APPLICATION OF OBJECT ORIENTED IMAGE ANALYSIS IN SLUM IDENTIFICATION AND MAPPING-THE CASE OF KISUMU, KENYA

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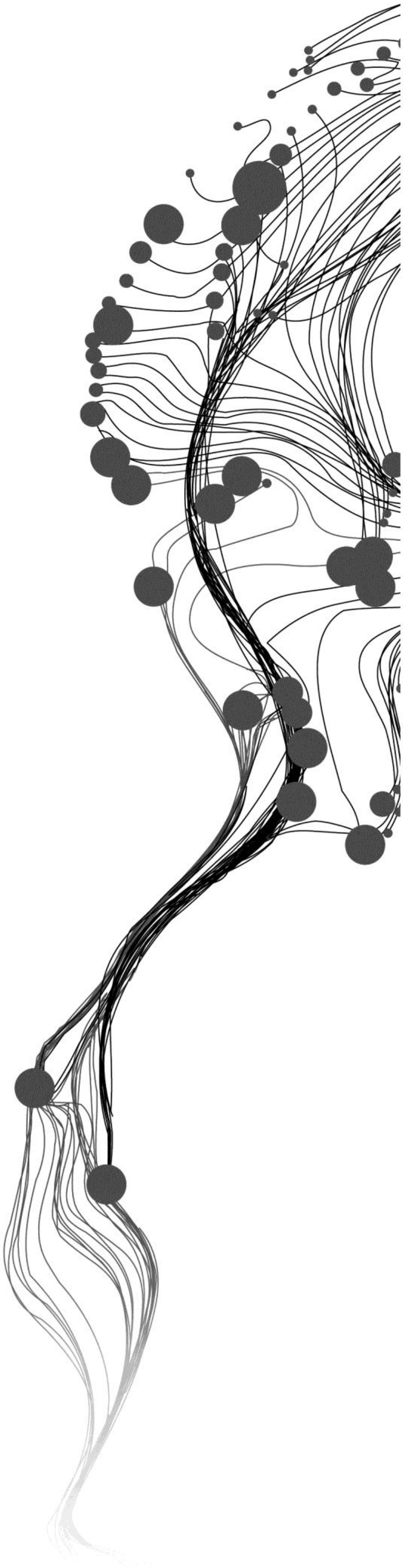

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CAROLINE WANJIKU MATHENGE
Enschede, The Netherlands, March, 2011

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
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Dedicated to:
My parents, siblings and my lovely nephew

ABSTRACT

Lack of knowledge on the location and extent of slums hinders the development of effective slum detection methods. Unfortunately, most methods rely on unreliable national census population data and field based mapping techniques. These are impractical and lengthy techniques such that when completed, the situation on ground may have changed thus not meeting the needs of dynamic situation of slums. Availability of high spatial resolution images, offers new perspective in remote sensing which allows for fast, regular and accurate survey of urban environment. The objective of this paper is to develop a conceptual framework to develop and characterise slums with VHR Geo Eye imagery of 2009 and domain expert knowledge on remote sensing. The approach is based on (1) finding out stakeholders involved in slum intervention and their information needs and what this research can find (2) definition of indicators of slums derived from expert knowledge and by visual image interpretation technique, (3) the development of a local ontology that represents the Kisumu slums and (3) transfer of these ontology concepts into an Object Oriented analysis method using the high resolution imagery. The methodology of this study builds on the idea of ontology driven slum detection in OOA. This study demonstrates how the concepts of ontology are linked with OOA to identify slums. The benefits and limitations of this methodology are discussed. The results are (1) needs assessment matrix for the stakeholders of slums (2) Identification of relevant indicators to define and extract Kisumu slums (3) linking of ontology to OOA (4) a local ontology characterising the slums. The results demonstrate the feasibility of the approach. In conclusion, the research reflects on the results, general limitations and future research.

Keywords: *Stakeholders needs assessment, Ontology, object oriented image analysis*

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Caroline Wanjiku Mathenge
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ACRONYMS

CBD	Central Business District
CBO’s	Community based organisations
DSM	Digital Surface Model
GEOBIA	Geographic Object Image Analysis
GUO	Global Urban Observatory
KIWASCO	Kisumu Water and Service Company
MDG	Millennium Development Goals
MoH	Ministry of Health
MoR	Ministry of Roads
OOA	Object Oriented Analysis
VHR	Very High Resolution

1. INTRODUCTION

This chapter presents an introduction to the study, the main topics and components of the thesis narrowing down to the research problem, research objectives, research questions and justification. It discusses the themes of the thesis where the focus of this research is on linking ontology with OOA for slum mapping and characterisation.

1.1. General Introduction

Rapid urbanisation has led to the migration of people from rural to urban areas in search of better opportunities like employment and services. This has increased the demand for affordable housing in urban areas. However, most of the urban economies of the developing countries are unable to meet these demands making people to move to the slum areas where they can afford thereby contributing to the growing number of slum population (UN-Habitat, 2003b).

A slum is a collection of households living in close proximity to one another in a number of buildings such that the households share one or more deprivations of: access to improved water; access to improved sanitation facilities; sufficient-living area; structural quality/durability of dwellings; and security of tenure(UN-Habitat, 2003b). According to UN-Habitat(2003a), the biggest proportion of world's total slum population is from the developing world. Every year the world's slum population increases by approximately 70 million people, leading to a greater demand for the provision of shelter, employment and urban services (UN-Habitat, 2003b). On a positive note, a total of 227 million people have moved out of slum conditions since 2000 (UN-Habitat, 2010) The report indicates an achievement of the United Nations Millennium Development Goals (MDG) which sought to improve the lives of at least 100 million slum dwellers by 2020. This not withstanding, the number of slum dwellers has increased from 776.7 million in 2000 to approximately 827.6 million in 2010(UN-Habitat, 2010). The increasing number of slum dwellers poses a threat to the environment and thus require more intervention efforts in this direction. The provision of suitable intervention requires adequate information about slums through effective detection for monitoring and also to understand the different phases of slum developments. The case study of Kisumu city in Kenya will is considered as it is part of the slum upgrading programme being implemented by UN Habitat (UN-Habitat, 2005)

1.2. Background and Justification of Research

1.2.1. Slum mapping approaches

In many countries, local authorities have limited understanding of the slum location, extent and their dynamics. Given the expected increase in the number of slum dwellers, there is also a growing need for sound methods to effectively identify and monitor slums and informal developments (Sliuzas et al., 2008). Reliable spatial information about informal settlements is vital for any actions of improvement of the living conditions (Hofmann et al., 2008).

Over the years, several approaches have been used to detect slums. The participatory approach measures poverty in terms of local perceptions of poverty, which are identified and quantified to construct regional poverty measures. Karanja (2010) used the participatory approach to map informal settlements by involving the inhabitants to collect data on house structures and features per household. Utilisation of this measure is limited to areas where people know about their neighbours and also participation from the people (Ravnborg, 2002 cited in Davis, 2003).

The livelihood approach locates areas of deprivation using expert opinions to categorise households by asset structures. This approach uses a combination of qualitative information and secondary data to reveal the location and determinants of poverty. Livelihood approach was discarded because it condensed so much information making the information meaningless. Multivariate weighted basic needs index which are used for disaggregated poverty mapping involves factor analysis, principal components and ordinary least squares (Davis, 2003).

Another approach is the use of census data either at household level or community level. Weeks et al., (2007) used this approach to identify slums in Accra, Ghana. The study utilised census data to acquire information on socioeconomic characteristics that related to the UN Habitat slum criteria. The study concludes that the pattern of slums is not continuous and images can be used to select indicators of slums using a combination of impervious surface, bare soil and little vegetation. Davis (2003) criticises this approach as the survey data are clustered and collected at too aggregated a level to be of much help in constructing disaggregated poverty maps. These current practices in spatial analysis related to slums are based on fairly simple aggregations of slum household data according to Enumeration Areas (EAs) in which the households reside. Any EA in which more than 50% of the population is deprived in terms of one of the four operational slum indicators of the UN Habitat is considered a slum (Sliuzas et al., 2008). This approach of spatially defining slums has been adopted out of pragmatic considerations largely relating to available data. This often results in several problems since variables or characteristics specific to the settlement level such as condition of the roads, drainage, air pollution, location, etc. are not considered (ibid). Traditional methods like statistical, regional analyses and fieldwork are limited to capture the urban process (Niebergall et al., 2007). Informal settlements are highly dynamic and therefore require an alternative approach and a reliable procedure for detection and monitoring. Hofmann(2008) acknowledges that remote sensing and image analysis can certainly contribute to monitoring the spatial behaviour of the informal settlements.

1.2.2. The role of remote sensing for detecting and analysing slums

In the past decades, aerial photographs have played an important role in mapping. However, satellite data are becoming increasingly available with spatial resolution of 1 m or better (Yu et al., 2006). They are considered to be an essential data source as they provide timely and valuable information for analysing the landscape. In general, the benefit of using remotely sensed data can be viewed from three perspectives:

- They provide spatially consistent datasets that cover large areas with both high detail and high temporal frequency (Herold et al., 2001);
- They save cost and time through quick detection as well as providing site specific information on natural and manmade features; and
- They combine both high accuracy and affordability since the same database can be used by a cross-section of agencies reducing data redundancy and effort duplication

Image analysis can be done in two ways:

- Pixel/spectral based supervised and unsupervised classification where classification is done based on spectral reflectance of a pixel;
- Object based- which utilises rule based, knowledge based techniques.

A number of attempts have been made to identify slums from remotely sensed data by use of traditional pixel based method. Šliužas (2004) studied the citywide estimation of development density in informal settlements from SPOT satellite images of Dar es Salaam. Jain (2007) exploited the potential of IKONOS panchromatic and multispectral fused product to identify informal settlements by applying pixel-based digital classification to find the extent of these structures with special emphasis on temporary structures using plastic roof material. The result of these studies led to misclassifications since urban areas are complex and have a high degree of heterogeneity. This weakness of pixel-based is confirmed by the study of Thomas et al. (2003), who compared three different methods namely (1) combined supervised/unsupervised spectral classification, (2) raster-based spatial modelling, and (3) image segmentation classification using classification tree analysis. The results showed that mapping high-resolution data using purely spectral information resulted in relatively low map accuracies while using image segmentation and classification tree approach increased map accuracy. Although supervised classification has been used to classify urban areas, they have also caused 'mixed pixel' problems particularly for specific urban classes. Sometimes pixel-based classification is referred to as spectral or point classifiers because they consider each pixel as a "point" observation (i.e., as values isolated from their neighbours). Although point classifiers offer the benefits of simplicity and economy, they are not capable of exploiting the information contained in relationships between each pixel and those that neighbour it (Campbell, 2002). They also cause mixed pixel problems especially while classifying urban classes. Failure of these approaches calls for an alternative image processing and classification approach to address these problems. Despite the innovative approaches in remote sensing, existing problems mentioned previously, have led to a paradigm shift from pixel based to object based methodology.

1.2.3. Object-oriented Analysis (OOA) for slum identification and mapping

Object Oriented Analysis (OOA) involves partitioning image into meaningful objects called segments, and assessing their properties by use of spectral signatures, geographical features and topological properties. These features are used in recognition and classification process (Durand et al., 2007). The use of this semantic information in classification is an important goal to increase the accuracy which is absent in per-pixel approach.

Several studies have demonstrated the usefulness of object based approach by comparing pixel based and object oriented classification. For example, a study to identify urban structures and its dynamics was evaluated using Quick Bird satellite image in Delhi India. OOA was used to classify different settlement types in the urban area with the aim to detect informal settlements (Niebergall et al., 2007). The results were compared with pixel based classification and found out the following limitations: It cannot be used for complex urban environment; it utilises only spectral response while object based contain additional information like texture, shape and relations to the neighbour. This is useful since information necessary to interpret an image is not represented in a single pixel but in image objects and their mutual relations (Bhaskaran et al., 2010).A comparison per pixel classification and object oriented classification(Yuan et al., 2006) was carried out using Quick Bird image of 2003. The results showed that object based classification produced more homogeneous land cover classes with higher overall accuracy compared to the results of the pixel based. Bhaskaran et al., (2010) used a combined approach of per pixel and object oriented classification to test accuracy improvement. First, pixel based classification was carried out which led to a good classification, however, there was mixed classification for two classes. This was followed by applying an object oriented approach which led to improved classification for both classes. The strengths of OOA are discussed below:

Spatial relationship

A human observer can easily categorize an image into classes of interest but it is generally difficult to reproduce the same result using a computer. The emerging object-based methodology for image classification appears to be a good way to mimic the human thought process(Marpu et al., 2008) It effectively integrates feature knowledge based on the definition of the objects by using shape and context information of a scene texture unlike pixel based techniques which only use layer pixel values. (Bhaskaran et al., 2010; Lang, 2008).It is based on segmenting the image into homogeneous pixels and classifying this objects using spectral, spatial, textural, relational and contextual relationships (Bhaskaran et al., 2010).This relationship increases the accuracy of the value of final classification which cannot be fulfilled by pixel based approach (Benz et al., 2004).

