in using the state of the art technology for sharing geospatial data/service?*

With the current technology, software are not able to understand the content of the web hence it is not possible to perform an intelligent query on the web.

3. *How can Geographic Information metadata he presented in a way that can he processahle by software applications?*

   By use of ontologies GI metadata was modeled in a way that is processable by software applications. OWL used in this research is a powerful ontology tool which provides richer expressions than WSDL to describe services and datasets i.e it has supported features for instance attribute, type constraints and procedural knowledge.

4. *What are the requirements to describe metadata in order to facilitate data discovery?*

   - An expressive language is needed to create semantically rich description. From this research OWL DL was found to be the best language to perfom inferences based on descriptions.
   - OWL DL was found to be the only sub-language of OWL that supports machine reasoning about metadata.
   - For effective geospatial metadata discovery interoperability at all levels (syntactic, structural and semantic) is needed.

6.2 Recommendations and Future Work

Semantic Web Services reseach has the overall vision of bringing the web to its full potential by enabling applications to be created automatically fom available web services in order to satisfy user goals. Fulfilling this vision will radically change the character of all online transactions. A Semantic Geoportal will open up a plethora of possibilities as it has already been demonstrated. Reasoning over the web is part of the great potentials that can be brought to reality. Based on this research it has been shown that ontologies can play a pivotal role in SDI data sharing. An interesting next step will be to search and access geo-services in a semantically enriched way.

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APPENDIX A

This is the OWL document produced by the prototype:

```
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xmlns:owl="http://www.w3.org/2002/07/owl#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xmlns:rdfs="http://www w3. org/2000/01/rdf-schema#"
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xml:base="http://www.owl-ontologies.com/unnamed.owl">
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</owl:Class>
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1	Delsol J.P	1995	Kenya Vegetation	vector digital data	\\CITRIODORA\GEONETWORK\kenya-vegetation.shp	Vegetation map of Kenya	For vegetation analysis and other natural resource management	1995	publication date	Complete	None planned	33.848408	41.897144	5.426326	-4.69078
2	Food and Agricultural Organizati	5/29/1905	Road map of Keny	vector digital data	AGL-Documentation-Centr	Road map of Ke	For road transport	No date	publication date	Historical Archi	As needed	33.9	41.9	4.62	-4.66
3	WCMC (World Monitoring Cons	1996	Protected areas of I	vector digital data	http://gislab.cifor.cgiar.org/	Protected areas	Protected areas of Ke	No date	ground condition	Published	Unknown	34.00159	41.5638	4.27137	-4.54487
4	CIESIN, Center for International	2006	Population Density	remote-sensing ima	http://research.cip.cgiar.org	Population Dens	Population Density of	2006	2006	Complete	As needed	33.816667	42.019267	4.683333	-4.766667
5	CIESIN, Center for International Earth Science Information Network, Colombia University	2006	Population Density (Mask) of Kenya	remote-sensing image	http://research.cip.cgiar.org/confluence/display/divagis/Home	Population Density (Mask) of Kenya	Population Density (Mask) of Kenya	2006	2006	Complete	As needed	33.816666	42.019266	4.683333	-4.766667
