Creating an Environmental Geographic Information System for the City of Kumasi, Ghana

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Abstract: The city of Kumasi in Ghana struggles with a number of environmental issues, including excessive road traffic, air and water pollution, flooding, and inadequate solid waste management. If there is a group that is directly affected by these issues, it certainly is the city’s population. At the same time, the people of Kumasi—who are the constituents of the local administration, called KMA—have few to none means of obtaining objective information about the state of the urban environment, and therefore no way of holding the city administration accountable concerning environmentally relevant decisions. This case study aims to explore the possibility of alleviating this transparency issue by creating an ‘environmental information system’ (EIS) for the city. The term EIS in this context denotes an information system which can be used to publish environmental information on the web, to be utilised by students, professionals, NGOs, and the general public. The case study seeks to provide answers to two research questions: What are the software requirements for an EIS for Kumasi? And: How can free software be used to satisfy these requirements? The case study takes an approach based on Soft Systems Methodology and agile software development techniques to explore the software requirements. As part of the study, a prototype of the EIS was developed in order to explore the requirements even more, and in order to determine the applicability of currently available free software.

The results of the requirements analysis include the following observations: geographical information is essential in presenting the city’s environmental issues, therefore the EIS is based on geographic information system (GIS) software and techniques; the information should be presented to the public in an easy-to-use and easy-to-understand way in order to reach the largest possible percentage of the target group; the environmental information that is available at local institutions (such as the largest local university KNUST, the city administration, and the Environmental Protection Agency) is scarce and semantically and syntactically heterogeneous—therefore, the EIS must be able to consolidate such information in order to present it in an easy-to-understand way; many of the involved actors have no or little knowledge in GIS techniques, therefore the EIS must be usable without such knowledge. In the implementation process, heavy use was made of free software components: GeoServer for publishing geographical data using WMS and WFS; PostgreSQL with the PostGIS extension for data storage; JPA/Hibernate for storing metadata in PostgreSQL; Spring MVC, jQuery UI and many other libraries for creating a user-friendly web application; OpenLayers for displaying and editing geographical data in the web application; GeoTools for handling geographical data on the server-side. During implementation, actual environmental information was entered into the EIS in order to provide a realistic semantic environment for the agile development process.

The study concludes that—while the implemented prototype does not include all of the features which were identified as required, and while a ‘full’ soft systems analysis (as opposed to the ‘soft systems perspective’ which was applied) would have led to a more complete picture of the software’s organisational environment—the implementation of an environmental information system for Kumasi, based solely on free software, is viable in the current technical and organisational environment. KNUST is foreseen to be an adequate organisation to manage the development and operation of the system, since the necessary technical knowledge is available. The successful operation of the EIS relies on environmental information being provided by data producers such as the KMA, the EPA, the Ghana Statistical Service, and various departments at KNUST.

Keywords: environmental information system, geographic information system, Ghana, Kumasi, environmental transparency, sustainable development

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Summary: The city of Kumasi in Ghana struggles with a number of environmental issues, including excessive road traffic, air and water pollution, flooding, and inadequate solid waste management. If there is a group that is affected directly by these issues, it certainly is the city’s population. At the same time, the people of Kumasi—who are the constituents of the local administration, called KMA—have few to none means of obtaining objective information about the state of the urban environment, and therefore no way of holding the city administration accountable concerning environmentally relevant decisions. This case study aims to explore the possibility of alleviating this transparency issue by creating an ‘environmental information system’ (EIS) for the city. The term EIS in this context denotes an information system which can be used to publish environmental information on the web, to be utilised by students, professionals, NGOs, and the general public. The case study seeks to provide answers to two research questions: What are the software requirements for an EIS for Kumasi? And: How can free software be used to satisfy these requirements? Free software is software that is published under a license which allows the usage of the software and its source code without restriction, which implies that the software can be used at no financial cost in the form of royalty fees. The case study takes an approach based on Soft Systems Methodology and agile software development techniques to explore the software requirements.

‘Agile’ software development is a development approach which sees most of the requirements analysis as part of the implementation process itself, avoiding the creation of large, speculative documentation beforehand. As part of the study, a prototype of the EIS was developed in order to explore the requirements even more, and to determine the applicability of currently available free software.

The results of the requirements analysis include the following observations: geographical information is essential in presenting the city’s environmental issues, therefore the EIS is based on geographic information system (GIS) software and techniques; the information should be presented to the public in an easy-to-use and easy-to-understand way in order to reach the largest possible percentage of the target group; the environmental information that is available at local institutions (such as the largest local university KNUST, the city administration, and the Environmental Protection Agency) is scarce and semantically and syntactically heterogeneous—therefore, the EIS must be able to consolidate such information in order to present it in an easy-to-understand way; many of the involved actors have no or little knowledge in GIS techniques, therefore the EIS must be usable without such knowledge. In the implementation process, heavy use was made of free software components for storing, visualising, and publishing geographical information on the web, and for creating an easy-to-use web application. During implementation, actual environmental information was entered into the EIS in order to provide a realistic semantic environment for the agile development process.

The study concludes that—while the implemented prototype does not include all of the features which were identified as required, and while a ‘full’ soft systems analysis (as opposed to the ‘soft systems perspective’ which was applied) would have led to a more complete picture of the software’s organisational environment—the implementation of an environmental information system for Kumasi, based solely on free software, is viable in the current technical and organisational environment. KNUST is foreseen to be an adequate organisation to manage the development and operation of the system, since the necessary technical knowledge is available. The successful operation of the EIS relies on environmental information being provided by data producers such as the KMA, the EPA, the Ghana Statistical Service, and various departments at KNUST.

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Abbreviations and acronyms

Ajax Asynchronous JavaScript and XML
API Application programming interface
CATWOE Customers, Actors, Transformation, Weltanschauung, Owners, Environmental constraints
CQL Common Query Language
CSW Catalog Service for the Web
DBMS Database management system
EIS Environmental information system
EPA Environmental Protection Agency
ESDI European Spatial Data Infrastructure
GIS Geographic information system
GPS Global Positioning System
HAS Human activity system
HTTP Hypertext Transfer Protocol
INSPIRE Infrastructure for Spatial Information in the European Community
ISO International Organization for Standardization
ISWM Integrated solid waste management
IWWA Integrated Waste Management in Western Africa (project title)
Java EE Java Enterprise Edition
JDBC Java Database Connectivity
JPA Java Persistence API
JSON JavaScript Object Notation
KMA Kumasi Metropolitan Assembly
KNUST Kwame Nkrumah University of Science and Technology
NAFGIM Ghana National Framework for Geo-Information Management
NGO Non-governmental organisation
NSDI National spatial data infrastructure
OGC Open Geospatial Consortium
ORM Object-relational mapping
REST Representational State Transfer
SDI Spatial data infrastructure
SLD Styled Layer Descriptor
SLU Sveriges lantbruksuniversitet (Swedish University of Agricultural Sciences)
SQL Structured Query Language
SSM Soft Systems Methodology
UMTS Universal Mobile Telecommunications System
URL Unique Resource Locator
WCS Web Coverage Service
WFS Web Feature Service
WMD Waste Management Department (of the KMA)
WMS Web Map Service
XHTML Extensible Hypertext Markup Language
XML Extensible Markup language
1 Introduction

If there is a group of individuals which is affected most by the state of an urban environment, it certainly is the city’s population. Therefore, when it comes to improving the state of a city’s environment, its population is an important stakeholder and consequently a potential driver of environmental improvement. In order to harness this potential, however, it is crucial that objective information on the state of the environment be made available to the general public. An informed public is better able to hold a (municipal) government accountable for its environmental policy.

The state of the environment in Kumasi, Ghana’s second-largest city, is arguably worthy of improvement. The United Nations Statistics Division observed that, while there exists some information on Ghana’s environment, most of it is not easily accessible since it is scattered across the various government institutions (UNSD 2006a). Among the most important producers of environmental information in Kumasi are the local Kwame Nkrumah University of Science and Technology (KNUST) and various departments of the city administration, called Kumasi Metropolitan Assembly (KMA). Finding a way to gather this information and to make it publicly available may contribute to the empowerment of Kumasi’s population regarding the KMA’s environmental policy. In addition to the issue of empowerment, the attitude of Ghanaians towards the environment presents a cause of environmental problems, particularly when it comes to the management of solid and liquid waste (Nyangbenu 2012, personal communication). Having a means to inform the city’s population about the effects of their behaviour, e.g. of littering, may contribute to bringing about the often called-for attitudinal change.