The value of an OOA can be proved by the following studies: Zhang et al.,(2001) tested the performance of different textural features on SPOT panchromatic imagery to identify the spatial pattern of the city of Beijing in China; Karathanassi et al.,(2000) used texture measures to classify built up areas according to different density categories; Su et al., (2008) utilised textural measures and local spatial statistics in object oriented classification of Kualur Lumpur in Malaysia using Quick Bird Image of 2004. The results showed that visually different urban patterns could be classified using a combination of different texture features. These use of texture information increases classification accuracy of remotely sensed data(Angelo et al., 2003).

Narumalaniet al.,(1998) utilized geometric attributes of spatial information to resolve some of the spectral confusion that occur during per pixel confusion. The accuracy levels of the image classification were significantly improved. Another study conducted by Grewe et al., (1993) also found out that integration of geometric and non-geometric information was ultimately necessary to obtain high classification of remotely sensed data. Classification by use of contextual information for example shadow (Zhou et al., 2009) have also improved classification. Jin et al.,(2005) used structural, contextual and spectral information for automated building extraction using IKONOS imagery of 2000 for the city of Colombia.

Iterative process

Objects of interest are extracted through an iterative process of segmentation and classification, this is very convenient to refine object based classification, (Yuan et al., 2006) and ensuring successful information extraction from an image (Benz et al., 2004). Object oriented analysis allows the use of different parameter settings through multiple segmentation options. Image objects can be extracted by using different segmentation parameters such as shape, colour, compactness and scale thus providing information on various scales(Hofmann et al., 2008). The user can define the acceptable level of heterogeneity with large scale parameter resulting into large objects and vice versa for small scale.

Capable of using multiple and thematic layers

OOA is also capable of using multiple data types during analysis to help create meaningful segments. Thematic layers add additional information to an image which are used to store and transfer results of analyses (Definiens, 2008).Layers such as DSM, parcel boundaries and roads can be used as thematic layers to create meaningful segments (Teo et al., 2004).Thematic layer information can be used to describe an image object and result into multiscale segments.

Fuzzy logic

OOA provides meaningful information by allowing integration of fuzziness in the boundaries of classes. It allows for this area of transition by using fuzzy classification (Benz et al., 2004).

Multiple scales

OOA allows for more than one level of analysis. For identification of features in an image through classification, it requires objects of different sizes which are linked(Benz et al., 2004). The objects are networked in a hierarchical manner where each image object is connected and knows its context, its neighbours, objects above it (super-objects) and objects below its (sub-objects).This is as shown in Figure: 1-1 below.

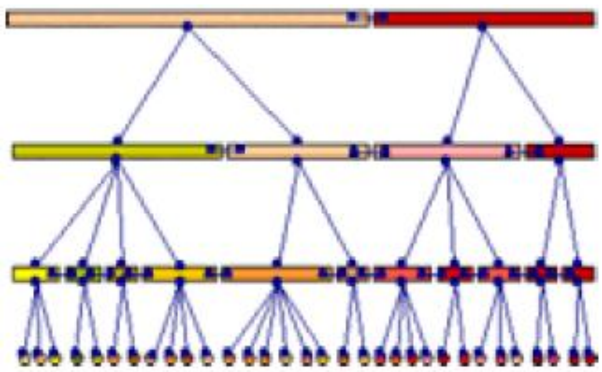

Figure: 1-1: Level of hierarchical network of image objects(Benz et al., 2004)

This spatial relationship allows for more than one level of analysis which is useful in providing information on several scales through different parameter settings. This is similar to using different spatial knowledge of different professionals in manual image interpretation, where the knowledge of each image expert is used for analysis. To ensure stable hierarchy levels, the hierarchical segmentation of the image is achieved through a predefined order, data membership factor and selected segmentation parameters (O Mavrantza et al., 2007)

1.2.4. Work done by use of OOA

OOA successfully identifies roads, buildings and other anthropogenic features better than pixel-based classification techniques which can hardly produce satisfactory classification results for identifying individual objects (Mladinich, 2010).In the domain of slums, OOA has been carried out in several studies: Hofmann et al.,(2008) detected informal settlements from Quick Bird imagery. Ontology was developed which was used to guide the classification process. Aminipouri (2009) used VHR orthophotos to detect slum buildings for three slum areas in Dar es Salam in order to estimate the slum population. Nobrega et al.,(2008)detected road features for informal settlements near Saulo Paulo, Brazil. OOA has also been applied successfully in urban environment. Durieux et al.,(2008), extracted buildings for urban sprawl monitoring. (Stow et al., 2007)detected residential buildings in Accra, Ghana.

OOA has also been used for studying urban social vulnerability assessment case study of Tegucigalpa in Honduras(Ebert et al., 2009). A combination of Quick Bird image and DSM were used in extraction of urban buildings which were used for vulnerability assessment. The height information in DSM was used to segment buildings that were exceeding a certain height and finally they were classified as buildings.

Apart from detection of built up environment, OOA has also been successful in other fields for example: reviving legacy maps (Kerle et al., 2009), urban forest mapping (Walker et al., 2007), assessment of landslide susceptibility (Park et al., 2008), mapping of benthic marine habitats (Lucieer, 2008) and oil spill contamination mapping (Hese et al., 2008). The advancement in feature recognition and advanced image analysis techniques facilitates the extraction of thematic information, for policy making support and informed decisions, irrespective of particular application fields (Lang, 2008). Förster et al.,(2008) detected forest types and habitats using VHR Quick Bird and additional data of altitude aspect, slope and soil type data. The results showed higher classification accuracy for the classification of forest types using ancillary information. Object oriented classification is therefore a useful and promising method for classifying objects from high resolution images particularly for urban features. Key interest in this research is in urban form and function for example roads, buildings, vegetation which are made up of objects rather than pixels.

1.3. Research Problem/Gap

i) Methodological Gap

In section 1.3 the application and usefulness of OOA have been discussed. Nevertheless, significant research questions remain. There is a need for developments in image classification techniques that offer improved representation of complex environment (Blaschke, 2010). For example, successful image analysis requires knowledge about the underlying problem. The better the knowledge about the process, the better this process can be represented in the system and the more useful the extracted information will be (Benz et al., 2004). One of the ways of incorporating expert knowledge into OOA is through clear definition of object of interest.

Ontology is an attempt to capture the knowledge in a systematic way by breaking it down into the types of entities (concepts) that exist and the relations that hold between them(Lüscher et al., 2008). It entails the description and representation of the knowledge about real world phenomenon using a defined language which has to follow predefined rules (Hofmann et al., 2008). Mapping slums in imagery using OOA, requires a good description of the knowledge about slums which is encoded into OOA for it to effectively detect them. The development of the slum ontology, based on morphological indicators for the classification of slums will be an answer to effective knowledge input. Ontology will help understand the characterise slum in order to effectively monitor and control them. Since ontology uses a combination of factors to describe an object, it is transparent, flexible and therefore less resource is used to achieve an optimal goal.

A generic ontology of slums was developed based on the following characteristics to differentiate slum from planned areas: orientation, size, tone, colour, shape, texture of buildings; presence of roads - type of road –gravel or sand/mud width / length of roads; presence of green spaces or parks (vegetation area); and neighbourhood of settlement and location in hazardous zones (Kohli, 2010). However, this generic ontology of slums is too general which can be used as basis for all slums but a local adaptation is required. This is because there is no one set criteria to define slums and description depends on the local context as there may be variation in size, density and building materials because of climatic conditions and dependency on local materials (Sliuzas et al., 2008).

Few researches have focussed on the development and use of the domain knowledge for identifying and classifying slums. For example only one research by Hofmann et al. (2008), have demonstrated ontology description of informal settlements as representation of their knowledge using a defined language. However, my research study was based on a broader framework integrating comprehensive knowledge from domain experts by testing the adaptation of the generic ontology in the development of a local slum ontology. Another research not related to slums by Lüscher et al. (2008) used ontology to automatically detect terraced houses. The research showed how textural description of urban pattern could be used to define an ontology which was then used to detect these patterns. Therefore major work in this research will be to find out how best ontology can be used to represent the slums. The generic ontology will be constrained to develop a local ontology of the slums which will be an input for OOA.

ii) Lack of specific definition of slums

Slums vary between countries and also within the same country. It is not necessarily the highly dense parts are slums. They are also defined differently in different countries. The generic ontology is meant to be universal therefore the local ontology should be adaptable to match with the local situations. There is a need for knowledge conceptualisation to effectively define the slums in the local situation in Kisumu.

1.4. Research objective

To develop a methodology using slum ontology and object oriented analysis for detection, mapping slums and its characterisation in the city of Kisumu, Kenya

1.4.1. Specific Objectives

In order to achieve the main objective, several sub objectives have been drawn:

1. To perform a needs assessment for the stakeholders of Kisumu
2. To develop a local ontology for slums in Kisumu based on the generic ontology of slums
3. To link ontology into OOA
4. To identify and classify slums based on the indicators identified from the local slum ontology

1.4.2. Research questions

In order to achieve the research objectives, research questions have been formulated for which specific answer will be sought. The research questions are written in the table below together with the corresponding research objective.

Table 1:1: Research objectives and questions

No	Research objectives	Research questions
1	To perform a needs assessment for the stakeholders of Kisumu Slums	Who are the stakeholders of slums? What are the needs information of the stakeholders? How can the needs of the stakeholders be answered?
2	To develop a local ontology for slums in Kisumu based on the global ontology of slums	What contextual and spatial characteristics define slums in Kisumu? How can generic ontology of slums be refined to enable to identify indicators that apply to Kisumu city?
3	To Link ontology to OOA	How to translate the indicators into image based parameters To explore how ontology can be used as a basis to bring knowledge into the OOA process
4	To identify and classify slums based on the indicators identified from the local slum ontology	Can object oriented analysis be used to classify slums?

1.5. Conceptual Framework

A conceptual framework concentrates on issues that the study is entailed relating it to the specific research problem (2005). In this study three (3) key concepts and their relationships that will be investigated to detect the slum areas of Kisumu. The linkages between concepts of ontology, OOA, and slum mapping will be explored (see the conceptual framework presented in Figure 1-2)

To be able to map the nature of slum, its location or the pattern of slum's development, there is a need to define what a slum is. These indicators can be identified by developing ontology for identifying slums. The ontology definition will help to come up with rules to be used in object-oriented classification. In slum ontology, two main aspects are distinguished: generic and local ontology. The former describes the characteristics of all slums at the global level. In the latter, it describes the characteristics of the slums in Kisumu.

These characteristics, as identified in the ontology will be used to build rule sets for the object-oriented analysis. OOA is process of image analysis characterized by transformation of knowledge which involves feeding rules into the computer (Lang, 2008). Image segmentation is the first and important step as it is the basis for classification of an image and results in group of pixels with similar values(Nobrega et al., 2008).

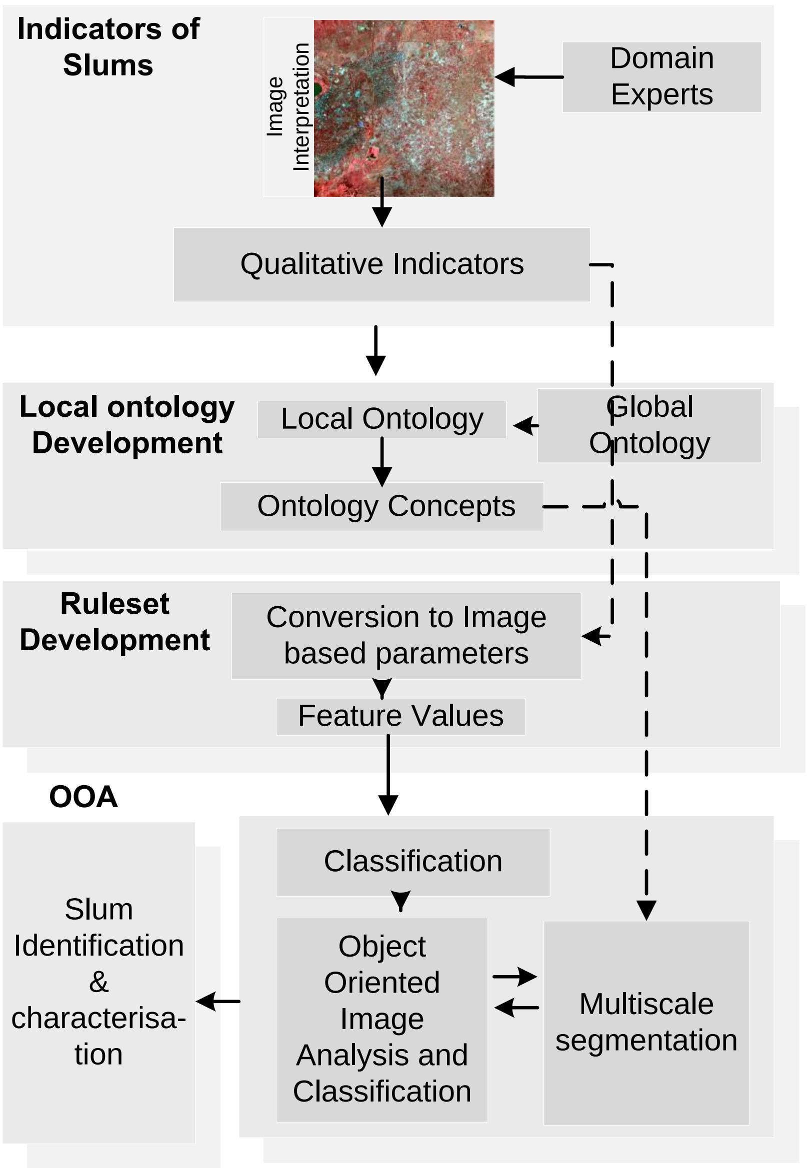

Figure 1-2: Conceptual Framework

1.6. Research Matrix

The research matrix below indicates the required data and the tools needed to accomplish the various sub-objectives and achievement of the main objective.