6	U.S. base. Legend: US Geological Survey, Global land cover characteristics data GS Land Use/Land Cover System	2006	Land Cover of Kenya	remote-sensing image	http://research.cip.cgiar.org/confluence/display/divagis/Home	Land Cover of Kenya	Land Cover of Kenya	2006	2006	Complete	As needed	33.819984	42.019952	4.679505	-4.770457
7	CIESIN, Center for International Earth Science Information Network, Colombia University	2006	Population Density of Kenya	remote-sensing image	http://research.cip.cgiar.org/confluence/display/divagis/Home	Population Density of Kenya	Population Density of Kenya	2006	2006	Complete	As needed	33.816667	42.019267	4.683333	-4.766667
8	U.S. Geological Survey, Global land cover characteristics data base. Legend: USGS Land Use/Land Cover System	2006	Land Cover (Mask) of Kenya	remote-sensing image	http://research.cip.cgiar.org/confluence/display/divagis/Home	Land Cover (Mask) of Kenya	Land Cover (Mask) of Kenya	2006	2006	Complete	As needed	33.816666	42.019266	4.683333	-4.766667
9	ILRI GIS unit	2002	Kenya Towns and Urban Centres	vector digital data	No Record	Kenya Towns and Urban Centres	Kenya Towns and Urban Centres	2002	publication date	Complete	None planned	34.01492	41.877476	4.903498	-4.658002
10	ILRI GIS unit	2004	Kenya Topography Grid Map	vector digital data	No Record	showing the available 1:50 000 hard	available 1:50 000 toposheets of Kenya at ILRI	2004	publication date	In work	Continually	33.90958	41.89101	5.482579	-4.674901
11	ISRIC – World Soil Information	1994	Kenya Soil	vector digital data	\\CITRIODORA\GEONETWORK\kenya-soil.shp	Kenya Soil	The database has been used for various studies, including assessments of water	1994	publication date	Complete	None planned	33.940689	41.883831	5.384588	-4.69259
12	ILRI GIS unit	Jun-05	Kenya Rice Yield	vector digital data	No Record	Rice yields in Kenya as in 1998	production as a source of information on agricultural planning	2005	publication date	Complete	None planned	33.90886	41.89908	4.62933	-4.67805
13	JICA water master plan project	Unknown	Kenya Rainfall Distribution	vector digital data	No Record	This coverage shows the annual rainfall distribution in	To be used in the JICA master water plan study	unknown	publication date	Complete	None planned	33.92665	41.89098	5.02277	-4.69259
14	ILRI GIS unit	2004	Kenya Poverty Map (1999)	vector digital data	No Record	Kenya poverty map as of the year 1999	Used to establish the well being of the people in Kenya as of the year 1999	2004	publication date	Complete	None planned	33.913399	41.912922	5.470521	-4.677419
15	ILRI GIS unit	Mar-05	Kenya Millet Yield	vector digital data	No Record	Millet yields in Kenya as of the year 1998	Generated from FAO project intended to show Kenya crop	2005	publication date	Complete	None planned	33.90886	41.89908	4.62933	-4.67805

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	kema Veftcuiion	Kama	1995	None	None	ICRAF	Meshack Nvabenae
	lm«H«r\ Bm Maps Earth Cove	Kenya	No dale	None	None	FAO - UN AGL Documentation	Danielle Courtolle
J	in»ti«l Jntnbution protected u	Kama	No dale	None	None	WCMC (World Monitor™ Con	
4	population demn>	kema	2006	None	None	International Poulo Cenler	Rcinhaxd Simon
5		kema	2006	None	None		Reinhard Simon
L	t and Cover. I'rtunbuih-up. IMMind crop vu pwure, Irngaiad crop Mid p M m ,	kema	2006	None	None	International Potato Ccnler	
7	lasler. population. donsils	kema	2006		None	International Poulo C enlet	Rcmhord Sinton
L	Laid C o w . lirl»anbuiH-up Dr> land crop and pasture. Imgaled crop aid pasture c r o p K f » » wood mosaic	kema	2006	None	None	International Potato (enter	Rcinhjud Simon
«	Kama to»ra	kama	2002	Contact 1LRI GIS unit	Inform ILRI OIS unil	International Livestock Research Institute (ILRI)	RUM Knuka