This is the idea that constitutes the motivation behind this case study. With a large part of Kumasi’s population having internet access and being computer-literate, an information system designed to provide environmental information about Kumasi over the web may turn out to be an effective and efficient way of keeping the public informed on environmental issues. In addition to the population itself using the system, NGOs which are concerned with environmental advocacy may use it as a source of information which can then be passed on to the public. This idea is especially relevant when it comes to informing illiterate or computer-illiterate parts of the population. KNUST may be an ideal institution to run and maintain the system and manage the information therein, as it is officially independent from any government institutions while holding a great amount of expertise in most of the environmental fields (Mensah 2012, personal communication) and being capable of technically maintaining the system (Ayer 2012, personal communication). Based on these insights, this case study seeks to explore the possibility of creating and maintaining such an ‘environmental information system’ (EIS) in Kumasi. Based on field research which was done locally in Kumasi, an EIS was designed and a prototype implemented. This report outlines the results of this work.

As will be explained in more detail at a later point in this paper, a large fraction of environmental observations—e.g. measurements of water quality in a stream, the locations of waste dumps, or traffic levels on roads—are geographically positions (‘geo-referenced’). Information systems designed to handle geo-referenced information are generally referred to as geographic information systems (GIS). A system to store and distribute geographical information is often described as a spatial data infrastructure (SDI). Most industrialised countries have created national spatial data infrastructures (NSDI) which are managed on a national level to store and disseminate all kinds of geographical information: aside from environmental information, they store cadastral, infrastructural, economic and other information.

An attempt to establish an NSDI in Ghana failed in 2006 (see section 4.4). The reasons for the failure included the participating institutions’ inability to agree on a common organisational and technical framework. Due to the failure of this top-down approach, the investigation of the possibility of a bottom-up solution—beginning at the city level—suggests itself, as it would involve a much smaller number of stakeholders, simplifying the process of establishing policies and infrastructures. While the small SDI that has been designed as part of this case study is not as thematically comprehensive as a typical SDI—because it is focused on information which pertains to the environment only—it should easily be possible to integrate it into a future larger-scale (N)SDI because it is
based on standard technologies and communication protocols which are expected to ensure interoperability for the foreseeable future.

The study was conducted as part of the European Commission’s IWWA (Integrated Waste Management in Western Africa) project. IWWA aims to establish and promote Integrated Solid Waste Management systems (ISWM) in western African countries by empowering all stakeholders participating in the waste management chain, through the reinforcement of institutional and legal frameworks and open transfer of knowledge and technology. (IWWA 2010)

The study was carried out in close cooperation with Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, as well as Sveriges lantbruksuniversitet (SLU) in Uppsala. Both institutions participated in the IWWA project.

The reason why this study is relevant to the IWWA project is that the monitoring and management of environmental information is a prerequisite for a successful waste management strategy. This is because the quality of a city’s waste management typically has a strong impact on the urban and peri-urban environment (UN-HABITAT 2010). An environmental information system can aid in this monitoring and management process. It can assist in evaluating current waste management practices by measuring relevant environmental parameters. Likewise, it can act as a decision support system: Through the creation of simulations, it may be used as a predictive tool that aids in evaluating possible future waste management scenarios in order to improve practices. Such simulations may, for example, rely on information on the locations and pollution levels of water bodies and wells, the locations of inhabited areas, rainfall and drainage statistics, etc.

2 Aim and research questions

This case study aims to explore how an environmental information system with the purpose of providing information to the general public on the city level may be implemented in developing countries. It takes a bottom-up approach to implementation: since there is neither a strong will, nor the required technical capabilities to be found within the local government authorities, the system needs to be championed and run by an institution which has both (Ramasubramanian 1999). In the case at hand, this institution can be KNUST. Specifically, the case study seeks to answer the following two questions:

1. What are the requirements for a ‘Kumasi EIS’?

A requirement is a specification of a desired behaviour of a software system. Requirements are logical consequences of the system’s purpose, and of the technical, political, cultural, and organisational environment in which it is supposed to operate. Requirements can be formulated as so-called use-cases. A use-case is a description of what an actor—human or machine—needs to be able to do with the software, and how the software has to respond. A use-case can involve more than one actor. Based on a list of use-cases, the software and its required points of interaction with the actors can be modelled, taking into account any requirements imposed by the software’s prospective technical environment.

2. How can free software be used to implement an environmental information system which satisfies the requirements?

At the present moment, the budget allocated for environmental protection purposes by the city administration or by KNUST is very limited (Mensah 2012, personal communication; UNSD 2006a), and it is likely that the situation is similar or worse in other cities in developing countries (UNSD 2006a). The application of free software is therefore interesting, since the total cost of ownership (TCO) of free software can be significantly lower than that of proprietary software (Wheeler 2007). On the other hand, free software is often lagging behind its commercial counterparts in terms of maturity, functionality, ease-of-use, and documentation (Michlmayr et al. 2005). Therefore, the question whether an EIS for Kumasi can be based on free software is interesting.

The case study’s scope does not extend beyond the implementation stage of the system. Especially the question whether the implemented system can be run and maintained within the proposed organisational structures is not answered. Also, the study covers only the processes from data entry to publication—any processes involved in the collection of data are outside its scope.
3 Methodology

The approach that was taken to answer the research questions can be broken down into three consecutive parts:

1. Requirements analysis
2. Software design based on the identified requirements
3. Implementation of the software design using free software components

Requirements analysis

The requirements analysis was conducted using Soft Systems Methodology (SSM) as described by Checkland & Scholes (1990). SSM has been successfully used especially to solve software engineering problems (Mingers & Taylor 1992; Checkland & Scholes 1990:53). It has been developed as a systematic approach to solving ‘messy’ problems. Any problem which involves human actors—or, in SSM terminology, human activity systems (HAS)—can in principle be considered messy due to the complexity and unpredictability of human behaviour. Since this case study is primarily concerned with information that is passed on (or not passed on) between human actors, and because the similar NAFCIM project failed not because of technical but because of organisational hindrances (Ayer 2012, personal communication), the importance of viewing the problem situation as an HAS is evident. SSM therefore presents a sensible approach to analysing the given problem situation and deriving software requirements from it. It is important to note that, due to a limitation of the study period, no ‘full’ soft systems analysis was conducted. Instead, the problem situation was viewed from a ‘soft systems perspective,’ which means that the investigation was carried out at a relatively superficial level of detail. Important results from the analysis include answers to questions such as:

- Who are the system’s prospective stakeholders?
- On which stakeholders does the system depend in order to ensure its operation?
- Who will interact with the system? Which actors take on which roles in producing, publishing, managing and consuming environmental information?
- Which actor is responsible for running and maintaining the system?
- What are the capabilities required of each actor to fulfil his or her role?

Soft Systems Methodology applies concepts from systems theory to messy problem situations, or soft systems. The approach comprises two streams of enquiry: a logic-based analysis, and a cultural analysis.

In the logic-based stream of analysis, the real-world problem situation which is to be addressed is identified and expressed. It is then modelled as a ‘purposeful’ human activity system, which means that the involved actors and their interactions are viewed as a system which has a certain purpose—in this case, the purpose is to make environmental information accessible to the public. The system is modelled as a so-called root definition which summarises the important properties of the system: what is the transformation process (purpose) that is done by the system; what is it that makes the transformation meaningful; which actors would do the transformation; who are the beneficiaries or victims of the transformation; what are the environmental constraints? Based on the root definition, a workflow-like model of the basic tasks which need to be undertaken by each involved actor in order for the HAS to fulfil its purpose is created.

In the cultural stream of analysis, the HAS is analysed on the cultural level: existing values and norms affect the qualities of the interactions within human activity systems—for example, an actor may need a certain incentive in order to fulfil a required task, there may be conflicts of interest, and existing power-relations need to be taken into account.

After having modelled the HAS in this way, it is then compared with reality: does the real-world system meet the purpose of the HAS, and how efficient is it in doing so? Based on this comparison, a change to the system is proposed which is both systematically desirable and culturally feasible—in our case, the proposed change is the introduction of an environmental information system. (Checkland & Scholes 1990)

During the course of this case study, the selected HAS was explored in interviews with representatives of some of the prospective stakeholders of the EIS. The interviews were semi-structured, meaning that while they were
designed to collect information required for the logic-based stream of analysis, the interviewees were given the
space to express any thoughts not related to an interview question, which contributed to the cultural stream of
analysis. The interviewees were: Dr Moses Mensah, researcher in chemical engineering at KNUST and co-
supervisor of this study; Mr John Ayer, researcher in geomatics at KNUST; Dr Francis Nyagbenu, regional
officer at EPA Ashanti; Dr Fred Anyemadu, researcher in civil engineering at KNUST; Mr Assibey Bonsu,
assistant engineer at the KMA Waste Management Department (WMD).

In addition to how information is exchanged in the selected human activity system, determining the nature of the
exchanged information itself is crucial for the design of the EIS. This was done by examining what the
environmental issues in Kumasi are and what information about them is or may be available. This analysis is
based on interviews with an EPA representative and reports available at the EPA main office in Accra.