Table 1:2: Research matrix

No	Research objectives	Analysis Method	Data Requirements
1	To assess the needs of the stakeholders	Literature review	Literature
2	To develop a local ontology for slums in Kisumu based on the global ontology of slums	Literature review Visual image interpretation	High resolution imagery Ground truth data of pictures showing different building types
3	To link ontology with OOA	Literature analysis OOA	Literature
4	To identify and characterise slums based on the indicators identified from the local ontology	OOA	Classified image

1.7. Significance of the proposed study

This study will focus on development of new methods and concepts that will involve a combination of slum ontology and image classification for slum mapping. The study will generate knowledge by extending the ontology framework to a local level which will effectively map the Kisumu slums. This information therefore, can be used by local authorities, government bodies and NGO's involved in slum upgrading and monitoring. The planning of the city can take into account the findings from this research.

1.8. Anticipated Results

- Information needed by stakeholders involved in slum intervention.
- A list of indicators that characterise slums of Kisumu are identified
- Local ontology
- Encoding of ontology into OOA
- Slum identification and mapping

1.9. Structure of thesis

Chapter 1 introduces the research, the background information and discusses the problem. The chapter discusses the main concepts based on which the objectives and research questions are defined. The chapter also discusses the main research approach of the study.

Chapter 2 reviews of related literature of the study. It explains the theoretical foundation of the study. It reviews the concepts of definition of slum, ontology and image analysis. Object-oriented image analysis technique in slum mapping was also reviewed. The chapter also reviews the concepts underpinning the development of indicators for slum identification.

Chapter 3 presents the demographic information and the physical characteristics (administrative and geographical location) of the study area. The chapter also discusses the data used and the limitations of the data.

Chapter 4 presents the methodological framework within which the research was carried out. It discusses the schematic presentation of study approach adopted for in the research.

Chapter 5 presents the results and discussion of the study in terms of the outlined research objectives. It first analysis stakeholders needs assessment followed by results and discussion of other objectives the development of the local ontology. It then presents the results on the object-oriented image analysis. The possible reasons for some of the results will be discussed.

Chapter 6 discusses the findings of the study. The discussions focus on the effectiveness of the ontological concepts in slum identification and results achieved in meeting the needs of the stakeholders involved in slum intervention and

Chapter 7 gives conclusions on the research based on the lessons learnt from the analysis and makes recommendations for further research work.

2. SLUMS, ONTOLOGY AND IMAGE CLASSIFICATION

This chapter looks at the various slum definition, elements of ontology, the importance of ontology, related work of ontology, and outlines the milestones achieved in this subject area. This is followed by a review of the OOA technique. For every image analysis there should be a mental concept constructed into methodological steps which is formalised in ontology and rule set is developed which is fed into OOA for it to recognize the objects of interest.

2.1. Slum Definition

Since it first appeared in 1820's the word slum has been used to identify poorest quality housing, most unsanitary conditions, places for crime and drug abuse. Moreover, in developing countries, the word lacks the critical and original connotation and simply refers to lower quality or informal housing (UN-Habitat, 2003a).The lack of precise definition of the concept 'slum' contribute to the lack of effective and tailored policy response'(http://www.ucl.ac.uk/dpu-projects/Global_Report/cities/nairobi.htm). Even though slums show some commonalities they have diverse characteristics and they are defined differently in different countries making international comparisons and global monitoring of intervention plans difficult. In the following table definition and description of some slums are shown in the Table 1:1.

City	Official definition	Unofficial definition
Nairobi, Kenya	None	Difficult areas that lack most basic services and infrastructure
Durban, South Africa	Previously Informal settlement that has degenerated and needs to be rehabilitated.	Bad area where unsociable activities occur
Los Angels, USA	Blight areas with deteriorated housing conditions.	Where no middle income person could spend a night
Bogota, Colombia	Urban settlements in which the occupation and development of the terrain occur without any plan and without the corresponding permits and licences officially requires.	Spontaneous settlements that do not fulfil the urban rules, and which concentrate migrants and poor populations.

Table 2:1: Slum definition in different countries

Source: (http://www.ucl.ac.uk/dpu-projects/Global_Report/world_map.htm)

To address this problem, definition of slum was developed by an expert group meeting organised by the UN HABITAT in the year 2002 with the following indicators of slum household for international usage

- Inadequate access to safe water
- Inadequate access to sanitation and other infrastructure
- Poor structural quality of housing
- Overcrowding
- Insecure land tenure

Local variations among slums are too wide to define universally applicable criteria (UN-Habitat, 2003a). It is important to solve the ambiguities involved in defining a slum in the local context through a consensus between various experts to ensure effective detection and analysing them. Therefore the need for understanding and representing knowledge about slums in the local context is important. To deal with the varying concepts of slums, there is a need to conceptualise them by use of slum ontology. The following section first discusses mapping by use of OOA alone, the later section defines and shows the importance of integrating ontology in mapping.

2.2. Approaches in bringing conceptualised knowledge into OOA

2.2.1. Data driven

There are several approaches in bringing formalized conceptual knowledge into OOA. Most classification methods adopt a data driven approach by using a single classification algorithm (Haiwei et al., 2010). However, real world objects are too complex to be classified by this monostrategy approach. Several studies have used these data driven approach for recognition of objects in an image. Recently (Martha et al., 2010) identified landslide candidates from a multispectral data and a digital terrain model in the rugged Himalayas of India by creating a routine in OOA. By visual image interpretation, features of interest were characterized and an algorithm was created in eCognition software for recognition and classification of landslides. They first identified landslide candidates, got rid of many different false positives and then classified the remaining segments into five landslide types. Here, landslides are morphological in nature where the definition is solely on the physical characteristics unlike in slum definition where it is defined from different aspects. Mavrantza (2008) designed a knowledge based system for the identification and classification of geologic lineaments. They used edge map, LANDSAT image, geologic layers and the ETM image. Segmentation was performed to achieve the target objects at each level. This was followed by classification using both spectral and contextual attributes that were determined for each designed objects at each level. The results were classification map at each hierarchy level. However, one of the setbacks they experienced is that the knowledge based created was dependant on data and too general to cover other geologic cases. Hoffman (2001) conducted object oriented informal settlements detection using IKONOS image data. He used explicit slum description obtained from the IKONOS data to extract the slum areas. The results were promising but were very dependent on the data used and the results could not be applied to other areas. This study would have benefited from the use of ontology as illustrated by a second study of Hofmann (2008) where they reapplied a redesigned class hierarchy of the first study and took ontology into account. Ontology was developed to identify unique properties of informal settlements and common characteristics with other types of settlements. Image segmentation and knowledge description was driven by ontologies of the desired objects than by the data used. To extract the informal settlements, image segmentation was done to generate image objects that represented the developed ontology. This was performed at two levels; base level segmentation to represent the roof and top level segmentation to represent the settlement areas. The results showed a significant simplification in the class hierarchy leading to a transparent and easy extraction of the desired objects and also with a higher accuracy. This can be confirmed by the work of Fonseca et al., (2002) who integrated ontologies with GIS. This led to high level integration and the user was provided with a guide for generalized operation. By using the ontology approach led to better integration, offers common ground for in which two technologies can meet each other.

2.2.2. Ontology driven/Use of Domain knowledge

Another approach in knowledge incorporation in object oriented analysis is to develop ontology of the objects to be detected. This involves formulating and applying image independent knowledge about the spatial behaviour of the desired objects (Hofmann et al., 2008). Ontology is very important in the urban field since the definition of objects for example slums is not only based on the physical characteristics as seen from previous review. There is a divergent physical, social, political point of view across different localities that give a formalized definition of a slum. Therefore, ontology will be able to breakdown the different representation of slums and show their relationship. Ontology is the backbone of OOA as Chandrasekaran (1999) points out that object-oriented design of software systems depend on an appropriate domain ontology. This can be illustrated by the work of Gamma (2002) who used concepts of ontology to design the object oriented software to be used by engineers in sharing the knowledge about the software design.

The term 'ontology' comes from the field of philosophy and is defined as knowledge representation about a concept (Gasevic et al., 2009). They are content theories of objects and the relations between them that are possible in a specified domain of knowledge (Chandrasekaran et al., 1999; Lüscher et al., 2008). This concepts may include for example buildings, water, vegetation etc where their characteristics and their relation to each other are defined (Durand et al., 2007; Gasevic et al., 2009). They provide potential terms for describing our knowledge about a domain (Chandrasekaran et al., 1999). It is the knowledge representation about a phenomenon using a defined language (Hofmann et al., 2008). Durkin (1996), defines this knowledge as an understanding of an area. Any given domain of reality can be viewed from a number of different ontological perspectives (Smith et al., 2004) as it is defined differently across diverse disciplines. Guarino et al., (1998) makes a differentiation between an ontology and conceptualization. In the same vein, Hofmann et al., (2008) also notes that this knowledge representation from various point of view is known as domain. In image analysis, there are two types of domain; image domain and real world domain. The former describes the general observable properties for example of an informal settlement. The latter describes the pattern of phenomenon that can be detectable from the image.

Ontologies are important due to the following reasons: They help to integrate structural knowledge about concepts into the reasoning process and hence is capable to detect complex concepts (Lüscher et al., 2008). They play a role of a dictionary as they provide names to define a subject area (Gasevic et al., 2009). This is because they help identify the categories that are involved in understanding discourse in that domain (Chandrasekaran et al., 1999). Some of the cons of the ontology is that it is tedious, time consuming especially when constructing from scratch (Kovacs et al., 2007; Matteo et al., 2007) and there is no coherent conversion from conceptual ontology to logical ontology (Kovacs et al., 2007)

Various researches have used ontology for object recognition. A recent attempt to detect objects using ontology was evaluated using a Quick Bird image in Strasbourg, France. The ontology was developed using a machine learning tool. Image was first segmented and resulted to regions which were characterized by features related to spectral, spatial and contextual properties. Each region was matched with the concepts of the ontology and it resulted to the identification of three classes of objects from the raw image that is water, roads and orange house (Durand et al., 2007). This paper defines clearly how to recognize objects based on ontology as the results showed that a large part of the image was recognized. However, caution was advised as there is no perfect segmentation method that exists as it resulted to some houses not correctly segmented. Reason being that, images can either be under segmented or over segmented leading to regions not in line with characteristics in the ontology. It is also knowledge driven and transferability of the methodology is difficult.