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U		kema	2003	contact IUUGIS mil	Inform ILRI GIS unil	International Uvenock Research liutitule (ILRI)	Rim Krmka
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KENYA METADATA

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5				No Record	FGDC Content Standards for Dicilal G»	FGDC-STD-001 -1998	local time	ESRI Metadata Profile
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	ILMOUum	Mar-05	kerns Marot To.™	vector digital data		me coverage shows the major towtu m Kama There are a total of S3	show tfte location oi important town tn Kema where most basic services are available	2005	publication date	Complete	Mnn, nlaiina-l oone piannec	34070148	41 840122	4 265939	1 -4 182497
h	FAOtafhcover protect)	2004	kema Land use	vector digital data	No Record	Kenya landuse map ai was done by the Afncover	Afncover project lo •how the various land use t>pes in Kern a as part of the Afncawide project	2004	publication date	Complete	None planned	33 94366	41 89291	5 43586	-170017
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20	ILtUGlSiaiu	2005	Kenya Dntncta	vector digital data		Map showing the district lev el of tn Kema as was	¥o show the 3rd level of administration in Kema for the	2005		Complete	As needed	33 9134	41 91292	5 47052	-467742
J"	lUUGBuntt	Unknot	Kam a Climate	vector digital data		Map showing information of	To show the different derived climate parameters of Kema		publication date	Complete		33 925	41 »75	5025	-4 675
n	1 'NtP GRID Nairobi	I9«2	Kama	vector digital data		/one* based on temperature (1-9> and moisture (1 VII) It **WM***	Provide the framework for ecological land use	I9«2	publication date	Complete		33.926651	41 8909*		
21	11 HI GIS i m	1997	KENYA	vector digital data	Home	Admmistrative boundaries of the first level subdivisions (such as State.	To provide firsi-Wnei administrative unit boundaries for the worid.			Complete		33.908859	41 899078	4 629333	-t 67R047
24	ILRI«Su«	Mar-05	Kenya Major	vector digital data		Map showing the dtstn button of Kema nmor watersheds	To show the location of mqjor water basins m Kema	2005	publication date	Complete	None planned	33 90722	4190895	501778	-4 68441
w	I rated States Geological Sunev (11SOS)	29-J,«.99	KEGCOLOGY	vector digital data	"html 0rl<1£*,erBS'_*E'>"i	Geological map	For Geological use		puhtkcalim	Complete	As needed	31.9(6}	43.9*31	IjHt	-5.9174
26	FAO • UN AOL Documentation	1951-01-01 (publication)	Geological map	Map Hardcopy	No Record					Itistoncal Arch	As needed	339	41 9	462	-4 66
	PAO • UN AOL Documentation	MOI	Foiati map of Kenya	**MBJCHM**	**ttctmuc**	Foraat map of Kema	Forest map of Kern a	2/20f200|	pub^—d-.	Complcte	As Needed	*3) 90722*	4190117	**46115**	-4 66962

KENYA METADATA

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»	Kci i. 1 Gaolll^J			None	None	DEMU PROJKT	MWA.NGI THtLRI	Information	c/a I'NDP DDC	P.O. BOX 30S52.	NAIROBI.	KENYA.	Microsoft Windows 2000 Vernon 5 0 (Build 2195) Service Pack 4. ESRI
				None	None	FAO - UN AOL Documatunon	Danielle Courtolle_	Information Offica	nwhng address	Via dalle Terme A CaracaUi_	Rome	hah	Microsoft Windows 2(100 Version 5 IMBuild 2195) Service Pack 4. ESRI
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Tally	Metadata Reference Information							
	Metadata Date	**Contact Voice Telephone**	**Contact Facsimile Telephone**	**Contact Electronic Mail Address**	**Metadata Standard Name**	**Metadata Standard Version**	**Metadata Time Convention**	**[metprof]**
16	20051028	254-20-4223000	254-20-4223001	pkariuki@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	ESRI Metadata Profile
17	20050928	254-20-4223000	254-20-4223001	pkariuki@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	Unclassified
18	20050928	254-20-4223000	254-20-4223001	pkariuki@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	Unclassified