Software design

As a prerequisite for implementation, some general design decisions for the EIS were made. Based on the
previously determined requirements, the specific behaviours which the software must exhibit were determined.
Some of these behaviours are the logical consequences of the previously determined characteristics of the
environmental information to be managed, because they determine how information is stored in the system.
Other behaviours include the specific use-cases and workflows which the software must support. At a
presentation of the EIS prototype given by Dr Mensah at a KNUST lecturer’s retreat in July 2012, some of the
attendants expressed ideas which were taken into account in the software design.

Implementation

In the final stage of the study, a prototype of the EIS was implemented in order to verify the technical feasibility
of the design and to determine to which extent free software components can be used to facilitate
implementation. To do so, an agile software development approach was used. This means that, after
determining the basic requirements of the software to be developed, any further, more detailed requirements
analysis is done during the implementation of the software. The implementation process therefore begins at a
very early stage in the project. Compared to traditional software development approaches which involve a long
conceptual design phase that precedes the software’s implementation, an agile approach has the advantage that
requirements can be more easily discussed with the stakeholders because the discussions can be based on what
has already been implemented. This allows for requirements to be defined organically as the system—and with
it, the vision for the system—develops. (Cohen et al. 2004)

A general implementation strategy was to take advantage of available free software components as much as
possible. Each component was chosen based on whether its set of features matches the requirements, its
compatibility with other components, its maturity, and whether it is being under active development. The
experience from this following this strategy is used to answer research question 2, ‘How can free software be
used to implement an environmental information system which satisfies the requirements?’

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1 For an introduction to agile methods, see Cohen et al. (2004).
4 Background

This section provides background information on the technologies to which this report refers, as well as on the specific conditions in Kumasi which have shaped the project’s course and result.

4.1 Kumasi

With a population of just below two million, Kumasi is Ghana’s second-largest city (United Nations Population Division 2008) and capital of the Ashanti region. It is situated about 200 km north of the coast (see the map in Fig. 2). Kumasi acts as an important trading hub for the region, which is illustrated by the fact that it hosts the largest single market in Western Africa. Trade and services account for 71% of Kumasi’s economy, manufacturing and industry for 24%, and primary production for 5%, much of the economic activity being informal (KMA 2006).

The literacy rate in Ashanti Region is 80.5% (males 86.6%, females 75.0%). The official language in Ghana is English. English literacy is at 69.6% (males 77.7%, females 62.3%). 13.0% of households in urban regions in Ashanti own a computer, 67.7% of the population own a mobile phone, and 12.8% use the internet (males 17.5%, females 8.7%). (Ghana Statistical Service 2012)

The climate is semi-equatorial with an average temperature of 28°C, and features a pronounced rainy season between March and October with an average annual rainfall of about 1,340 mm (Keraita 2003).

Kumasi’s roads can be extremely congested at times, especially during rush hour, causing high levels of air pollution and noise. Public road transport (in the form of taxis and mini-buses known as tro-tros) constitutes an important means of transport for most of the city’s inhabitants. Open sewers line most roads, and water pollution within the city boundaries is severe (Nyagben 2012, personal communication). Electricity supply is widespread, though power cuts are common. UMTS (‘3G’) wireless broadband coverage and performance in Kumasi are good.

4.2 Environmental and geographic information systems

In this report, the term environmental information system (EIS) is used to denote a class of software which is able to capture, store, and present environmentally relevant data. The purpose of an environmental information system may be decision support if it is aimed at being used by policy makers and planners. It may also serve as an aid to researchers by making environmental information more readily accessible. Furthermore, it may serve purposes of public education and transparency if some or all of its data are made publicly available.

The term geographic information system (GIS) refers to a class of software which is designed to capture, store, analyse, and present geo-referenced data. What this means is that the data handled by a GIS are associated with a geograhical position. In other words, the data contained in a GIS can be used to describe geographic space. Applications of geographic information systems range from the production of maps, to decision support for urban planning, to the prediction of natural phenomena. (de By 2001) Fig. 3 illustrates what a user front-end of a GIS (in this case, the open-source Quantum GIS) may look like.
Environmental information (such as an air quality measurement, or the location and shape of a water body) typically has geospatial properties, i.e. it relates to a known geographical position. Therefore, geographic information systems may be—and often are—used as environmental information systems if they support the required applications, specifically regarding their analysis and presentation capabilities. As indicated, GIS are not limited to handling environmental data. It is therefore possible to enrich the set of possible applications of a GIS-based environmental information system by including other, not directly environment-related types of geographical information, such as socio-economic data.

De By (2001) furthermore makes the important distinction between project-based and institutional GIS applications. A project-based GIS application has a clear-cut purpose and is typically short-lived. It denotes the one-time usage of GIS techniques for solving a specific problem. An institutional GIS, on the other hand, is long-lived and focuses on the continued provision and management of spatial data. The study at hand is only concerned with the institutional variety.

Finally, it is important to define what constitutes an urban environmental information system. Urban environments differ from their rural counterparts in a vast number of ways (Pickett et al. 2001). For instance, urban soils tend to be more contaminated by heavy metals than soils in rural areas, posing a potential threat to the quality of groundwater (ibid.). Therefore, the monitoring of heavy-metal-emitting processes and the assessment of their spatial relation to groundwater bodies may be deemed more important in urban areas. Likewise, the well-known interaction between vegetation and air pollution (ibid.) may justify the monitoring thereof, aiming, for example, to optimise the locations and types of patches of vegetation, or to optimise traffic flows. These examples illustrate that the set of environmental variables whose measurement is considered desirable in an urban environment—for example by city planners—is different from the set of variables which are important in rural areas. Likewise, the set of applications for environmental data is different. This implies that the design of an EIS for a city environment may have to be different from other EIS applications. Also, since different cities typically face different environmental challenges and management needs, some of the applications of an urban EIS may be city-specific.

To summarize, the case study examined the prospect of establishing an institutional urban GIS with the purpose of managing environmental data for the metropolitan area of Kumasi.

### 4.3 Standards in geographic information technology

This section provides an overview of the current industry standards in geographic information technology and how they are typically employed in real-life scenarios.

#### 4.3.1 Types of geographic data

When dealing with geographic information systems, it is important to distinguish three principal types of geographic data (de By 2001):

*Primary data* are actual values of measurements, usually represented either by a raster or as vector data (e.g., collections of points or polygons). Primary data can be used for computational analyses. Examples of primary

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2 There is, of course, environmental information which is not associated with a specific geographical location or where the location is not important (for example, a city’s total carbon emissions). However, it became apparent during the course of the study that most of the desired applications of the system involve geographical data, which is why functionality for data that is not geo-referenced has been treated with a low priority and may be left for implementation at a later point.
data are the average annual rainfall in millimetres, the concentration of particulate matter in the air, the locations of groundwater wells, the outlines of water bodies, and surface elevation. Items of primary data are often referred to as ‘features.’

Maps are visual representations of geo-referenced primary data. Thus, they provide an interface between the data and a human user. They cannot directly be used for computational analyses because they do not contain computer-processible information. Instead, they are solely for use by humans. It is common to combine different maps into one so as to provide a human viewer with an additional geographical context. For instance, a map which displays only the locations of groundwater wells is less meaningful to its user than a map which in addition includes satellite imagery for geographical reference. Maps can (and typically are) created from several ‘layers’ which are superimposed to jointly form the map. A layer is a visual representation of one set of primary data. For example, a typical city map consists of one layer with roads, one layer with buildings, one with bus stops, etc.

In general language, the term Metadata refers to data that describes other data. In the context of geographic information systems, the term is typically used to refer to data which describes primary data or maps. In practice, geographic metadata comprises at least a textual description of the referenced data (a name), along with a description of how to locate the data (typically a URL which points to a web service that provides the data). Metadata may also contain information on the geographical area that is covered by the data, the resolution of the data, licensing information and more. It is usually made available to its intended audience through searchable metadata catalogues.

4.3.2 Standard technology and architecture

The Open Geospatial Consortium (OGC) has defined standard communication protocols which enable the exchange of primary data, maps, and metadata. These protocols are widely accepted, and have been adopted by the International Organization for Standardization (ISO) in the ISO 19100 series. The OGC standards for serving raster and vector primary data are called WCS (Web Coverage Service) and WFS (Web Feature Service), respectively. Maps are served using WMS (Web Map Service). Metadata is communicated through CSW (Catalog Service for the Web). In order to automatically create visual maps from geographical data, software must be instructed on how to visualise the data, which is commonly done using the standard format SLD (Styled Layer Descriptor).