Another study using ontology approach was carried out to detect informal settlements in Rio de Janeiro (Hofmann et al., 2008). This approach was based on development of a general ontology based on characteristics of super objects (informal settlement) and sub objects: buildings, roads and vegetation. Image segmentation was done at two levels to match the ontology description of an informal settlement. Top level consisted of settlement area while base level consisted of small houses, small road segments and small vegetation areas. The image objects of each segmentation were linked to each other in terms of hierarchical net of objects. This made it possible to describe the spatial relationship between informal settlement and small houses which were expressed by the detectable indicators like roofs and shadow which acted as informal settlement indicators. The density of these indicators was used to identify informal and formal settlement. The results showed that ontology driven class description is more transferable to different data driven class hierarchy and produced enhanced projects and classification results with high accuracy. Ontology has to describe a phenomenon both in the real world domain and in the image domain and therefore both phenomenological and remote sensing ontology was developed with their specific elements as illustrated in figure 2-2 and 2-3

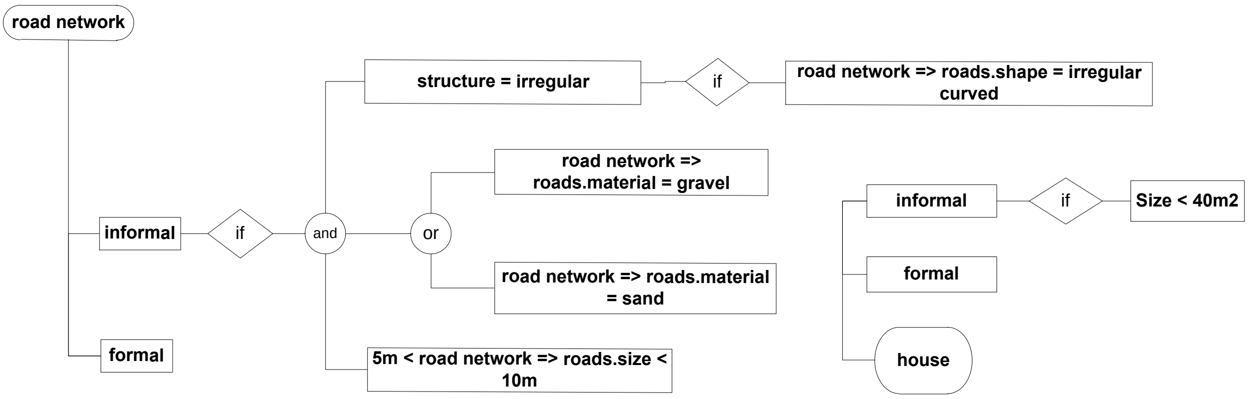

Figure 2-2: Ontology description of road network and house in the real world domain (source: Hofmann et al., 2008)

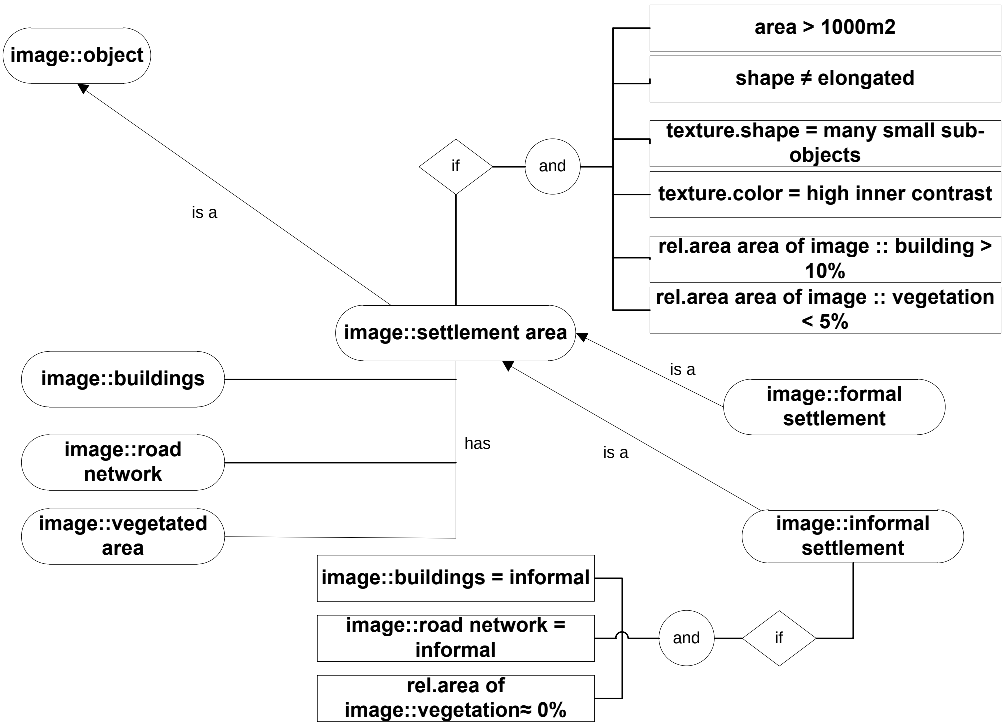

Figure 2-3: Ontology description for informal settlement in the image domain (Hofmann et al., 2008)

This ontology of informal settlements was developed from a general point of view and therefore there is potential for enhancement in automation and quality.

This ontology driven approach was also applied in urban environment on Master Map data of Edinburgh, Scotland (Lüscher et al., 2008). The approach utilized textual description of urban patterns to define ontology which was in turn used to automatically detect terraced houses among the urban buildings. They implemented the recognition procedure in Java. The graphical representation of the ontology was constructed in such a way the framework could be transferred in another area by modifying the concepts. The results were promising however, the ability to operationalize the concepts posed a challenge mainly in coming up with a proper way to deal with thresholds and fuzziness. Dealing with concept interdependencies when integrating simple and complex concepts was another difficulty they encountered and they call for more research in this area. A project of the Ordnance survey worked at identifying fields like farming land in Master Map data. They utilized ontology to define fields and then mapped to the database to identify them in a master map (Kovacs et al., 2007). This search engines need ontology to organize information and direct the search process (Chandrasekaran et al., 1999).

This ontology approach has also been recognized for coming up with a common term for object image analysis (Hay et al., 2008). With paradigm shift from pixel based to object based image analysis, many groups are using the different terms for the same meaning or same term with different meanings for the new discipline. They note that, to hasten a consolidation of this new paradigm, an ontology needs to be created with a common language and understanding. Key issue faced by this new discipline is to come up with a well understood and easily defined ontology. They suggest that a way of creating this ontology would be by creating a GEOBIA guide book to which practitioners can contribute, share into the understanding and hasten the synchronisation of this new paradigm.

Recently, Xu (2007) have discussed an approach for ontology development and architecture which can be used for emergency response. They gave an example of disaster management in Netherlands where different departments are charged with the responsibility for the emergency response and they are required to coordinate to ensure effective response. For the management of such a disaster, information from different sources needs to be obtained and integrated. The main challenge is dealing with semantic interoperability from the different departments. One possible way to deal with the problem is the use of ontology to reveal the implicit and hidden knowledge. They present an approach for ontology development and ontology architecture, which can be used for emergency response.

2.3. Levels of Ontology

2.3.1. Generic ontology

Levels of ontology can be used to guide processes for extraction of more general and detailed information and the use of ontologies allows of information in different stages of classification (Fonseca et al., 2002). This different types of ontology can be developed according to their level of generality (Guarino et al., 1998), degree of detail used to characterize a conceptualization and depending on the subject of conceptualization (Guarino, 1997) .

Top level ontology describe very general concepts like space, time, matter, object, event, action, which are independent of a particular domain (Guarino et al., 1998).They are useful in supporting very broad concepts and act as reference ontology to other levels of ontology. They can either be used as neutral reference format or can be imported in all the local ontology while building the local ontology (Uschold, 2000) . The scale of the global ontology is very important because if it is large enough, it will contain all the concepts proper for a common vocabulary (Minghua et al., 2008) which would be reasonable for large communities of users (Guarino et al., 1998). Various researches have focused on the development of global ontology. In the field of urban, Kohli (2010), part of her on going PhD. research work, has developed a generic ontology for slums which will be used in the development of a local ontology for Kisumu.

2.3.2. Review of generic Ontology for slums

In this study, methontology, an ontology development process suggested by (Lopez et al., 1999) was used. It comprised of three major stages. First, Specification, which in the study involved identifying terminology such as image-based detection with focus on spatial and contextual indicators, and classification of slums; Second, Conceptualization – involving organization and structuring of the acquired knowledge during the specification phase, and involving use of tools such as interviews and questionnaires to obtain knowledge about peoples interpretation of slums and the various indicators; Thirdly Implementation, which involved the use of ontology development environment using the protege 3.4 ontological editor to represent and implement the products of specification and conceptualization phases.

The results of the process showed that morphological variability of a settlement can help to differentiate slum from non-slum areas. The results further show that buildings in a slum settlement tend to have different characteristics than the ones in non-slum areas. Slum indicators/concepts were identified at three levels: the Object level (internal structure characteristics such as buildings, roads), Settlement level (overall form/shape of settlement) and the Neighbourhood level (surroundings of settlement).

The value of a combination of attributes helped to distinguish or identify slums on a satellite image. Other slum characteristics and/or attributes included: irregular road layout with variable road types and widths, an irregular shape easily distinguishable from planned areas, high density often with very high roof coverage with very low or nil open spaces and vegetation, and poor connectivity with infrastructure in neighbouring areas.

2.3.3. Local ontology

However, it is not possible to have a universal agreement in all the concepts. Global ontology is infeasible because of the heterogeneity of the data and communities are free to use their own vocabularies. This semantic conflicts can be solved by use of local ontology (Hajmoosaei et al., 2008). He defines them as domain based local ontology since they are related to a specific domain which uses particular vocabulary. Also, global ontology is too broad and conceptual to be of practical use in OOA coding. There is no universal model of a slum in a physical sense that would allow the development of a standard method for all slum identification and mapping. Although certain variables are likely to be important in most situations the parameter settings will almost certainly always require local tuning (UN-Habitat et al., 2008a). These will be through a development of local ontology which would be more comparable in detail to what is needed for rule set development.

This knowledge will form the basis of classification using the object-oriented approach. The usefulness and success of slum identification and mapping depends on how well the strategy is laid out to adequately classify the objects. As noted by (Kohli, 2010) comprehensive knowledge is important for addressing problems related to slum upgrading and improvement. For global intervention and monitoring of slums, standardized definition and methods for spatial quantification are required. They propose ontological framework based on the morphological indicators for conceptualizing slums including the knowledge from various contexts. The global ontology provides a comprehensive framework for slum definition which provides a basis for the development of the local ontology to define a slum at the local level.

2.4. Object Image Analysis

Object image analysis consists of two steps: segmentation and classification.

2.4.1. Segmentation

Image segmentation is the first most crucial steps which involve grouping pixels into meaningful objects of homogeneous spectral properties (Bhaskaran et al., 2010; Blaschke, 2010). Image segmentation links objects in a network which offers important context information for classification. There are two basic segmentation principles; top down segmentation which cuts the image into smaller pieces and bottom up approach that merges smaller objects into bigger objects(eCognition, 2010). This depends on the type of segmentation. Seven types of multiresolution algorithm are available in eCognition software which includes: chessboard segmentation, quadtree-based segmentation, contrast split segmentation, multiresolution segmentation, spectral difference segmentation, multithreshold segmentation and contrast filter segmentation. A brief review of multiresolution segmentation, chessboard segmentation and spectra difference segmentation is made since this three are used for this study.

Multiresolution segmentation

This is a bottom up region merging technique which considers each pixel as a separate object and pairs of image objects are paired to form bigger segments (Rejaur et al., 2008). The merging is based on homogeneity criterion (Figure: 1-14) of scale, colour, smoothness, and compactness (Thoms et al., 2003). These criteria are used to constrain the exact reproductively of segmentation (Benz et al., 2004).

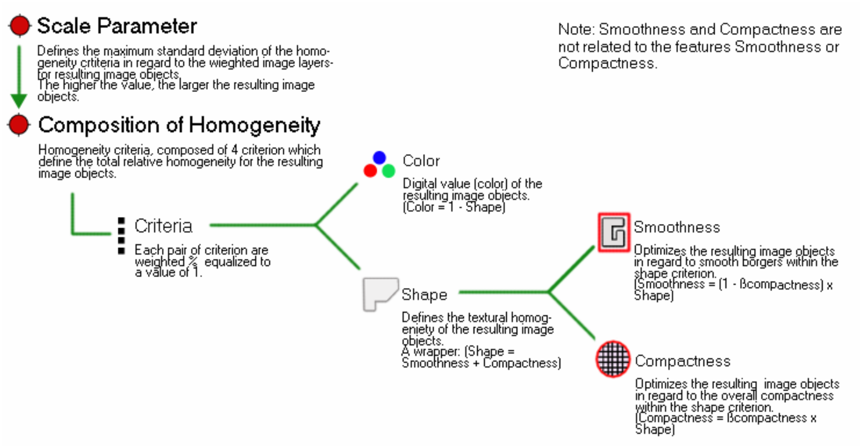

Figure 2-4: Multiresolution segmentation work flow diagram
Source: (eCognition, 2010)

Homogeneity criterion depends on colour and shape properties. If higher weight is given to spectral criteria there will be lesser impact of shape in image object formation and vice versa.
Shape criteria are further divided in smoothness and compactness. Smoothness influences the smoothness of the object while compactness determines how compact objects will be.
Among these parameters, scale parameter is the most important factor since it determines the heterogeneity for the target image objects(Chen et al., 2009).The larger the scale parameter, the more objects are fused and the larger the objects grow (Benz et al., 2004). This allows for the representation of image information simultaneously at different scales thus achieving a hierarchical network of objects. For example the classification of a single building and a settlement requires would require a different scale to classify them. Therefore, it is important while analysing various objects in an image to perform it on several scales in a hierarchical manner.

Chessboard Segmentation

Chessboard segmentation is a top down region splitting principle which splits the pixel domain or an image into square image objects(eCognition, 2010). Object size which is determined by the scale size, defines the square grid in pixels.

Chessboard segmentation is simple and fast. It generates seed segments which are used for further analysis.

Spectral difference Segmentation

Spectral difference merges neighbouring image objects according to their mean image layer intensity values. It cannot be used to create new image object levels based on the pixel level domain. Instead, it is used to refine segmentation results by merging layer mean intensities below the value specified.