19	20050928	254-20-4223000	254-20-4223001	pkariuki@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	Unclassified
20	20060704	254-20-4223000	254-20-4223001	pkariuki@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	Unclassified
21	20051101	254-20-4223000	254-20-4223001	pkariuki@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	Unclassified
22	20060921	254-20-7224258	254-20-7224001	m.nyab3enge@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	ESRI Metadata Profile
23	20060518	No record	No record	r.simon@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	ESRI Metadata Profile
24	20050928	254-20-4223000	254-20-4223001	pkariuki@cgiar.org	FGDC Content Standards for Digital Geospatial Metadata	FGDC-STD-001-1998	local time	ESRI Metadata Profile
25	No record	254-020-622020	No record	mwangi.theuri@unep.org	FGDC Content Standards for Digital Ge	FGDC-STD-001-1998	local time	ESRI Metadata Profile
26	No record	No record	No record	AGL-Documentation-Centre@fao.org	ISO 19115	FDIS	local time	ESRI Metadata Profile
27	No record	No record	No record	No Record	ISO 19115	FDIS	local time	ESRI Metadata Profile

Tally	Identification Information							Time Period of Content		Status		Bounding Coordinates			
	Originator	Publication Date	Title	Geospatial Data Presentation Form	Online Linkage	Abstract	Purpose	Calendar Date	Currentness Reference	Progress	Maintenance and Update Frequency	West Bounding Coordinate	East Bounding Coordinate	North Bounding Coordinate	South Bounding Coordinate
29	FAO - UN AGL Documentation (	1978	City of Nairobi, Map and guide	Map Hardcopy	No Record	City of Nairobi, Map and guide	City of Nairobi, Map and guide	City of Nairobi, Map and guide	publication date	Historical Archive	As needed	33.9	41.9	4.62	-4.66
30	GTOPO5 (U.S. Geological Survey)	2006	Altitude 5 min (Mask) of Kenya	remote-sensing image	http://research.cip.cgiar.org/confluence/display/divagis/Home	Altitude 5 min (Mask) of Kenya	the needs of the geospatial data user community for country scale	2006	2006	Complete	As needed	33.832478	41.999145	4.666446	-4.750221
31	Kassam, A.H., Van Velthuizen, H.T., Sloane, P.H., Fischer, G.W., Shah, M.M.	1991	Land Resources Assessment for Agricultural Development	Map Hardcopy	http://research.cip.cgiar.org/confluence/display/divagis/Home	Generalized land suitability for rainfed pasture	004301; Type of material: inserted in report, digitized; Related document	unknown	publication date	Historical Archive	As needed	33.9	41.9	4.62	-4.66
32	Programme Against African Trypanosomiasis	2007	Aggregated landcover database for Kenya (Africover) for tsetse habitat	Map Digital	Programme Against African Trypanosomiasis	Aggregated landcover database for Kenya (Africover) for	Thematic aggregation has been performed by the Programme Against African	unknown	publication date	Completed	As Needed	33.90722	41.90517	4.6225	-4.66962
33	World Monitoring Conservation Centre)	1993	KEROADS	vector digital data	http://www.princeton.edu/~geolib/gis	Roads were extracted from DCW.		unknown	publication date	Completed	As needed	31.9862	43.9431	8.8044	-5.9274
34	World Monitoring Conservation Centre)	1996	Protected areas of I	vector digital data	http://gislab.cifor.cgiar.org/download/prot/ppt_ken.zip	Protected areas of Kenya - Point		unknown	ground condition	Published	Unknown	34.02062	41.38333	4.1833	-4.71667
36	World Monitoring Conservation Centre)	1993	KERAILWAY	vector digital data	http://www.princeton.edu/~geolib/gis	The railway was extracted from DCW.		unknown	publication date	Completed	Completed	31.9862	43.9431	8.8044	-5.9274
37	U.S. Geological Survey, Global land cover characteristics data base. Legend: USGS Land Use/Land Cover System	2006	Land Cover (Mask) of Kenya	remote-sensing image	http://research.cip.cgiar.org/confluence/display/divagis/Home	Land Cover (Mask) of Kenya		2006	20061023	Complete	As needed	33.816666	42.019266	4.683333	-4.766667