Fig. 4 illustrates the interplay of these technologies in a typical GIS usage scenario. The depicted workflow is generally referred to as publish-find-bind. In the scenario, a provider (or holder) of data publishes their metadata in a catalogue service. The actual (primary or map) data is stored with the provider, which means that the provider maintains control over their data and can, for example, enforce access restrictions. The catalogue can be part of a hierarchy, or cascade, of catalogues: its metadata is published (copied) upwards where it is then made available along with metadata from other catalogues. This is the first step, publish. In the second step, find, a data consumer locates data they wish to retrieve by accessing any of the catalogues in the cascade using their GIS client software or, as is often the case, a directory website provided by the catalogue service. In step three, bind, the consumer retrieves the desired data from the data provider using the URL contained in the metadata. The user can then utilise the data, e.g. to create a map or to perform a computational analysis.

The possibility of storing metadata separately from the data itself enables data providers to retain full control over their data. This can be an advantage because it typically allows for the more efficient maintenance of the data by the provider, and because the provider can enforce access privileges if necessary.
The architecture shown in Fig. 4 also features a separation of data and the application thereof; because all communication interfaces are standardised, a user can use virtually any available GIS client software to access the data and the metadata. This way, client software can be chosen by each user according to the user’s and the software’s capabilities. In addition, institutional user interfaces can be connected to the same data stores. These may be easy-to-use, application-specific, web-based user interfaces for non-expert users in urban planning as proposed by Culshaw et al. (2006), or a web-based viewer application intended for use by the general public like the Swedish ‘Geodataportal’ shown in Fig. 5.

![Screenshot of the Swedish 'Geodataportal'](image)

Fig. 5. Screenshot of the Swedish ‘Geodataportal’

On the data provision side, several ways exist to create data which can then be published. The most common way is the use of desktop GIS software which allows the creation of WMS/WCS/WFS-compatible data based on user entries. More specialized solutions allow the direct entry of data through web user interfaces or GPS-capable mobile devices such as smartphones. Data may also be created using automated measuring stations as they are common in meteorological applications, for instance.

4.4 Previous attempts to establish similar systems in Ghana

Up until 2005, Ghana’s Environmental Protection Agency (EPA) undertook an effort to establish a national spatial data infrastructure called NAFGIM (National Framework for Geo-Information Management). However, NAFGIM is now defunct (Karikari 2006; Ayer 2012, personal communication). According to John Ayer, researcher at KNUST, the main reason for NAFGIM’s failure was the lack of an organisational body that was both dedicated to managing and maintaining the infrastructure and the data, as well as adequately funded. Instead, the responsibility for the system was with the EPA which itself was interested in only a subset of the data supposed to be managed by NAFGIM. For the lack of financial compensation from NAFGIM’s other users, the EPA therefore felt unable to finance the system’s maintenance. In addition, data producers were reluctant to contribute to NAFGIM’s data repository for fears of their proprietary data leaking into the public domain: there
are accounts of corruption which involved individuals who illegally sold data to which they had access. (Ayer 2012, personal communication)

5 Results

The results of the case study are presented here in three parts. Section 5.1 describes the results of the requirements analysis which was conducted. Based on the requirements, the EIS was designed in generic terms. The resulting design is explained in section 5.2. Finally, based on the design, a prototype of the EIS was implemented. The implementation details are presented in section 5.3.

5.1 Requirements analysis

This section outlines the results of the requirements analysis. Based on the soft systems analysis, the stakeholders of the proposed EIS were identified. Thereafter, as is described in section 5.1.3, the ways of interaction of the stakeholders with the system were determined. Since it is not only important for a complete requirements analysis who conveys information through the software system but also what information is exchanged, section 5.1.4 characterises the environmental information which can be foreseen to be handled by the EIS.

5.1.1 Soft systems analysis

The first step in conducting an analysis using SSM is to identify those human activity systems (HAS) which are relevant to the project. SSM distinguishes two kinds of HAS; primary-task systems which are purposeful systems that have boundaries which are manifest in the real world, e.g. an organisation; and issue-based systems which are purposeful systems that can be observed but do not have institutional boundaries in the real world. Since there is no existing institution that has the purpose of gathering and publishing environmental information about Kumasi, the top-level HAS to be selected for the analysis is an issue-based system by necessity. However, many primary-task systems—i.e. institutions—are relevant to the top-level HAS; first and foremost those which produce environmental information, those which would use (‘consume’) it, and those which have interests that concern its publication.

In order to clearly understand and state the purpose and environment of an HAS, Soft Systems Methodology proposes to create a ‘root definition.’ A root definition is a view on a system which treats it as a transformation process, taking a defined input entity and transforming it to produce a certain output. In addition, a root definition specifies the ‘customers’, ‘actors’, ‘Weltanschaung’ (or ‘worldview’), ‘owners’, and ‘environmental constraints’ of the system. In SSM, these aspects are summarised by the mnemonic ‘CATWOE’ (Checkland & Scholes 1990). Fig. 6 and Table 1 illustrate the root definition which was created for the previously selected HAS. The root definition of the HAS can be summarised as ‘a system, owned by KNUST, to make existing environmental information accessible to the public, in order to support the development of Kumasi.’

When comparing the above model with reality, it becomes apparent that the transformation T is hardly taking place: most environmental information that is generated is not made public at all, and when it is public it takes a substantial effort on the part of the data consumer to acquire it; after finding out which information is available and who has produced it, one must often pay the data producer a personal visit or go to a library, e.g. at an EPA office or a university (Ayer 2012, personal communication). In addition, once one has gotten hold of the information, it may not be presented in a way that makes it easily understandable by the layperson.

One component of Soft Systems Analysis that makes it ‘soft’ is the incorporation of a cultural stream of enquiry. As stated by Checkland & Scholes (1990), although facts and logic have a part to play in human affairs, the feel of them, their felt texture, derives equally (or more) from the myths and meanings which human beings attribute to their professional (and personal) entanglements with their fellow beings. (Checkland & Scholes 1990:44)
Table 1. The root definition

<table>
<thead>
<tr>
<th>C, customers</th>
<th>The general public, professionals, students</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, actors</td>
<td>KNUST, KMA, EPA, other data producers</td>
</tr>
<tr>
<td>T, transformation</td>
<td>The purpose of the system is to make existing environmental information accessible to the public, which means that it must transform existing information into accessible information.</td>
</tr>
<tr>
<td>W, Weltanschauung</td>
<td>Environmental information being public will be useful to the development of the city.</td>
</tr>
<tr>
<td>O, owners</td>
<td>KNUST</td>
</tr>
</tbody>
</table>
| E, environmental constraints | - Environmental data is scarce.  
|                             | - Financial budget is very limited.  
|                             | - Most actors do not have GIS knowledge.  
|                             | - Involved institutions may have conflicting interests. |

The cultural stream of enquiry not only includes observations regarding societal norms and values, but also the analysis of political systems which examines the individual interests of stakeholders and the power relations between them.

One important cultural observation that was made during the course of this study is that many data producers may not be overly interested in investing any effort in providing data for or entering it into the proposed EIS. There are several potential solutions to this issue: since accomplishment and prestige appear to be very important values and therefore potential drivers of action in Ghanaian society, raising awareness among data producers of how the publication of their data may reflect their work effort may help. In the long run, i.e. if there will ever be a substantial budget allocated to the EIS, financial incentives may be given to data producers. In addition, in order to ease the burden on the data producers to provide data, the actual data entry process may possibly be carried out at the KNUST Department of Geomatic Engineering (Mensah 2012, personal communication). For data producers which are part of KNUST, the acquisition of support from the higher management levels may be useful in order to provide the departments incentives for or to enforce cooperation.

There are two potential political issues which have been observed. The first is the issue of data ownership: it may be difficult for many data producers on a legal level to provide data for the EIS due to licensing restrictions. In these cases, KNUST—being the institution which would store and manage the data—would have to enter into negotiations with the data producers in question, which can be expected to be successful in most cases (Ayer 2012, personal communication). The second political issue which has been observed has to do with the fact that the two primarily targeted institutions—KNUST and KMA—are not homogeneous, but instead consist of various actors with differing agendas. In fact, when in this report the KMA or KNUST are mentioned as if they were single actors, this is a simplification. While in the case of KNUST this may not be an issue for the purposes of this study, the situation with the KMA looks different, because some actors within KMA may not be interested in or even opposed to an increased level of environmental transparency. These complex political relations are

![Diagram](image-url)

*Fig. 7. The generic activities of the actors in the proposed HAS as a use-case diagram*
However outside the scope of this study, and they may even be impossible to explore without actually attempting to implement the EIS and to get some of the KMA actors on board (Mensah 2012, personal communication).

This study proposes the implementation of an environmental information system as a change to the described HAS which is both systematically desirable and culturally feasible, and which would enable the HAS to fulfil its purpose. Fig. 7 illustrates how an EIS may aid in making environmental information accessible.

5.1.2 Stakeholders

The stakeholders of the EIS which have been identified in the soft systems analysis are:

*The general public.* The public is the target audience of the information that is disseminated through the EIS. The information needs of the public therefore have a determining influence on which information is published and how it is presented.