2.4.2. Classification

In the second step, image segments are classified by generating class hierarchy based on fuzzy logic(Rejaur et al., 2008). Each classification class contains a class description and each class has fuzzy expression that allows evaluation of specific features. The image classification in eCognition is based on user defined fuzzy class descriptions based on spectral and spatial features(Bhaskaran et al., 2010). Fuzzy classification is suited to handle vagueness in remote sensing information extraction by allowing objects to have membership in more than one class (Bardossy et al., 2002; Benz et al., 2004). Objects that fulfil the criteria of more than one class are seen to be ambiguous and fuzzy concepts helps to describe these ambiguities(eCognition, 2008) A fuzzy rule can have one single condition or several conditions for assigning objects to a class. These fuzzy sets are defined by membership functions in eCognition software.
The advantage of this classification is that it allows expressing uncertainties of the class description. It makes it possible for an object to belong to more than one class but with varying degrees of membership. This is very important in slum detection as it allows inclusion of the divergent expert knowledge which must be combined to achieve appropriate results.

2.4.3. Spatial metrics

According to Herold et al., (2001) "spatial metrics can be defined as measurements derived from the digital analysis of thematic categorical maps exhibiting spatial heterogeneity at a specific scale and resolution". There are many different metrics on shape, complexity and interspersion but very few of these metrics contain unique information (Schneider et al., 2005). Some of the commonly used spatial metrics in the field of urban studies are patch density, edge density, largest patch index, cohesion, contagion index, mean patch fractal dimension. Contagion index measures to what extent landscapes are aggregated or clumped (O'Neill et al., 1988). Fractal dimension describes the complexity and fragmentation of a patch by perimeter-area proportion. Low values for fractal dimension are obtained when a patch has a rectangular form with a small perimeter to the area to the area while high values are obtained when the patch is more complex and fragmented with a higher perimeter (Herold et al., 2002). Spatial metrics have been tested in the detection of slums on Dar es Salaam, Tanzania (UN-Habitat et al., 2008b) The approach tested various metrics and the best performing metrics were found to be patch density, Euclidean nearest neighbour coefficient of variation, clumpiness, proportion of like adjacencies and aggregation index. The research recommends further research on the utilisation of spatial metrics on object oriented image classification results.

2.5. Summary

This chapter reviewed the knowledge about slum definition, definition of ontology, previous studies were reviewed on ontology. It also reviewed knowledge about OOA about different types of image segmentation that were applied in this research which are multi resolution segmentation, chessboard segmentation and spectral difference segmentation.

3. STUDY AREA AND DATA DESCRIPTION

Brief description of the study area and data structure is presented.

3.1. Physical condition

Kisumu, the case area for this study is the third largest urban centre in Kenya after Nairobi and Mombasa. It is located in Kisumu District, Nyanza province at the arm of the Lake Victoria. Geographically, it is located approximately 00 0 06' S and 34 0 45' E. Kisumu has an area of approximately 417 Km², 35.5% of which is under water. Geologically, Kisumu sits on tertiary lava whose formation is attributed to the tectomagnetic activities associated with the Kano-Rift valley system.

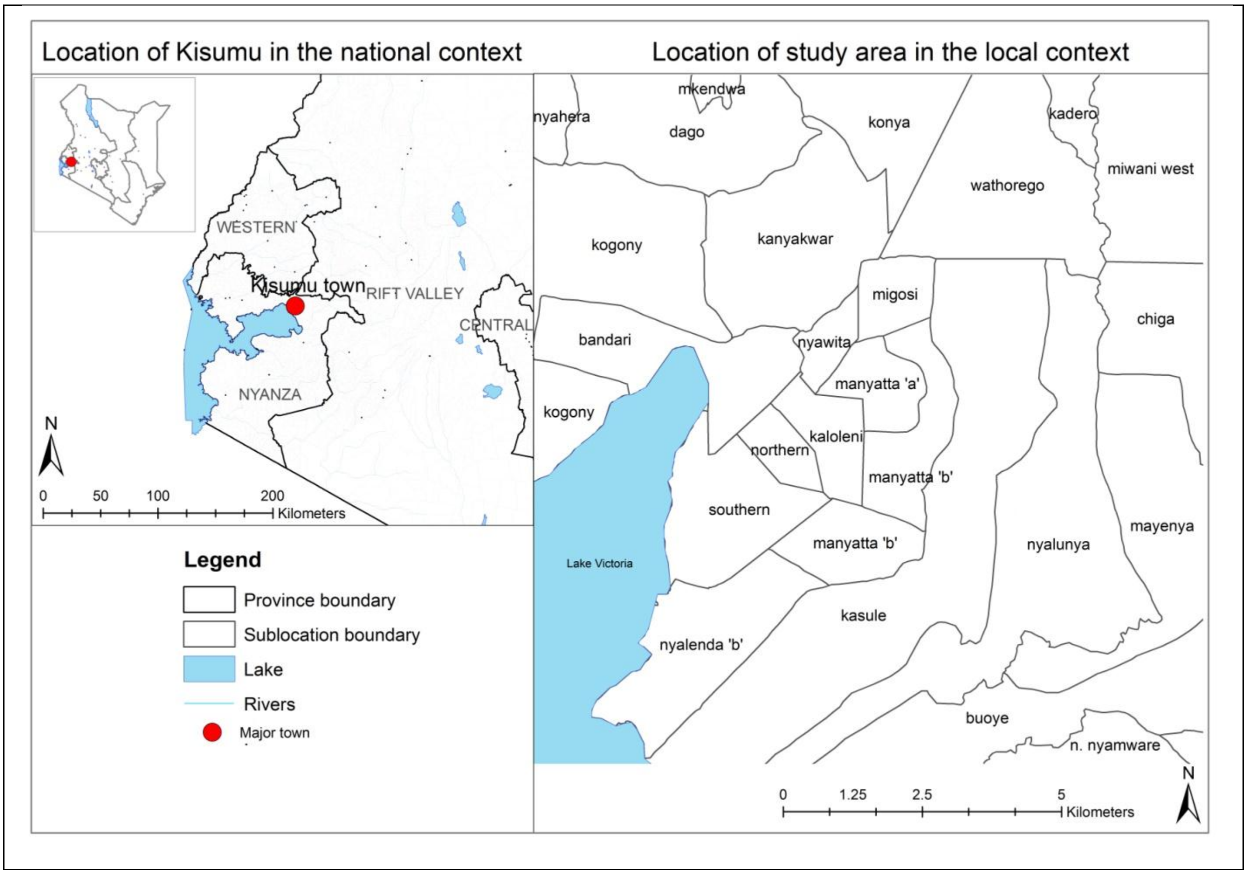

Figure 3-1 Location of study area

3.2. Urbanisation

In 1969 when the first plan of Kisumu town was prepared it covered an area of 19.8km² .However, in 1979 the Government acquired about 10.54km² other land for town expansion within Kanyakwar, Kibos that were predominantly rural in character. This urbanisation has transformed village dwellings to become urban settlements. This is because the land ownership in this area is mainly free hold putting the responsibility on the pattern of development to the owners of the land. With the rising demand for housing, with limited space with urban centres, private developers acquire land for housing with little consideration of the physical planning regulations. Therefore, the CBD of Kisumu town is surrounded by a ring of slums stretching to about 23.3 km2. Residential developments are jumping the slum belt and are being put up within the urban fringes lacking key infrastructure. This is likely to expand the slum belt.

3.3. Social and Economic Aspects

The town started as a railway terminus and internal port in 1901 and now it has become a hub of commercial, industrial, communication and administrative centre within the Lake Victoria basin. The town serves as the communication and trading centre for the Great Lake region –Tanzania, Uganda, Rwanda and Burundi. It is a home to higher institutions of learning like Maseno University, Kisumu polytechnic and several private colleges. Therefore many students and people from surrounding areas come for temporary stay or make a living there. Kisumu is the leading commercial, fishing, communication and administrative centre in the Lake Victoria basin. It has a well developed road transportation network linking Kenya to the East African countries via road, water and air. Still with the above economic potentials, Kisumu experiences the highest urban poverty levels at 48% against a national average of 29% due to the collapse of most of the industries. Kisumu city lacks adequate shelter with approximately 60% of the urban population both in the peri urban and informal settlements lacking basic services. There is high congestion with 150 housing units per hectare which are temporary and semi permanent in nature (KCC, 2009)

3.4. Demographic characteristics

Most urban areas in Kenya have been urbanising rapidly and by 2030 the proportion of Kenyan population living in urban areas is estimated to reach 60 per cent (Government of Kenya, 2007). In Kisumu city, there has been a major increase in the population since the 1970's up to date due to; the 1971 boundary extension that included the immediate peri-urban area outside the old municipality and the rural urban migrants into the city. As per the 2009 national census the city's population figures was at 618,556. Table 1 shows the trend of population growth of Kisumu from 1948 to 2009.

Table 3:1: Population Trend of Kisumu (1948 -1999)

Census Year	Population	Decadal Change	Growth Rate (%)
1959	23526		
1969	32431	8905	**37.9**
1979	152643	120212	**370.7**
1989	255381	102738	**67.3**
1999	345312	89931	**35.2**
2009	618556	273244	**79.1**

Source: Kenya population census 2009

3.5. Housing

Housing is a major concern in Kisumu where there is inadequate shelter with approximately 60% of the urban population resident in the peri-urban and informal settlements lacking basic services. Approximately 75% of the peri-urban inhabitants live in temporary and semi-permanent structures(Physical-Planning-Department, 2009). Poor planning standards, poor housing typologies, inadequate infrastructure and services are the major factors that have lead to the development of slum dwellings.

3.6. Challenges

Rapid growth has provided Kisumu with many economic opportunities and the biggest challenge that the city managers are face is how to manage the growth sustainable by dealing with problems of mushrooming informal settlements. There are seven slum settlements within the city namely Manyatta A, Manyatta B, Nyalenda B, Bandani, Obunga, Nyamasaria and Kaloleni. These settlements were among the first group selected to pilot the global Cities Without Slums (CWS) initiative under the Kenya Slum Upgrading Programme (KENSUP) framework (UN-Habitat, 2005). Because of a variety of its resources, Kisumu continues to attract population from the surrounding districts and pockets of slum settlements are developing gradually in Kanyakwar, Chiga (Kibos) and Korando.

3.7. Intervention undertaken to Improve the slum situations in Kisumu

Under the Kenya Slum Upgrading programme, Kisumu municipal council was one of the three cities selected for slum upgrading. The Kenyan Government in collaboration with the UN HABITAT has undertaken the programme which will be within the National policy framework. The objective of the programme is to improve the livelihoods of people living and working in the slums. The programme intends to review the policies that contribute to the growth of the informal settlements. The programme will examine these policies and propose necessary reviews that will promote the growth of sustainable urban settlements. The UN HABITAT Urban management programme for the Lake region has developed a City Development Strategy including an action plan for Kisumu.
Another project undertaken in Kisumu is Pamoja trust which is involved in slum mapping from door to door for socioeconomic survey of the slum dwellers. This information would then help in the slum upgrading processes.

3.8. Data

A Geo eye 2009 satellite high resolution image (0.5 meter pixel size) was used for this study. The image data set was available in both panchromatic and multispectral (red, green, blue and NIR bands) forms.
A GIS road layer for a small section of Kisumu was available that was used as a thematic layer in OOA.

3.9. Geo Eye-2009 Image characteristics

- Sun Angle Azimuth: 45.4300 degrees
- Sun Angle Elevation: 60.71967 degrees
- Acquisition Date/Time: 2009-07-23 08:21 GMT

3.10. Software and limitations

Definiens 8.0 was used to carry out the segmentation and classification process of the Geo eye image. There a lot of challenges in processing large datasets where it takes a lot of time in carrying out analysis on a whole image. Therefore, analysis has to be carried out on a subset of the image which does not show a synoptic view of the whole image. The solution would be to use a super computer that can handle large data sets or carrying out the analsis on different subsets and mosaic them together.