38	ILRI GIS unit	Mar-05	Kenya Wetlands	vector digital data	http://research.cip.cgiar.org/confluence/display/divagis/Home	This coverage shows the wetlands in Kenya	To show the location of wetlands within Kenya	2005	publication date	Complete	None planned	33.90886	41.51528	4.61507	-4.6645
39	International Livestock Research Institute (ILRI)	2000	Kenya towns	vector digital data	\\CITRIODORA\GEONETWORK\kenya-alltowns.shp	Kenya towns	General applications related to market access	2000	ground condition	Complete	None planned	34.01492	41.877476	4.903498	-4.658002
40	ILRI GIS unit	Mar-05	Kenya Sorghum Yield	vector digital data	http://research.cip.cgiar.org/confluence/display/divagis/Home	Sorghum production as of the year 1998	show crop production in Kenya for agricultural planning	2005	publication date	Complete	None planned	33.90886	41.89908	4.62933	-4.67805
41	ILRI GIS unit	Mar-05	Kenya River Network	vector digital data	http://research.cip.cgiar.org/confluence/display/divagis/Home	Map showing Kenya detailed river network both perennial	To show information on the river water sources	2005	publication date	Complete	None planned	33.90886	41.89524	4.62414	-4.64953
42	ILRI GIS unit	Mar-05	kenya Rainstations_1890 1985	vector digital data	http://research.cip.cgiar.org/confluence/display/divagis/Home	The coverage shows 110 rainfall stations with data	Show the locations of active rain stations between the year 1890 and 1985	2005	publication date	Complete	Continually	34	41.9	4.2	-4.03
43	World Conservation Monitoring Center's (WCMC)	2002	Kenya Protected Areas	vector digital data	http://research.cip.cgiar.org/confluence/display/divagis/Home	This coverage shows the Kenya protected areas.	To show areas protected from human landuse activities in Kenya	2002	publication date	Complete	None planned	34.00159	41.5638	4.27137	-4.54487
44	Africover	2004	Kenya Political Boundaries	vector digital data	http://research.cip.cgiar.org/confluence/display/divagis/Home	Map shows the layout of Kenya external conutry boundaries	show political boundaries of Kenya	2004	publication date	Complete	None planned	33.908859	41.911373	5.428018	-4.680452

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43		ess*__		cotuci IIJU tns	Inform ILRI GIS unit	ILRI	Rues Kruska	Head GIS lab	tnaslx« and pbyucal address	Box 30709 old Na^aaha road		Kenva	Microsoft Windows XP Version 5 1 (Build 2600) Senice Pack 2. ESRI ArcCatalog 9 0 0.535
44	Political, map	Kant	:c»W	Inform ILRI-GIS unil	Inform IIJU-GIS uml when used for publication _	M !		Rtaaknaka	k - O K U b	mailing and pbincal address	Box 30709 old Naivasha	Nairobi	Kcm«	Microtoit w mutiw-h Ar Version 5 1 (Build 2600) Senice Pack 2. FSRI ArcCatalog 9 0 0 535

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	11 R1 CIS unit	Mar-05	Kama Major	vector digital data	hop 'research cip eglar org 1 confluencttdisptr dii ayii Home	Map showing the distribution of Kem a m^jor vkalc: theds	To ihow die location of major w ater balms m kona	2005	publication date	Complete	None planned	33 90722	41 90895	5 01778	-4 '.X441
46	lUUdStaart	Mai J)!	Kama M1u1 Yields	vector digital data	cwifluencft-'duplavdiiagH Ik-IIK	1 his coverage shows the total producoon m tones for Kama	ihow the general mai/e production tn Kama	2005	publication date	Complete	None planned	33 9088ft	41 899118	4 62933	-4 67805
47	lUUGIStaat	Mar-in	Lam. harth	veclof digital data	http.rcacarchcip qpii org /ctaifluanca/diiply/divagM	kema health		2005	publication date	Complete	None planned	33 975805	41 861814	5 387024	-<66227