*KNUST, various departments.* Because the project has been initiated at KNUST, and because the university is intended to be the owner and maintainer of the system, a number of departments are central stakeholders: technical maintenance and hosting services may be provided by the Department of Computer Engineering (Ayer 2012, personal communication), though no definitive decision on this has been made during the course of this study. The Department of Geomatic Engineering holds expert knowledge of GIS technology and is therefore suitable to have authority over the system’s content, for example in defining data types and categorising information (ibid.). *Other departments,* such as the Department of Civil Engineering, are among the main producers—and possibly consumers—of environmental information in Kumasi (Mensah 2012, personal communication). It is therefore important to gain their support for the EIS in order to ensure the provision of environmental information.

*KMA.* The Kumasi Metropolitan Assembly (KMA) is a stakeholder in a number of ways. It is a producer of environmental information which—in the case of cooperation—would ideally be incorporated into the EIS. However, since by increasing transparency the proposed EIS has the potential to facilitate public resistance against the KMA’s policies, the KMA may oppose the project and/or deny cooperation. Yet, the KMA also acts as a consumer of environmental information which is why the KMA may also benefit from the EIS.

*EPA (national).* Among other activities, the national branch of the Environmental Protection Agency (EPA) is responsible for creating environmental policy guidelines which may be useful information to be published by the EIS. EPA guidelines and reports are generally published in the public domain and could therefore be used by the EIS (Nyagbenu 2012, personal communication).

*EPA (Ashanti Region).* The EPA has subsidiaries in each of the ten regions of Ghana. The responsibilities of the regional subsidiaries differ from those of the national EPA. A main function of the EPA’s Ashanti branch is the monitoring of environmentally relevant activities of private companies as well as of the public administration (e.g. the KMA). These monitoring processes generate information which may potentially be published through the proposed EIS (ibid.).

*Other producers of environmental information.* Many other (government) institutions produce environmental information which may potentially be included in the EIS, such as the Ghana Statistical Service, the Water Research Institute, the Community Water and Sanitation Agency, the Forestry Commission, and the Ghana Tourist Board (UNSD 2006b).

While the above groups and institutions are stakeholders of the proposed environmental information system in that its operation affects and can be affected by them, they do not necessarily interact with the EIS directly. The following section describes which general interactions with the EIS can be foreseen.

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3 For a comprehensive list, see UNSD (2006b).
5.1.3 Actors and their roles

Stakeholders become ‘actors’ as soon as they interact with the proposed EIS directly. When an actor interacts with the software, they do so by taking on one or more roles which need to be defined. The roles which have been identified are: technical maintainer, content authority, data producer, and data consumer. Table 2 summarises the roles the different actors may take on.

*Table 2. Actors and their potential roles in relation to the EIS.*

<table>
<thead>
<tr>
<th>Role</th>
<th>Actors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software maintainer</td>
<td>KNUST (Computer Engineering, Computer Science, Geomatic Engineering)</td>
</tr>
<tr>
<td>System maintainer</td>
<td>KNUST (Computer Engineering, Computer Science)</td>
</tr>
<tr>
<td>System administrator</td>
<td>KNUST (Geomatic Engineering)</td>
</tr>
<tr>
<td>Content authority</td>
<td>KNUST (Geomatic Engineering)</td>
</tr>
<tr>
<td>Data Producer</td>
<td>KNUST (various departments)</td>
</tr>
<tr>
<td></td>
<td>KMA</td>
</tr>
<tr>
<td></td>
<td>EPA (Ashanti Region)</td>
</tr>
<tr>
<td></td>
<td>Other institutions</td>
</tr>
<tr>
<td>Data Consumer</td>
<td>The public</td>
</tr>
<tr>
<td></td>
<td>KNUST (various departments)</td>
</tr>
<tr>
<td></td>
<td>KMA</td>
</tr>
<tr>
<td></td>
<td>EPA (Ashanti Region)</td>
</tr>
<tr>
<td></td>
<td>Other institutions</td>
</tr>
<tr>
<td>GIS Analyst</td>
<td>KNUST (various departments)</td>
</tr>
<tr>
<td></td>
<td>KMA</td>
</tr>
<tr>
<td></td>
<td>EPA (Ashanti Region)</td>
</tr>
<tr>
<td></td>
<td>Other institutions</td>
</tr>
</tbody>
</table>

The following paragraphs describe the ways in which actors in each role interact with the system.

**Software maintainer.** The software maintainer is responsible for ensuring the operation of the EIS by maintaining its source code. ISO/IEC 14764 describes four categories of maintenance activity, which are:

- Corrective maintenance: the correction of software problems after their discovery.
- Adaptive maintenance: making necessary modifications to the software in case its environment changes.
- Perfective maintenance: making modifications in order to improve the software’s performance or maintainability.
- Preventive maintenance: the correction of known software problems before they cause malfunction of the software. (ISO 2006)

**System maintainer.** The system maintainer provides the EIS’s runtime environment and ensures the operation of the EIS. This includes the provision of the hardware on which the EIS runs (the ‘server’), the management and maintenance of the software environment on the server, and the monitoring of the EIS’s operation.

**System administrator.** The system administrator manages users and their access privileges. Each user should only be able to access and manipulate the data they are concerned with: data producers can only access their own datasets, and the rules that define how data is stored and published can only be set by the content authority. The system administrator creates and manages user accounts and sets each user’s privileges.

**Content authority.** The content authority administers the information that is stored in the EIS. These administrative activities include:

- Deciding which information is stored.
- Deciding how information is stored (i.e. defining data models).
- Deciding how information is published.

Because the definition of data models for geographic information requires some amount of expertise in the GIS field, the Department of Geomatic Engineering at KNUST’s College of Engineering—which has already been a part of the development and implementation process of the EIS—is the logical choice of actor to take on the role of the content authority.
**Data producer.** Data producers use the EIS to store information in its database. Since most of the data producing institutions do not have expertise in the GIS field (Mensah 2012, personal communication), the EIS needs to provide a user interface which allows for data creation without the use of professional GIS software. Data producers should be able to create new datasets and to make corrections to existing datasets which they have created themselves.

**Data consumer.** Data consumers have access to the information published on the web by the EIS. Since the main target audience of the EIS is the general public, GIS knowledge cannot be presumed, and the public user interface must be as easy-to-use as possible and—ideally—in line with web mapping applications with which the average user is familiar (such as Google Maps). The EIS should also provide some simple analysis capabilities, e.g. for measuring geographic distances (Mensah 2012, personal communication). Furthermore, information should be easy and quick to locate in the EIS. With a rapidly growing number of internet users in Ghana and the success of social networks such as Facebook (socialbakers.com 2012), the EIS should make it easy for users to share information they found on the EIS with their online friends.

**GIS analyst.** A GIS analyst is an advanced data consumer who requires direct read access to the geographical features stored in the EIS. The EIS must therefore provide an interface to provide this read access, and the interface should be usable by common GIS software.

### 5.1.4 Characterising environmental information

Dr Francis Nyagbenu, regional officer at the Ashanti branch of the Ghana Environmental Protection Agency (EPA), reports that the most pressing environmental issues in Kumasi concern waste management, flooding, water scarcity, public sanitation, air pollution, and noise pollution (Nyagbenu 2012, personal communication). Fig. 8 illustrates how these issues are interlinked. The remainder of this section elaborates on the most central issues and on what their causes and consequences are.

**Waste management.** Inadequacies in waste management appear central to many of the city’s environmental problems. Since public garbage bins do not exist in most areas of the city, littering is common practice. A lack of awareness of environmental issues among the population aggravates this problem. Plastic packaging materials constitute a large and the most problematic fraction of the litter; since they do not decompose, they accumulate until they block sewage and rainwater drains, significantly contributing to flood problems which are common in some areas of town during the rainy season. A further symptom of inadequate waste management is the prevalence of illegal open waste dumps. These dumps contribute to the problem of litter pollution. In addition, a common method of removal of open waste dumps is their incineration. Car tyres are also commonly disposed of by incineration. These practices contribute to air pollution with dust particles, carbon dioxide, sulphur dioxide, and other pollutants. (Nyagbenu 2012, personal communication)

**Flooding.** As in any urban area, a large percentage of Kumasi’s surface area is sealed by roads and built structures. The surface’s capacity for water infiltration is therefore highly dependent on the capacity of artificial water drains. In addition to the drains being frequently clogged by litter, the risk of flooding is continuously aggravated by a changing local climate. This change, likely to be caused by global climate change, air pollution, and the urban heat-island effect, results in altered, more irregular rainfall patterns in the rainy season which feature higher peak rainfall levels, in turn leading to a higher stress of drainage systems (Douglas et al. 2008; Nyagbenu 2012, personal communication).