3.11. Summary

Kisumu experiences the highest urban poverty levels at 48% against a national average of 29% due to the collapse of most of the industries. The city lacks adequate shelter with approximately 60% of the urban population both in the peri urban and informal settlements lacking basic services. There is high congestion with 150 housing units per hectare which are temporary and semi permanent in nature

4. METHODOLOGY

This chapter describes and presents the methods followed to answer the research questions. The main focus of this research is developing a method using ontological framework as a knowledge base for OOA based slum identification. To effectively identify slums it important to first conceptualise its definition and then develop a strategy to delineate it. The methodology discusses these major steps in answering the research objectives. Research question 1 focuses on performing a needs assessment Research objective 2 focuses on developing the local ontology from the generic ontology. Research objective 3 discusses the linkage of ontology to OOA to detect and characterize slums. Research question 4 discusses how slums are identified and characterised by ontology and OOA. The methodology is geared towards providing information needs of the stakeholders therefore needs assessment is first carried out. The workflow of this research is shown in Figure 4-1

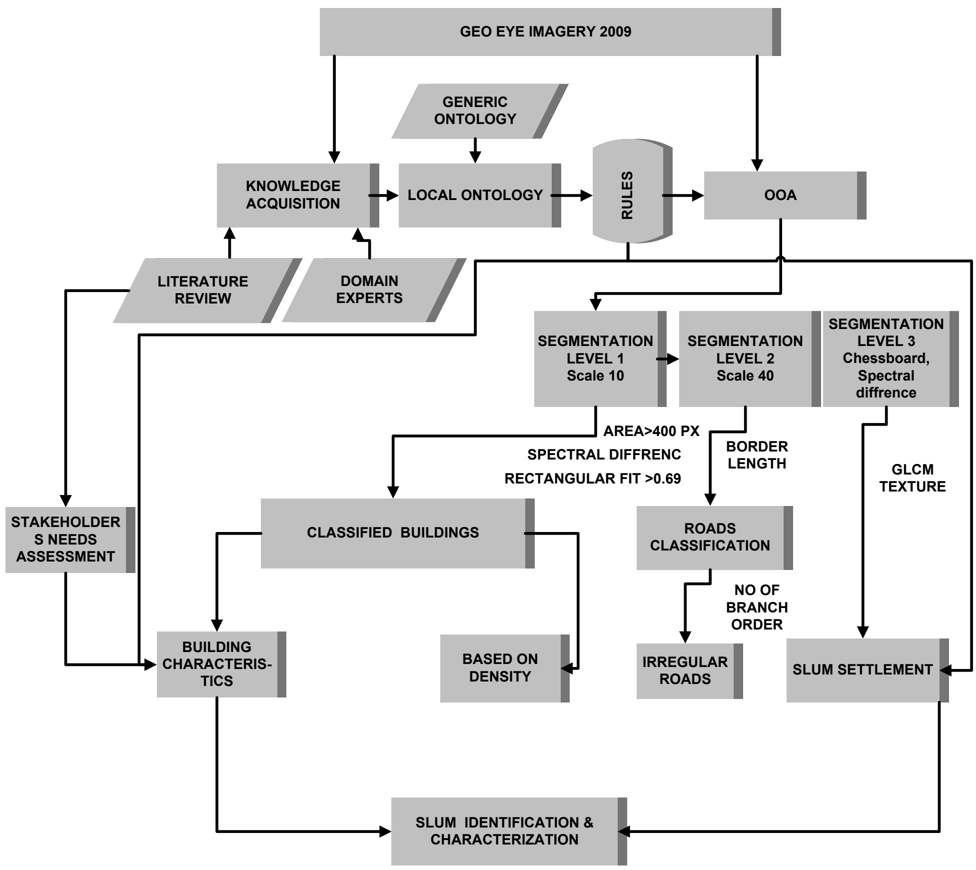

Figure 4-1 Methodology Flow

4.1. Research Objective 1:To perfom a stakeholders needs assessment

Rational and Justification
The rational applied involved determining the information requirements of the stakeholders for slum intervention.
Methodology
The procedures applied are outlined below

Step 1: Identification of the stakeholders
Through literature review, groups or bodies involved or having an interest in slum mapping and monitoring were identified. This considered all the bodies or institutions that have an influence on the slums or have an interest in improvements in the slums of Kisumu.

Step 2: Identifying their roles in slum intervention
The roles of the stakeholders in slum intervention are discussed. Comprehensive assessment of various resources like reports and policy documents provided a synoptic view of their current work. A needs matrix table was developed to address these requirements.

4.2. Research Objective 2: Local Ontology Development Process

Rational and Justification

As discussed in the previous chapter, the generic ontology includes knowledge of slums from various contexts. Considering the variability of slums across different countries, it was important to test it by adapting it to local conditions. This was done by laying out a strategy of filtering the concepts applicable to the case study area. The rational was to conceptualise knowledge by determining the indicators that fit to slums of Kisumu. Local ontology development process adopted the generic ontology development process suggested by Fernandezet al., ((1999) called Methontology.

Methodology
The adaptation comprised the following phases;

4.2.1. Specification

This step represents the framework for the ontology's terminology, level and scope .Since the goal of this research was image based detection and classification of slums, thus the focus was on spatial and contextual indicators for the development of ontology.

4.2.2. Conceptualisation

This involved acquisition of knowledge to acquire all the concepts and relationships related to slums for development of local ontology. Knowledge acquisition was done through visual image interpretation and domain expert interviews. In both methods, slum indicators were identified at three levels object level, settlement level and environs. This was crucial since each object is characterised by not only its spectral, shape or textual features but also by its unique neighbours, its sub and super objects (Benz et al., 2004).This is as shown in Figure 4.1.

- **Visual Image Interpretation**

To determine the necessary information to describe a slum, visual interpretation of the image and review of various literatures was done to come up with indicators specific to local conditions. The image interpretation for slums was done by observing the variation in the pattern, shape, texture, association, size and other related image characteristics. The characteristics used in image interpretation of the slums were used to form the local ontology.

- **Domain Experts**

As discussed earlier, the biggest problem in identifying slums is that there is a lack of standard definition of the term 'slum' and the definition differs from country to country and also within the same country. For instance, slums are mostly identified by looking at most densely spaced neighbours but this is not always right. Slums vary enormously in character and certainly, huge contrast exists globally. For these reasons, it was important to conduct an expert survey so as to understand how domain experts conceptualize slums in Kisumu. This was acquired through questionnaires and interviews which were based on-going PhD research work (Kohli, 2010). A total of thirty questionnaires were used. Domain experts were remote sensing specialists, urban planners, academicians and those with local knowledge on Kisumu slums. The need of the domain experts was impeccable as they provided domain specific knowledge on slums and remote sensing based indicators essential for slum mapping. A series of questions asked ranged from the knowledge of the slums to visual interpretation for identification of slums. The information was used to identify the properties that the experts used to distinguish slum from non-slum areas.

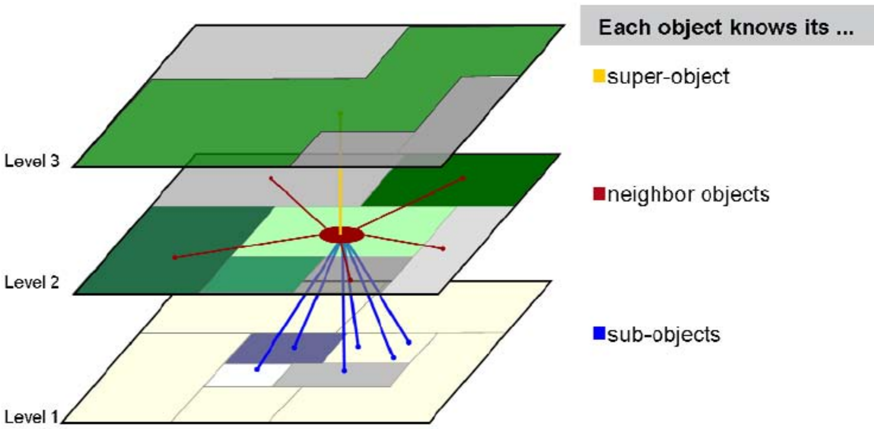

Figure 4-2 Image object hierarchy (source eCognition 8)

4.2.3. Implementation

This step involved the integration of experts' knowledge into the concepts of ontology. In the generic ontology (Kohli, 2010), the concepts of slum were represented at three levels i.e. at object level, settlement level and at environs level (see figure 4-3). Local ontology was formed by adapting indicators at these three levels according to the characteristics of Kisumu slums.

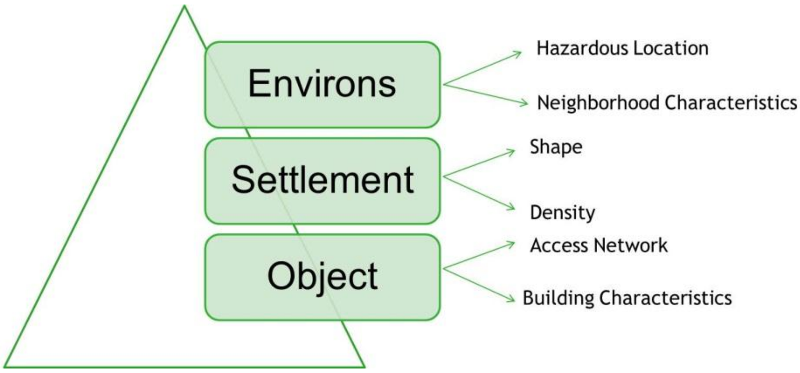

Figure 4-3 Concepts at three levels adopted from the generic ontology of slums.

(Source: (Kohli, 2010)

4.3. Research Objective 3- Linking ontology to OOA

Rational and Justification
Analysis of research objective 3 involved linking the results of the ontology to OOA. The rational was to use the ontology as a basis for OOA parameterization. The approach involved understanding, conceptualisation, and development of a strategy to recognise objects of interest in OOA. Development of the local ontology represented the understanding and conceptualisation part while OOA implemented the strategy. The rational was to determine whether the slums can be identified using the various ontological concepts. This was in a bid to answer to the various needs of the stakeholders.

Methodology
The research question was executed using eCognition software. The concepts identified in the local slum ontology were encoded as rules and used for classification. The procedures applied are outlined in the steps below.

4.3.1. Step 1: Translation of indicators into image based parameters

To perform OOA, it required translation of ontological indicators into image based parameters. In OOA, features can be distinguished at three levels; intrinsic features which is the objects physical properties determined by the pictured real world and the imaging situation. It describes colour, texture and form of the objects. Topological features level describe geometric relationships between the objects while context features describe the objects relationships between each other(eCognition, 2008). This levels represent the same ontology levels at object, settlement and environs level.

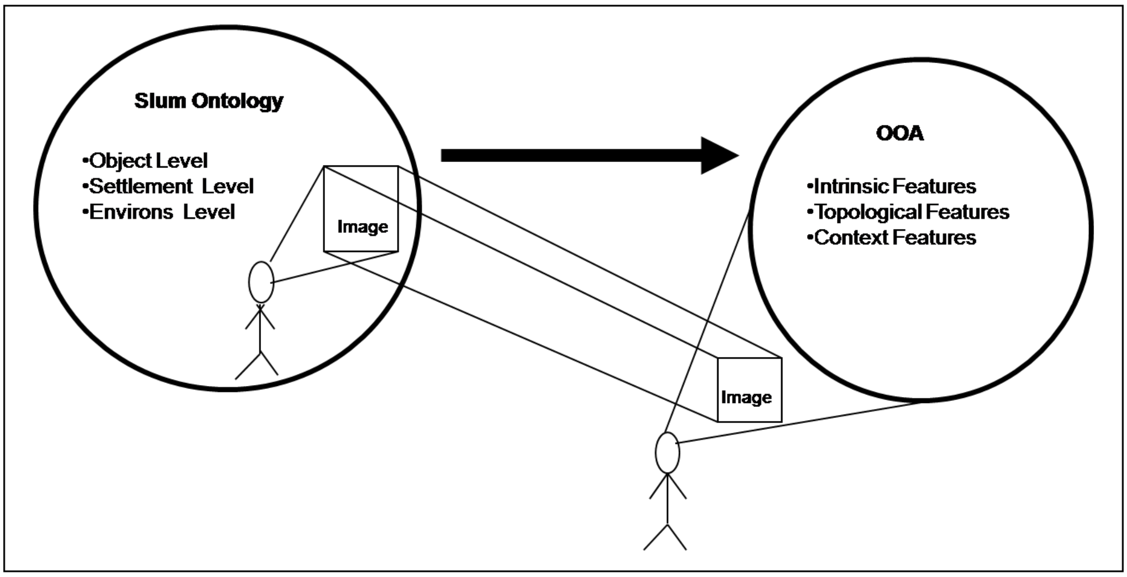

Figure 4-4 Translation of ontology into image based parameters

Therefore, the first step in linking ontology to OOA was to translate the knowledge obtained from the domain experts and visual image interpretation into image based indicators. These were later encoded into OOA to identify and characterize slum areas

4.3.2. Step 2: Basic classification

The second step involved image analysis using the image based parameters translated from indicators of slums. This involved multi resolution segmentation and classification of the image aiming at achieving the concepts of the ontology. First, a basic classification was performed to detect the shadows, roads, vegetation and buildings. These classes provided a base for the use of ontology concepts from which conceptualisation of slums was done. The applied work flow for linking ontology to OOA classification is shown in Figure 4-5 below

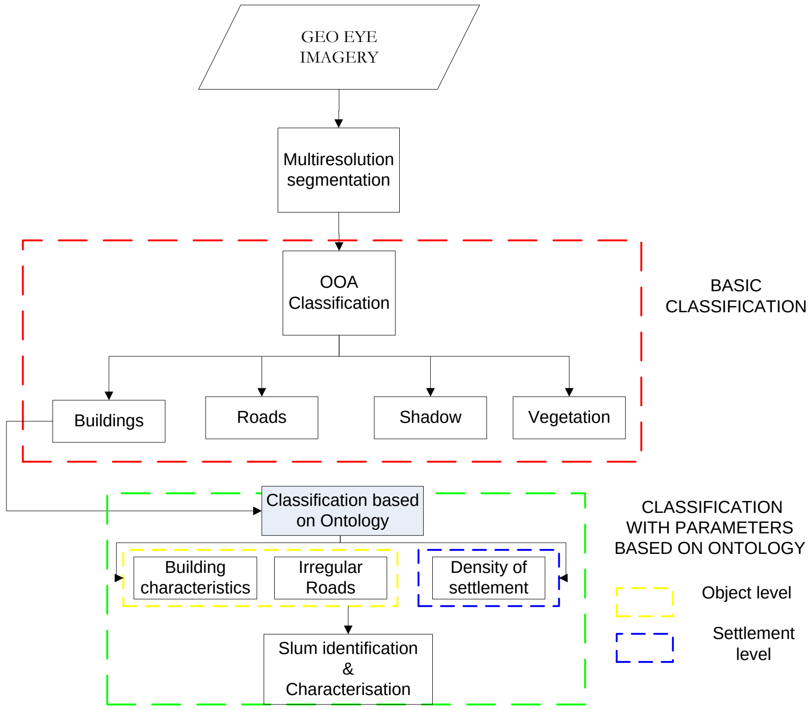

Figure 4-5: Applied workflow for linking ontology to OOA

- **Test area**

To address this research question, image analysis was experimented on a test area to ensure efficiency in the process. Two subsets of the image were chosen as a representative of the data to test the rule sets. This was because the processing time took too long on the whole data set. The test areas are shown with a black rectangular box in the high resolution Geo-eye image (figure 4-6). The dimensions of the test areas were 1885 pixels x 3228 pixels (approximately 1070 m x 1835 m).