4>	AAlcoves	2004	KanvaGeotofp	vector digital data	confluenco'dBptiY^n mi Home	The Otology of Kona at small	Provide lome indication on the potential mineral	2004	publication date	Complete	Contuiualh	33 908859	41 911373	5 428018	-4 68(1452
49	Welcome TruM and pmicuih called LondtMiinna thp	2003	kern a DnisKXle Map (2000)	vector digital dau	Uu;' mwnii bin mm jii > i• • cooOucikc dtiplv dlMttu I t ™	Dii mom Map (2000)	Show Kema division boundaries	2002	publication dale		None planned	33 90958	41 89101	5 482579	-4 674901
90	ILRIGlSiaM	Unknown	kern a crop pfo«lu	lector digital data	ba&iaaa[ch.£ut.tgM-Qfg cynlluctKcdiiplsv diiagn /Horn.	livestock production in Kami m the	Used to show crop and livestock production in Kfliva	unknown	publication date	Complete	None planned	33 9009	41 89101	5 48258	-4 6749
PI	A£»ks (JICA)	2003	kema Annual	lectot digital dau	vrmuoDORArfONFT	showns annual rainfall distribution of Kama	Support National Water Mailer Plan of Kema	2003	publication dale	Complete		33 926651	41 89098	5022773	-4 69259
	II K! C1lS uw	2005	kern. 1989 Cnuxm	sector digital data	jCITRIODORALOIONET	Map showing population data baaed on the 19*1 cenrus	Lied to establish die population derails withm the cotaitn	2005		Complete	None planned	3390958	41 89101	5 48258	
51	FAO-UNAOLDoomwuiwX	1977	AbcrduM md Lake Nakuru		•CITRIODORANGEONET WORK kcma-rainfall ihn	DOS 2797. Ed			publication dale	Historical Archive	Completed	339	41 9	462	
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»	GTZ Foran> Sml Centre	1993	kenva forest wed	.aoo. digital dala	CTTRIOPORANGEONET	Kam i foren wed /ones		1993	publication date	Complete	None plwied	33 938801	41 8*4144	5 427908	-4 729353
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60		2002	dalabaae for Kail	Map Digital	UttlflBW datable for	Aggregated Multipurpose Landcover dalabaae for		unknown	publication dale	Complcttd	Compiled	33 90722	41.90517	46225	-4 66962 1

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41	watersheds	Kema	2005	Inform ILRI-GIS	Inform ILRI-GIS tun when used for publication	ILRI	Run kruska	Head GIS lab	mailing and phvsical address	Box J0709 old Natasha road	Nairobi	Kemi	Microsoft Windows XP Version 5 1 (Build 2600) Service Pad 2. ESRI ArcCatalog 9.0 0 535
46	Maze Yield	Kama	2005	Inform ILRI-GIS	Inform ILRI-OIS unit when used for	ILRI	Russ kruska	Head GIS lab	mailing and phvsical addreas	Box 30709 old Nataaha mi		kema	Microsoft Windows XP Version 5 1 (Build 2600) Service Pack 2. ESRI ArcCatalos 9 (10 535
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	Topographs. Nature Reaervea geology. Inhotop. ore depoata. sttaugfaphy. gravity contour				None	FAO - UN AOL Documentation Center	Danielle Couneslle	Head GIS		Via dalle Tonne di Caracal la	Rome	luk	Microsoft windows xp Version 5 1 (Build 2600) Service Pack 2. ESRI ArcCatalog 90 0 535
		Kama			None	Organisation - Somalia Water A Land Information Management (SWAUM)	Crag son llaiien	HeadGIS		Crescent rd. ofT Partlanda id. Partlandv PO Box 3(1470	N a n *	Kema	Vernon 5 1 (Build 2600) Service Pack 2. ESRI
			199J	None	contact GTZ Forestry Seed Centre Munusa	GTZ Forestry Seed Centre	Bernard M Kamondo	—	madam address	Po Box 41607,	Nairobi	Kema	MiCTMtoft'windows XP Version 5 1 (Budd 2600) Service Pack 2. ESRI ArcCatakw 9 1 o 722
			2006	None	None	International Potato Center	Reinhard Simon	Head. Rewarch	mailing and physical	La Molata 1895 Avenue	U M o t a a	Peru	Microsoft Windows 2000 Vernon 5 n (Build 2195) Service Pack 4, ESRI ArcCatalog 9 1 0 722
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60	landcover. environment, natural resourcea. agriculture.	Kff1fi	Miamm	None	Nona	FAO-1IN	IS latham		1 1	Viale ddle 1 erme di < B a B i	Roma	Itah	Microsoft Windows Xl> Version 5 1 (Build 2600) Service Pack 2. ESRI ArcCatalou 9 0 0 535

APPINDIX •

KENYA METADATA

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