**Water scarcity.** Whilst global climate change leads to higher peak rainfall levels in the rainy season, it is also held responsible for the trend that the rainy period as a whole is becoming shorter and droughts during the dry
Public sanitation. In addition to open waste dumping and littering, untreated waste water from households and public toilets finds its way into public places through the open sewage system which can be seen in most areas of the city. The problem can be aggravated during the rainy season when flooding leads to the sewers overflowing. Where public toilets are unavailable, open defecation is common. Apart from being an olfactory nuisance to city dwellers, these sanitation issues present a danger to public health as they facilitate the spread of diseases. (ibid.)

Air pollution. Pollution of the air with particulate matter, carbon oxides, sulphur oxides, and other substances is mainly caused by high levels of road traffic in combination with the poor environmental performance of most motor vehicles. Other causes include the open incineration of waste and car tyres, industrial activities, and the use of wood fuel in households. (ibid.)

Noise pollution. The main cause for noise pollution is the high level of road traffic. Minor causes include air traffic related to Kumasi’s domestic airport, religious activities such as street preaching, and nightlife. (ibid.)

Table 3 shows a list of potential categories of information which are relevant to monitoring the main environmental issues. As can be seen, most of the information is, or may be, a geo-referenced. It is therefore important that an EIS for Kumasi can handle geographic information. Furthermore, environmental observations are always subject to change, which suggests that the EIS should treat the temporal dimension—i.e. the date on which an observation was made—explicitly so as to be able to compute trends.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Relevant information</th>
<th>Geometry</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste management</td>
<td>Locations of collection points</td>
<td>point</td>
<td>size, containment, emptying frequency</td>
</tr>
<tr>
<td></td>
<td>Locations of landfills</td>
<td>point/polygon</td>
<td>capacity, used capacity, fill rate</td>
</tr>
<tr>
<td></td>
<td>Coverage of street cleaning</td>
<td>line/polygon</td>
<td>cleaning interval</td>
</tr>
<tr>
<td></td>
<td>Coverage of door-to-door collection service</td>
<td>line/polygon</td>
<td>percentage of households covered, amount of waste collected, collection interval</td>
</tr>
<tr>
<td></td>
<td>Street cleanliness/incidence of open dumping</td>
<td>polygon</td>
<td>cleanliness index</td>
</tr>
<tr>
<td>Flooding</td>
<td>Incidence/severity of flooding</td>
<td>point/polygon</td>
<td>flood index</td>
</tr>
<tr>
<td>Water scarcity</td>
<td>Stream water levels</td>
<td>point</td>
<td>yearly minimum/maximum water level</td>
</tr>
<tr>
<td>Public sanitation</td>
<td>Locations of public toilets</td>
<td>point</td>
<td>mode of waste water sanitation, usage frequency</td>
</tr>
<tr>
<td>Air pollution</td>
<td>Air pollution measurement</td>
<td>point</td>
<td>ozone, particulate matter, CO2, CO, SOx</td>
</tr>
<tr>
<td></td>
<td>Industry CO2 emissions</td>
<td>(non-geographic)</td>
<td>amount of CO2/year</td>
</tr>
<tr>
<td>Noise pollution</td>
<td>Road traffic level</td>
<td>line</td>
<td>daily minimum/maximum vehicles/hour</td>
</tr>
<tr>
<td></td>
<td>Air traffic routes to/from Kumasi airport</td>
<td>line</td>
<td>average air vehicles/day</td>
</tr>
<tr>
<td></td>
<td>Acoustic noise measurement</td>
<td>point</td>
<td>daily minimum/maximum sound pressure</td>
</tr>
<tr>
<td>(indirect)</td>
<td>Incidence of diseases</td>
<td>polygon</td>
<td>incidence rates of the most common diseases</td>
</tr>
<tr>
<td></td>
<td>Income level</td>
<td>polygon</td>
<td>average household income in area</td>
</tr>
<tr>
<td></td>
<td>Water quality</td>
<td>point</td>
<td>water quality index</td>
</tr>
</tbody>
</table>

It has been observed that, as of now, there is little environmental information that is collected consistently in regular intervals covering a defined area in Kumasi. However, universities such as KNUST and administrative institutions such as EPA and KMA do generate a fair amount of environmentally relevant information as the result of scientific studies, regulatory monitoring, and development projects. Because the information is generated by independent sources, it is typically heterogeneous and possibly contradictory. The information may particularly differ in respect to semantics (what is measured and how; how is the measurement expressed), space (which area or location is covered), and time (when was the measurement taken). Since this information constitutes a large fraction of all available environmental information, it is important that the EIS be able to consolidate heterogeneous pieces of information on the same topic, preferably with a minimal amount of human effort.
5.1.5 Summary

Table 4 formally lists the requirements which have been identified. Requirements 1 through 3 are derived from the characterisation of relevant environmental information: the information is geographically and temporally positioned, and is heterogenic in regards to semantics, geographical coverage, and time of collection. Requirement 4, specifying that the system should be ready to be integrated in larger-scale SDIs, is not a requirement that is immediately posed by the current situation; it is rather based on the suspicion that satisfying this requirement will be beneficial for the long-term success and acceptance of the EIS. The remaining requirements are derived from the activities each actor needs to be able to carry out as described in section 5.1.3.

Table 4. Summary of the identified system requirements

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>System can store and present geographical data (points, lines, polygons).</td>
</tr>
<tr>
<td>2</td>
<td>System supports data with a temporal dimension (time of collection).</td>
</tr>
<tr>
<td>3</td>
<td>System is able to combine geographical data that differs in respect to semantics, geographical coverage, and time of collection.</td>
</tr>
<tr>
<td>4</td>
<td>System should be ready to be integrated in larger-scale SDIs.</td>
</tr>
<tr>
<td>5</td>
<td>The content authority can define data models for environmental information.</td>
</tr>
<tr>
<td>6</td>
<td>The content authority can determine which information is published.</td>
</tr>
<tr>
<td>7</td>
<td>The content authority can determine how information is presented.</td>
</tr>
<tr>
<td>8</td>
<td>Data producers can store geographic data without GIS knowledge.</td>
</tr>
<tr>
<td>9</td>
<td>Data producers can create datasets.</td>
</tr>
<tr>
<td>10</td>
<td>Data producers can make corrections to datasets they created.</td>
</tr>
<tr>
<td>11</td>
<td>Data consumers can view geographic data without GIS knowledge.</td>
</tr>
<tr>
<td>12</td>
<td>Data consumers can run simple analyses (e.g. measure distances).</td>
</tr>
<tr>
<td>13</td>
<td>Data consumers can locate information easily.</td>
</tr>
<tr>
<td>14</td>
<td>Data consumers can share information easily online.</td>
</tr>
</tbody>
</table>

5.2 Software design

Based on the identified requirements, a rough design of the EIS was created. The most important design details are described in this section: which basic data structures are used by the system internally to represent environmental and operational information; and the most important use-cases and workflows as perceived by the users of the system.

5.2.1 Data structures

Requirement 3 (‘System is able to combine geographic data that differs in respect to semantics, geographic coverage, and time of collection’) suggests that the system must distinguish between two types of geographical data: data that has been entered by a data producer, and combined data for publication. In the following, the former type of data will be called a dataset, while the latter will be called a composite layer.

Datasets are primary data which are the result of surveys conducted by data producers. A dataset may use a data model which is specific to the dataset and differs from the data models used by other datasets on the same issue, e.g. water quality.

Composite layers describe how the data contained in one or more datasets are published. Data in a composite layer will necessarily have to comply with a certain data model. Fig. 9 illustrates this relationship between datasets and composite layers.

![Composite layers diagram](image-url)
Composite layers not only refer to a set of datasets which they include, but also contain information on how to present the data to the data consumer. As is shown in Fig. 10, composite layers and datasets both are associated with a ‘data model’. Data models describe geographical data both syntactically and semantically: they specify what type of geometry (points, lines, or polygons) can be used in a dataset or composite layer; which attributes are associated with each such geographical feature; and provides textual descriptions of the attributes. Since data producers should only be able to access their own datasets, each dataset is associated with the user who is its owner.

5.2.2 Use-cases and workflows

Three user roles interact with the system’s administrative interface: system administrator, content authority, and data producer. The content authority manages composite layers and data models, while data producers manage their datasets. The system administrator manages user accounts and their access privileges.

From data entry to publication

Two user roles are involved in this process: the content authority defines a data model which is then used by a data producer to create a dataset and fill it with data. The content authority can then add the dataset either to an existing or a new composite layer. At this point, the data from the dataset can be viewed publicly by a data consumer. Fig. 11 illustrates this process.