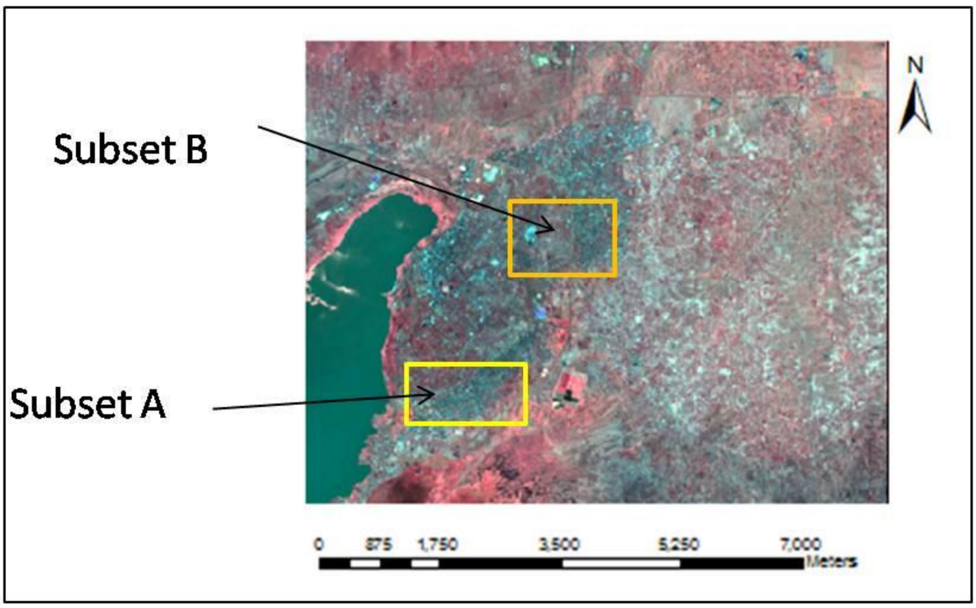

Figure 4-6: Kisumu Municipality scene from Geo-eye 2009 imagery

The criterion for choosing the test area was based on the heterogeneous character of the area to represent both slum and non slum area.

- **Segmentation**

A bottom up, hierarchical segmentation strategy with three levels of image objects was implemented. This enabled generation of image objects that represented the instances of the ontology as the key component of this study is to test the use ontology for OOA.

Table 4-1 shows the segmentation strategy. The Geo-eye imagery was segmented into three levels by setting different scale parameters and layer weights. The finest scale (Level 1) represents land cover at the object level like shadow, buildings and vegetation. These were individual internal structure that formed the slum settlement and thus required a small scale to delineate them. Red, green, near infra-red and panchromatic bands were used for multiresolution segmentation. Small scale factor and higher weight on shape factor was assigned to level 1 so as to target shadow, buildings and vegetation. In the second level, segmentation based on multiresolution segmentation was increased so as to correspond with roads. In the third level chessboard segmentation was carried out targeting the settlements. This represented the overall form of the settlement combining objects at object level and therefore required a larger scale. Image information is represented at different spatial resolution and which require different scales for extraction. The sequence at which different levels are segmented is very important (eCognition, 2008) .

Table 4:1: Segmentation parameters

Level	Segmentation mode	Layer Weights	Scale Parameter	Colour/Shape	Compactness/ Smoothness	Target objects
1	Multi resolution Segmentation	Green=1 Blue=1 Red=1 NIR=1	10	0.3/0.7	0.5/0.5	Buildings Shadow Vegetation
2	Multi resolution Segmentation	Green=1 Blue=1 Red=1 NIR=1	40	0.1/0.9	0.5/0.5	Roads
3	Chessboard Segmentation Spectral difference	_	200 10			Slum and non slum areas.

- **Classification**

Object oriented image classification process followed after image segmentation. First a classification of shadow, vegetation and buildings were performed. Next, classification of slums was tested using the various concepts of ontology. The rational was to determine whether the slums can be identified using the various ontological concepts. This was in a bid to answer to the needs of the stakeholders of identifying where the slums are located. The following was the classification and Table 4:2 shows the specific thresholds for classification.

- **Shadow**

First, shadows were extracted by using their low spectral reflectance in the fused image. Their classification was important as it acted as a proxy in the classification of the buildings. A mean value of green, red and NDVI values were used in the classification of shadow. To extract building shadow was determined by using the mean layer of green and NDVI.

- **Vegetation**

Normalised vegetation difference vegetation index (NDVI) was calculated by using NDVI algorithm to classify the vegetation:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

A NDVI threshold of less than or equal to 0.677 was used to delineate vegetation from non-vegetated areas.

Table 4:2: Specific threshold for classification

Class	*Object feature*	*Threshold*
Shadow	NDVI Mean green	<=0.75 <=103
Vegetation	NDVI	>=0.677
Buildings	Maximum difference Rectangular fit Elliptic fit Area	<=1.55 <=0.69 <=0.1 <50 pixels
Roads for subset A Roads for subset B	Border length Thematic layer of roads	>=470 pixel Code <=11

- **Building classification**

Buildings classification was also done using the spectral and other geometric properties. Maximum difference of less than and equal to 1.55 was used to classify the buildings. Maximum difference Geometric attributes like rectangular fit and elliptic fit was also used to classify the buildings. Elliptic fit feature describes how well an image fits into an ellipse of similar size(Definiens, 2008).

- **Roads**

A border length of more than or equal to 470 pixels was used to classify the roads in the first subset. Border length is the neighbourhood relation between two image objects multiplied by the slice distance. It is counted by the number of the elementary pixel borders along the common border shared by two objects.
In the second subset of the image a thematic layer of roads was used for classification. In the first subset, the road layer was not available.

4.4. Research Objective 4: Linking local Ontology with OOA to classify slums

After basic classification of the buildings, roads, vegetation and shadow, ontology concepts were introduced as rule sets to detect the slum areas. Ontology concepts like building characteristics, access network, and density were used in OOA to identify slums. The linking of each concept of ontology with OOA is discussed in the following sections

4.4.1. Building characteristics

The rational was to determine whether individual slum buildings can be detected so as to answer to the stakeholders needs. From the image, there were all kinds of different types of buildings varying from the spectral reflectance, size, shape and also the location. It was difficult to get parameters that perfectly represented segments of all the buildings in the study area and therefore a single method could not be used to delineate all of them. Detecting them cognitively would be different and to address these, the buildings were characterised into major generic categories. This allowed for easy targeting of an approach to effectively answer the needs raised by the stakeholders.

- Slum Building classification using shadow

To identify slum building based on their shadow, relation between sunlight and building was analysed. Next step was separation of the shadow for vegetation from the shadow of buildings was done by use of asymmetry of the image objects. Shadow for slum buildings was small in size than those of the planned area. This was separated by length/width ratio. The angle of the building to the small shadow was analysed by looking at the time the image was taken to determine the direction of the sun. Using a simple case where the buildings occurred in isolation, angle to image object algorithm was used to calculate angle to a single object with a trial of various angles. Angle to a single object calculates the angle to a single object and stores the value into the object variable 'angle to image object, which constitutes of a single object. This was used to locate the buildings on the sun side of shadow.

- characterisation of slum buildings using roof colour

The different colours of roofs were used to characterise the slum areas. The buildings were classified with two roof colours; brown roof and bright roof. It was assumed that the roof colour could say something about the durability of the buildings. Those with NDVI of <=0.701 was used to classify the bright roofs and a GLCM entropy of green layer of >=2.8 was used to classify the brown roofs.

4.4.2. Access Network

Another ontological concept that characterised the slums in Kisumu was irregular road network. From the classified class of roads, irregular roads were detected using number of branches of order (1).In the first subset where there was no thematic layer, branch of order (1) of less than equal to 18 was used to classify slum roads. While in subset two, branches of order (1) of less than or equal to 49 under the skeletons property was used. The skeleton provides centreline of elongated object of second and higher order branches. This method was used by (Benz et al., 2004) to extract the centreline of the roads. Relative border to irregular roads with less than or equal to 139 was used to identify the slum areas in OOA.

4.4.3. Density concept

Ontological concept of density was used to describe the Kisumu slums. In comparison with the planned areas, slums that were at consolidated and maturity stage of slums development had a higher density than the planned areas. The differences in density were tested using texture analysis in eCognition. Next spatial metrics were used for two reasons: to validate the results of texture analysis and for characterisation of slums.

- By Texture

A powerful technique in the analysis of image objects based on sub objects is texture analysis. Texture dissimilarity method was used to identify the slum areas. OOA supports multiscale analysis where image can be represented at different scales by building up a hierarchical network of image objects. This presented an efficient way to describe the complex semantics of slums. Slum neighbourhoods look different at different spatial scales and degradation of an image several times gave different textures which are quite unique for slum and non-slum areas. In eCognition, the texture attribute, commonly used is called "texture after Haralick". It is based on the grey level co-occurrence matrix (GLCM) calculated by different combinations of pixel grey levels occurrence in an image. Several statistical texture measures exist in definiens but contrast measure was found to be efficient for the study area. The calculation of any Haralick texture feature is very processor intensive because of the calculation of the GLCM takes a long time. eCognition offers a performance optimized version labelled quick 8/11. The feature performs only on data with a bit depth of 8-bit or 11-bit. The Geo eye that was used in this research has a depth of 11 bit.

Chessboard segmentation with a scale of 100 was performed. This was followed by merging the areas with a spectral difference of 10. Next, a texture analysis of GLCM contrast quick 8/11 blue (all direction) with a threshold of less than or equal to 9 was performed.

Contrast measures the amount of local variations in the image. It is calculated as follows:

$$\text{Contrast} = \sum_{i,j=0}^{N-1} P_{i,j}(i - j)^2$$

Where i is the row number,

j the column number

P_{ij} the normalised value in the cell i, j

N the number of row and columns

- By spatial metrics

Statistical method by use of spatial metrics was also used to identify the slum areas and compare the results with texture analysis. As discussed previously, spatial metrics describes the characteristics and geometry of urban land cover features. When applied to a classified image, the metrics can be used to analyse the heterogeneity in an urban environment to identify the slum areas by use of fragstat software.

About fragstat software

Fragstat is a programme for spatial pattern analysis for quantifying landscape structure. It quantifies the areal extent and spatial configuration of patches within a landscape. There are two types of analysis in fragstat; standard window analysis gives output inform of numeric values. Moving Window is performed when the scope of analysis is local landscape structure. In moving window, window of specific size and shape is passed over each cell and for selected metric is calculated for each window.

Methodology

The input for the calculation of the metrics was a grid map. The grid map was a conversion of the classified image performed in eCognition software. A "moving window" was conducted using a 20 meter radius window over the study areas. The window calculated the selected metrics within a window returning the value to the centre cell.

Types of metrics

There are several metrics on area, shape, contagion among others that are available on the Fragstat software. The selection of the metrics for this research was based on the understanding of the metrics that was useful in discriminating the slum areas. For this study, three landscape metrics were selected for the analysis: Class Area (CA), Largest patch Index (LPI), and total edge (TE). High values were used to represent slums. The three selected landscape metrics were calculated for building class. This represented the core urban structure elements. The definition of the metrics used and their significance selected from the fragstat software is defined as follows

Class area (CA)

This is a measure of landscape composition; specifically, it is how much of the landscape is comprised of a particular patch type.CA equals the sum of the areas (m2) of all the patches corresponding patch type, divided by 10,000(to convert to hectares).