Combining heterogenic datasets in a composite layer

When two datasets use different data models, their data cannot simply be combined in one composite layer. This is because it would violate the requirement that the data consumer be presented with easy-to-understand and therefore coherent information, and because standard data formats and software make it difficult to treat heterogenic data as a unit. This issue can be resolved by providing the possibility of transforming data between data models as shown in Fig. 12. The transformation process would take place each time a dataset is included in a composite layer, or the data in a dataset changes. The transformation would be specified by the content authority upon inclusion of a dataset in a composite layer.

For example, suppose there is a composite layer called ‘Water quality’ with a data model which has a single attribute ‘Quality index’ which generically specifies water quality on a scale from 1 to 5. If this composite layer is to be used to publish data from various datasets, some using their own quality indices, some simply containing raw measurements, each of these datasets can be included in the composite layer if a transformation can be provided that calculates the ‘Quality index’ attribute from the dataset’s attributes.

Geographical features may be associated with an observation date, and data from different datasets in one composite layer may overlap geographically. It has been decided that, since data is generally scarce, this issue does not need to be tackled explicitly as of yet. However, data consumers should be provided the ability to filter data based on their observation date.
5.3 Implementation

Fig. 13 illustrates the architecture of the implemented system. Central to the system is the EIS web application which is based on the Java EE-platform and provides both a public web front-end to be used for viewing the published environmental information, as well as a data administration front-end to be used by data producers and the content authority in order to manage the data. Both front-ends make use of Google Maps in order to enhance the maps they display with satellite and road map imagery. For data storage, the DBMS PostgreSQL is used, and it contains two databases: one to store metadata (data which describes the geographical data), and one for the actual geographical data. In the latter database, the PostgreSQL extension PostGIS facilitates the storage and management of the geographical data. For publishing the geographical data using the standard WMS and WFS protocols, GeoServer was chosen, which is able to read geographical data stored in the PostGIS format. The maps generated by GeoServer are displayed by the public front-end, and feature data is made available to advanced GIS users using the WFS protocol.

The following subsections detail the implementation of the various components and explain the software choices.

5.3.1 EIS web application

The EIS web application was developed as part of this case study, is based on the Java EE-platform, and utilises only free software components.

**Used free software components**

On the server-side, the popular Spring Framework (including Spring MVC) is used to provide the basic web application functionality. Hibernate, and implementation of JPA (Java Persistence API), provides object-relational mapping (ORM) in order to access the database which holds geographic metadata, while geographical data is managed using plain SQL over JDBC. The library GeoTools is used for handling geographical data internally. GeoServer features an API which allows for the management of most of GeoServer’s internal data structures. The API is based on the REST standard. The application takes advantage of this in order to publish and un-publish geographical data which is available in the database.

On the client-side, the application provides an Ajax-enabled and XHTML-compliant web user interface. In order to provide a desktop-like user experience, the library jQuery UI and some additional jQuery-based components such as Jeditable and DataTables are used. The widely-used library OpenLayers is used for displaying and modifying geographical data visually on a map. The standard GeoJSON format is used for exchanging geographical data between client and server; GeoJSON communication is facilitated by OpenLayers on the client-side and by GeoTools on the server-side. OpenLayers also makes it easy to incorporate third-party map material such as satellite imagery from Google Maps, which is taken advantage of. OpenLayers displays the EIS’s geographical data by fetching via WMS and WFS from GeoServer.

All used software components were found to have a high level of maturity, an exception being GeoTools which was found to be poorly documented.
The public web user interface

Fig. 13. Simplified illustration of the implemented architecture.

Fig. 14 shows the public web user interface of the EIS. It allows for the viewing of geographical data much in a Google-Maps-like fashion. Geographical features can be selected to see their attributes in a dialog window. At the time of this writing, the temporal filtering of information is not yet supported; this should however be easily implemented since WMS includes the possibility for filtering data using CQL (Common Query Language) (OGC 2006) which is supported both by OpenLayers and by GeoServer (GeoServer 2012a). The user interface features a toolbar which provides tools for measuring distances and areas visually, and a ‘Link To This Map’ button which generates a web link which can be used to display the exact same map at a different time or on a different computer, therefore making it easy for the data consumer to share information online. An ‘Add Layers’ dialog window, as seen in Fig. 15, allows for adding and removing data layers from the map. In the dialog, information can be located by filtering the list of all available layers using the keywords which are associated with each layer. Depending on how large the set of available layers may become, this mechanism may have to be extended or replaced by a tree-like categorisation system and a full-text search function. While the creation of this user interface required a considerable amount of programming, it was much facilitated by the free software components OpenLayers and jQuery UI.
Fig. 14. Screenshot of the public web user interface of the EIS

Fig. 15. The 'Add Layers' dialog of the public user interface
The administration user interface

The administration interface is accessible only to the system administrator, the content authority, and the data producers.

The content authority manages composite layers and data models through simple form- and table-based user interfaces like the one shown in Fig. 16. jQuery UI and other jQuery-based components like DataTables are utilised to provide an easy-to-use interface. The user interface enables the content authority to exercise all the use-cases listed in Table 4.

![Kumasi Environmental Information System](image)

Fig. 16. Screenshot of the 'Composite Layers' screen

Data producers create and delete their datasets through a similar interface. In order to edit the actual geographical data of each dataset, they use the editor which is shown in Fig. 17. Just like in the public user interface, the data editor uses OpenLayers to display the geographical data of the dataset, along with an optional background layer from Google Maps. The data producer can add geographical features—points, lines, or polygons—visually on the map and move them around. The attributes that are associated with the features are displayed in a table below the map and can be edited in-place by clicking a table cell. The table is synchronised with the map. The features to be displayed in the table can be filtered by selecting one or more features visually on the map. For advanced users, the editor allows the importation of features from ESRI Shapefiles, a de facto standard file format for geographical data. Upon loading or saving a dataset, the features are transferred between client and server in the GeoJSON format. On the client-side, the functionality to decode and encode GeoJSON data is provided by OpenLayers. On the server-side, this is done using the GeoTools library.
5.3.2 GeoServer

In the EIS, GeoServer is used for two purposes: making the geographical data contained in composite layers available through its WFS interface, and rendering visual maps from the same data and publishing them through its WMS interface. The public web interface accesses the WMS interface in order to display maps to data consumers, and it uses the feature data provided through WFS in order to display feature attributes. In addition, the WFS interface can be accessed by GIS analysts to download the feature data in order to perform more advanced analyses than are possible using the public web viewer. GeoServer can be controlled programmatically using its REST API. The EIS uses this API to control which layers are published by GeoServer. GeoServer is able to interpret Styled Layer Descriptors (SLDs) in order to determine the appearance of a layer—i.e. the colours and graphics used to render geographical data. At the current stage of implementation, SLDs need to be entered manually using GeoServer’s own web user interface. It is, however, technically possible to have the EIS create the SLDs through GeoServer’s REST API (GeoServer 2012b), a feature which could be taken advantage of in the future.

5.3.3 PostgreSQL database

PostgreSQL is used to store both metadata—i.e. information about datasets, composite layers, data models, and users—and the geographical data of datasets and composite layers. The database for geographical data uses the PostGIS extension for PostgreSQL which allows for the querying of geographical data. All data in the two databases is created and manipulated by the EIS web application. GeoServer, with its capability to query PostGIS-enabled databases, reads the composite layer data from the geographical database in order to publish it using its WMS and WFS interfaces.

5.3.4 Environmental data used in the implementation process

During implementation, the system was fed with real data in order to confirm the applicability of the system and aid the agile development process. While the EIS is eventually meant to be concerned with environmental information about the entire area of Kumasi, it was suggested by Mensah (2012, personal communication) that for the purposes of the design, development and demonstration of the system a pilot project should be initiated.
which is limited to the area of the KNUST campus. For this reason, there are two categories of datasets which were used: one set of datasets for the coverage of the Kumasi area as defined by its official administrative boundary; and one set of datasets which are specific to the KNUST campus area. Table 5 shows the datasets which were used for the Kumasi application area. Relatively static base data such as the road and river networks was found to be available at KNUST’s Department of Geomatic Engineering. In addition, a dataset was used containing the locations of all public toilet blocks in Kumasi based on a study conducted at the KMA Waste Management Department (WMD) in 2011. The locations and properties of some waste collection points in the city were derived from Oberg (2011), and some water quality measurements of the Aboabo stream which runs through the city were taken from Boakye (2012). The utilised data was found to be of good quality, with the exception of the very incomplete ‘Built-up areas’ dataset.

Table 6 shows the datasets used for the KNUST campus area. Good quality base data was available at KNUST’s Department of Geomatic Engineering. In addition, the locations and basic attributes of some of the waste collection points on the campus were collected using a GPS-capable smartphone in order to get a feel for a possible way of data collection.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road network</td>
<td>KNUST Geomatics</td>
</tr>
<tr>
<td>Rivers</td>
<td>KNUST Geomatics</td>
</tr>
<tr>
<td>Built-up areas</td>
<td>KNUST Geomatics</td>
</tr>
<tr>
<td>Public toilets</td>
<td>KMA/WMD</td>
</tr>
<tr>
<td>Bantama waste collection points</td>
<td>Öberg (2011)</td>
</tr>
<tr>
<td>Kumasi administrative boundary</td>
<td>KNUST Geomatics</td>
</tr>
<tr>
<td>Water quality of the Aboabo stream</td>
<td>Boakye (2012)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road network</td>
<td>KNUST Geomatics</td>
</tr>
<tr>
<td>Rivers</td>
<td>KNUST Geomatics</td>
</tr>
<tr>
<td>Buildings</td>
<td>KNUST Geomatics</td>
</tr>
<tr>
<td>Waste collection points on Ring Road (south) and Okodee Road</td>
<td>collected by author</td>
</tr>
<tr>
<td>KNUST campus boundary</td>
<td>KNUST Geomatics</td>
</tr>
</tbody>
</table>

6 Discussion

During the course of the study, a basic prototype of an EIS for Kumasi has been implemented based on requirements which were captured by application of a soft systems perspective. The first thing to note is that the conducted analysis is by no means a ‘full’ soft systems analysis, but more of an analysis that takes a soft systems perspective. This is because the amount of time available—3 months—to conduct interviews with the stakeholders and to design the system was not sufficient for the intensive and interactive enquiry process that is SSM. A more detailed analysis would certainly have led to a more accurate list of system requirements. One may however argue that, considering the success of agile software development methods in the industry, the analysis which was conducted in this study produced results which are sufficient for beginning the agile development process, as agile methods only require a rough ‘vision’ of a software system in order to begin implementation (Cohen et al. 2004). Nevertheless, being that—as of now—only a prototype of the EIS has been implemented which is not in productive use, a more detailed soft systems analysis would have permitted better predictions of the required use-cases, workflows, and the organisational sustainability of the system.

The free software components which were used in the EIS prototype were found to provide functionality which allows for most of the identified system requirements to be satisfied without much further work. As far as the EIS is concerned, the specifications of the used standard technologies such as WMS, WFS, and GeoJSON are well met by the used components. While some components were found to be in a less-than-mature state at the time of study, most were easily integrated into the system and fulfilled their respective purpose.

Two essential features described in this report have not been implemented in the prototype of the EIS: support for the time dimension, and the ability to transform geographical data from one data model to another. The study can therefore make no statement about how these specific features may be integrated into the EIS and implemented using free software. One way to go about implementing support for the time dimension may be to add a filter function to the public user interface which allows filtering data within a layer by time. This function may rely on the CQL support of WMS and WFS. Alternatively, in order to allow for more complex temporal
selections, GeoServer may be used to publish multiple versions of the same composite layer, each of which is based on a PostgreSQL view that selects a subset of geographical features in each layer (GeoServer 2012c). As for the issue of transforming data from one data model to another, it may be possible to use an open-source expression parser library such as JEP for defining the computation of an attribute value based on the source attribute values.

There are many possible future features of the EIS which have been found to be reasonable additions, and most of which should be easily implemented with the used stack of technologies. These possible features include:

- In order to make it easier for the data consumers to share maps with their online friends and colleagues, the public user interface could feature buttons which allow the user to quickly share a map on social networks such as Twitter, Facebook, and Google+.

- As was suggested by a lecturer at a presentation of the prototype at KNUST, the EIS could feature a feedback mechanism for users to report environmental issues or incorrect data (Yevugah 2012, personal communication).

- As of now, geographical features in the EIS can have attributes which are either numbers or strings (i.e. texts). If images were added as a third attribute type, information about geographical features could become much more plastic as this would give rise to the possibility of adding, for example, to the information about a waste dump a picture of that waste dump.

- Metadata to be displayed in the public user interface could include legal regulations and recommendations set by the EPA concerning all kinds of environmental observations. This metadata would likely be associated with the data models in the EIS.

- At the moment, layer metadata is not published using the CSW protocol. Once the EIS is to be integrated into a larger-scale SDI, CSW support has to be added. This could be achieved by using open-source software such as degree or GeoNetwork.

An interesting question is how the results of this case study translate for other cities. It appears that the EIS which has been designed for Kumasi depends on (at least) three external conditions:

1. Information about the locally important environmental issues is largely geographical.

2. There is an institution—like KNUST—which is willing to manage the system and drive its implementation, possesses the necessary knowledge in IT, GIS, and environmental sciences, and is independent from the government.

3. There are data producers which are willing and able to provide the locally important environmental information, and possibly an EPA which sets environmental standards in order to provide a frame of reference for the environmental information.

As for other large cities in Ghana, where the institutional landscape can be considered similar to the one in Kumasi and where the most important environmental issues are similar, it is likely that an EIS can be implemented in much the same way as it was in this case study. Towns which do not match the above criteria, such as most smaller towns, will have to take a different, possibly regional approach.

7 Conclusions

The case study has shown that the implementation of an environmental information system for Kumasi, based solely on free software, is viable in the current technical and organisational environment—as far as can be told without actually operating the system productively. KNUST is foreseen to be an adequate organisation to manage the development and operation of the system, since the necessary technical knowledge is available. The successful operation of the EIS relies on environmental information being provided by data producers such as the KMA, the EPA, the Ghana Statistical Service, and various departments at KNUST. The study found that, since environmental information about Kumasi certainly does not exist in abundance, it should be possible to include much of the information that is there in the EIS.

\[^4\] See http://sourceforge.net/projects/jep/
The study found that in creating an environmental information system for Kumasi, the ability to process geographical information is essential. It became evident that especially two of the identified system requirements are of paramount importance: the system must be able to handle heterogenic data, and it must be as easy-to-use as possible in order to become an effective means of environmental communication. With the help of well-known and successful free software components—particularly GeoServer, OpenLayers, PostGIS, and jQuery UI—it is possible to satisfy the requirements with only a relatively small investment of labour. Open communication standards like WMS and WFS enable the system to be integrated in potential larger-scale SDIs at a later point. While some of the required features which were pointed out in this report, as well as many other potential features, have not been implemented yet, it appears certain that their implementation should easily be possible using the technological platform which is already in place.

One particular area of interest was outside the scope of the study: the issue of the organisational sustainability of the EIS. Currently, the system is hosted on an internet server external to KNUST and even to Ghana, and it is not in productive use. Based on the findings, however, it can be assumed that potential issues mostly concern a possible lack of commitment of the system’s stakeholders, especially of the data producers. In addition, if the EIS is to be deployed for actual use, the allocation of a small financial budget for the system’s development and maintenance in order to guarantee a high level of reliability seems inevitable.

The question remains whether, once an environmental information system is set up, it will be accepted and utilised by the targeted data consumers. If it will, it may contribute to increased transparency and therefore to the improvement of environmental policies in Kumasi.

Acknowledgements

I would like to express my gratitude to a number of people without whom this study would not have been possible. First and foremost, I would like to thank my supervisor at SLU, Dr Cecilia Sundberg, for her valuable support and comments on my research, and for making my field research in Ghana possible. Just as much I would like to thank my co-supervisor, Dr Moses Mensah at KNUST, for his direction and support. Mr John Ayer, also a researcher at KNUST, has been incredibly supportive with his connections and his GIS knowledge, as have his assistants, most notably Ms Lily Lisa Yevugah. Dr Fred Anyemadu, researcher at KNUST, and his student, Mr Robert Boakye, have been very helpful in obtaining environmental data to work with during development, as have been Mr Francis Nyagbenu from the EPA Ashanti, and Ms Augustina Boateng and Mr Assibey Bonsu from the KMA Waste Management Department. Dr Tomas Thierfelder, researcher at SLU and evaluator of this thesis report, has provided valuable direction and comments. Finally, I would like to thank my fellow student David for being great company during the stay in Ghana; Prosper, Nelsi, Franca, and Henry for their friendship, help and hospitality; and all my fellow students in the Sustainable Development Master’s programme for countless discussions which have been an inspiration.
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Appendix. Screenshots of the EIS prototype

This appendix contains screenshots of most screens of the implemented EIS prototype.

**Fig. A1.** The public user interface in its initial state

**Fig. A2.** The public user interface with some layers added
**Kumasi Environmental Information System**

**Fig. A3.** Selecting features in the public user interface

**Kumasi Environmental Information System**

**Fig. A4.** Measuring a distance in the public user interface
**Fig. A5.** Logging into the administration area

**Fig. A6.** The home screen of the administration area

**Fig. A7.** Administration area: the list of data models
Fig. A8. Administration area: creating a data model

Fig. A9. Administration area: the list of datasets

Fig. A10. Administration area: creating a dataset
Fig. A11. Administration area: editing a dataset's geographical data

Fig. A12. Administration area: the list of composite layers
Fig. A13. Administration area: creating a composite layer

Fig. A14. Administration area: user management