Class area approaches zero as the patch type becomes increasing rare in the landscape. Class area is equal to the total area when the entire landscape consists of a single patch type that is when the entire image is comprise of a single patch.

$$Class\ area(CA) = \sum_{j=1}^{n} a_{ij}$$

Where, n = number of patches, i = patch metric for particular class, j = patch number, a_{ij} *= area (m*^{2}*) of patch ij. Class area equals sum of areas (m*^{2}*) of all patches of corresponding patch type.*

Largest patch index (LPI)

LPI is a simple measure of dominance where it quantifies the percentage of total landscape area comprised by the largest patch.

LPI approaches 0 when the largest patch of the corresponding patch type is increasingly small. While LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type, that is, when the largest patch comprises of 100% of the landscape.

$$Largest\ patch\ index\ (LPI) = \frac{max\left(a_{ij}\right)_{j=1}^{n}}{A} \cdot 100$$

where, a_{ij} *= area (m*^{2}*) of patch ij, A = total landscape area (m*^{2}*)*

Largest patch index at class level indicates the percentage of total landscape area comprised by the largest patch.

Total edge (TE)

This is the absolute measure of the total edge length of a particular patch type. TE equals the sum of the lengths (m) of all edge segments involving the corresponding patch type.

$$Total\ Edge(TE) = \sum_{k=1}^{m} e_{ik}$$

Where,

e_{ik} =*Total length (m) of edge in landscape involving patch type (class) i; includes landscape boundary and background segments involving patch type i.*

TE=0 when there is no class edge in the landscape; that is when the entire landscape and landscape border ,if present, consists of the corresponding patch type and it is specified that none of the landscape boundary and background edge could be treated as edge.

4.5. Summary

This chapter described the methods that were applied in this research. They consist of development of a needs assessment matrix to identify the needs of the stakeholders which can be addressed in this research. Indicators that represented Kisumu slums were identified through domain experts and visual image interpretation. This was followed by development of local ontology by refinement of the generic ontology using indicators identified. A basic classification was first carried out using segmentation informed by the local ontology. Ontology concepts consisting of building characteristics, roads and density were linked with OOA to identify and characterise the slum areas. Spatial Metrics was also performed to validate the results of texture analysis and also to characterise slums.

5. RESULTS AND DISCUSSION

This chapter presents the results of the application of the methodology discussed in the preceding chapter. Results are reported for each research question and are followed by a discussion that interprets the outcome.

5.1. Research objective 1-Stakeholders Needs assessment

5.1.1. Identification of Stakeholders and their needs

As shown in table 5:1, a matrix table was developed showing the stakeholders and their data needs for slum intervention. This considered all the bodies or institutions that have an influence on slums or are involved in improvements of the lives of slum dwellers. In summary the needs are listed for the different stakeholders. The needs ranged from identification of slum areas, building footprints, size of the slum, development stages. The stakeholders were classified into three categories- Government, Non-profit organisations, international bodies and local government. The results that showed that most of the stakeholders were interested with identification of the slum areas

5.1.2. Identifying different roles of Stakeholders slum intervention

. The roles of each of these are discussed below:

Role of the City Planners (Government)

Plan preparation and implementation is the main task of the planners of the central and local govt respectively. Preparation of strategic, local development, zoning plans and policies for upgrading, and development control are the main activities of the city planners (KCC, 2009). The information on the location of the slums, their densities would assist them to know which slums require prioritisation in drawing of action plans. The plans influence patterns of development, ensure compatible land use and guide land development (UN-Habitat, 2009).An expert group meeting organised by the UN-HABITAT in the year 2008, reported that many local governments lacked mechanism to monitor informal urban growth. Therefore, a monitoring system to track changes in the spatial dimension of the slums can control their development.

Role of NGOs

There are many NGOs involved in the slum intervention ranging from health, education, services, community empowerment to mapping. A Kenyan NGO called Pamoja Trust is very active in carrying out field mapping of the slums in Kisumu. It is involved in carrying out the enumeration exercise for all the slum households in Kisumu. The work involves collection of data of each household, numbering each structure for the purpose of preparation of detail maps defining the boundaries of each household structure. For each of the household structure there is an inventory with details of the history of its formation, location, type of structure, land tenure, main sources of employment and services available. This information will provide details needed for upgrading and providing secure tenure for the slum dwellers. Detailed mapping of buildings and road infrastructure could be used as a base layer for attaching further GIS information to the households.

Global Urban Observatory under the UN Habitat

One of UN Habitat's contribution in the achievement of Target 11 of the Millennium Development Goals is the estimation and regular monitoring the number of slum dwellers worldwide. Global urban observatory under the UN Habitat is the body involved in monitoring of the achievements of Target 11. An expert group meeting organised by the UN-HABITAT in the year 2006 recommended incorporating spatial contiguity into the calculation of the number of the slum dwellers. Peer review report: "Global Slum Measurement: A Peer Review of UNHABITAT Approach to Monitoring Target 11, 2006). Survey of average inhabitants per dwelling and density per unit area for the different slum types within a city (tenement density) would be useful for population modelling.

Kisumu was selected as one of the cities for the pilot phase of "Cities Without Slums" initiative by the UN habitat(UN-Habitat, 2005). UN Habitat in collaboration with the Kenya Government engages in the slum upgrading programme. An action plan that identifies issues and situation in the slum was developed. One of the activities for the development of an action plan was physical mapping to identify issues and conditions prevailing in the informal settlements.

The global report on Human Settlement 2009 by the UN HABITAT recognised the need of surveying the informal settlements. This would help them to identify settlements in unsafe locations for speedy evacuation in emergencies.

An expert group meeting organised in the year 2008, reported on remote sensing and slum monitoring methods for identification and delineation of slums. Its goal was to establish the requirements and needs for slum mapping to update the Global Urban Observatory (GUO) of UN HABITAT. Three key points from this meeting were(UN-Habitat et al., 2008b):

- It is essential to understand the nature of the slums both by the nature of the individual buildings, the settlement and the characteristics of the vicinity conditions such as location in the urban area and amount of natural vegetation.
- There is need to understand and consider the slum development process when deciding on the slum identification and mapping methods. There is need to consider how slum characteristics change according to the development stage of a slum.
- They recognised there are diversities in slum conditions that may exist even in one city where there are different characteristics of slums in the same city. The different manifestations of slums require specific methodological adjustments for identification and mapping. Therefore the need to identify the inter variability between slums.

Extracting knowledge about a building, settlement and its site characteristics through the use of remote sensing can help identify slum areas. However, it is worth noting that out of the five slum indicators listed in chapter 2, the aspect of durability and, to some extent, overcrowding can be assessed using remote sensing techniques. Clearly, not all indicators relevant for slum identification identified by the UN-Habitat can be mapped from the satellite imagery. This represents a risk in missing the actual slums because perhaps in terms of durability they might not be considered as slums. These presents a limited physical evidence to work with as it relies on a small part of definition of slums. However, other parameters could potentially serve as proxy information to say something about the indicators. Therefore there is the need in the assessment of each indicator of the slum in differentiating well slum and non-slum areas.

Table 5:1 Matrix table showing stakeholders and their information needs

	Stakeholders						
	National Government		Local authorities		Non profit Organisations		International Organisation
Requirements for slum intervention	**MoR**	**MoH**	**Planners**	**KIWASCO**	**CBOs**	**NGOs**	**GBO**
Location	✓	✓	✓			✓	✓
Size			✓				✓
Building footprints			✓			✓	
Density			✓				✓
Temporal changes			✓				
Development stages			✓				
Sanitation							
Water Accessibility				✓			✓
Landtenure Systems							✓
Housing quality		✓					✓
Road accessibility	✓						✓
Utilities Accessibility			✓				
Income					✓		

Other questions ontology can address

Mapping of hazardous sites within the slums

The extent of physical deprivation

✓–Requirements that can be assessed by remote sensing

✓–Requirement that can be assessed partly by remote sensing

✓–Requirements that can not be assessed by remote sensing

5.2. Research Objective 2-Local ontology development

5.2.1. Specification

This step, as mentioned earlier, deals with determining the domain and scope of the ontology. The scope of developing the local ontology is to have a conceptual framework which can serve as a basis for image-based identification and characterization of slums in Kisumu.

5.2.2. Conceptualisation

Based on the input from generic ontology, domain experts and literature review, a list of indicators was compiled that helped in conceptualising the basic knowledge about slums. This formed the basis for refinement of the generic ontology in developing local ontology.

- **Visual Image interpretation**

Table 5:2 Results of visual image interpretation

The results from the local domain experts were used to refine the knowledge.

Level	Land cover	Quantitative Indicator	Qualitative Indicator
Object level	Roads	Shape colour	Irregular street patterns Unpaved roads
	Buildings Vegetation	Shape Colour Orientation Size Spectral	Roof mostly rectangular Most range from bright grey to dark brown, few have bright blue and red. Variation is high even in the same building where there are different colours of the roof. Haphazard buildings with no order Small and Medium
Settlement Level	Informal settlement	Pattern Density	Irregular and have no linear arrangement Slums follow the road network The density of the buildings is high
Environs	Local contrast to the formal neighbourhood Slums are in proximity to	Texture Typology	Planned area proximity Mostly unfenced grouped buildings surrounded by narrow roads or streets farmlands, bare ground swamp proximity

- **Knowledge Expert**

The interviews with domain experts included an exercise asking the experts to delineate the slums in Kisumu. The process of image interpretation followed some well-defined rules or logical reasoning in the mind of the interpreter. Thus, the experts were asked to list the visual interpretation indicators used by them to identify slums. The basic indicators used to delineate slums from the imagery included: poor orientation of buildings, lack of well-connected road network, lack of defined roads, higher densities as compared to planned areas, low vegetation, proximity to major highway, association. Fig…shows results of slum delineation by different experts.

5.2.3. Implementation

The facts and rules used to identify the slums were encoded into the format of local ontology. They are presented inform of symbology and links (Figure 5-1).The generic ontology was refined and in some cases extended to sufficiently represent the local situation of Kisumu slums to develop the local ontology. Based on the generic ontology, the concept of a slum is represented at three levels at object level by buildings and roads, at settlement level, at vicinity level by site and neighbourhood. Combination of these characteristics assisted to identify and characterize slums from the high resolution image. Following is a discussion about the levels of classes existing in slum ontology.

Building Characteristics

At object level a slum has buildings that are part of a certain site and neighbourhood. The concept of building is attached with existence of floor, walls and a roof.

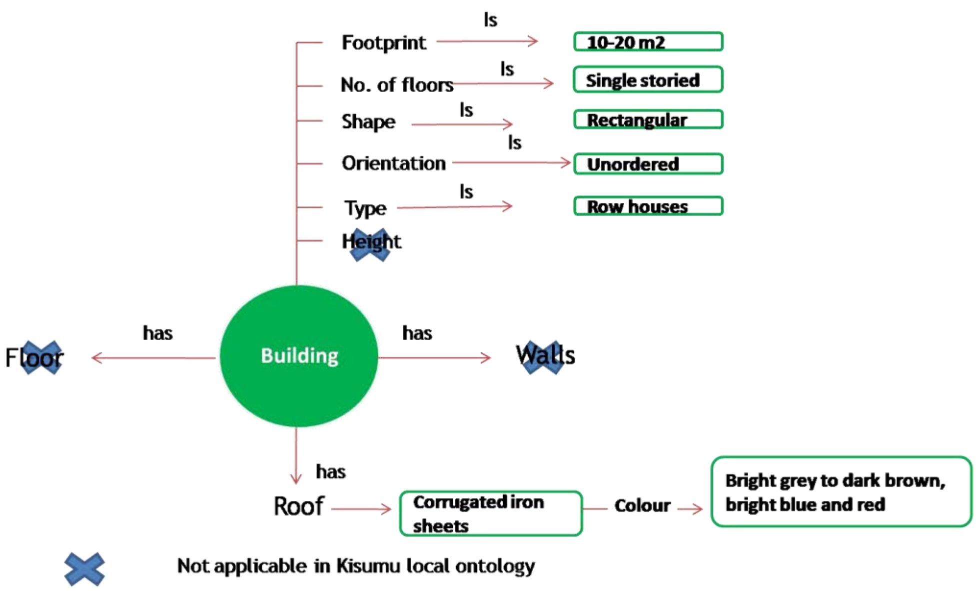

Figure 5-1 Building characteristics

From the image it was not possible to see the floor and the walls, so in the local ontology, roof is the only indicator which was further defined by the type, shape, and orientation of the building. The type of the buildings in Kisumu slums is mostly row houses, which are rectangular in shape and have unordered orientation. Row house here means several units of houses that are under one roof. From the field information, the buildings were mostly single storied. The concept of height was omitted due to the absence of DSM or Lidar data.

Access Network

At the object level, roads were identified. The concept of road was of regular or irregular structure that had a certain range of width. Most of the roads in the slums were tertiary roads which were not paved with width ranging between 3-4m. It was not possible to map unpaved roads by use of geoeye image but domain experts who had ground knowledge confirmed their presence n the slum areas. Most accessibility was through the footpaths that offer access to the household units.

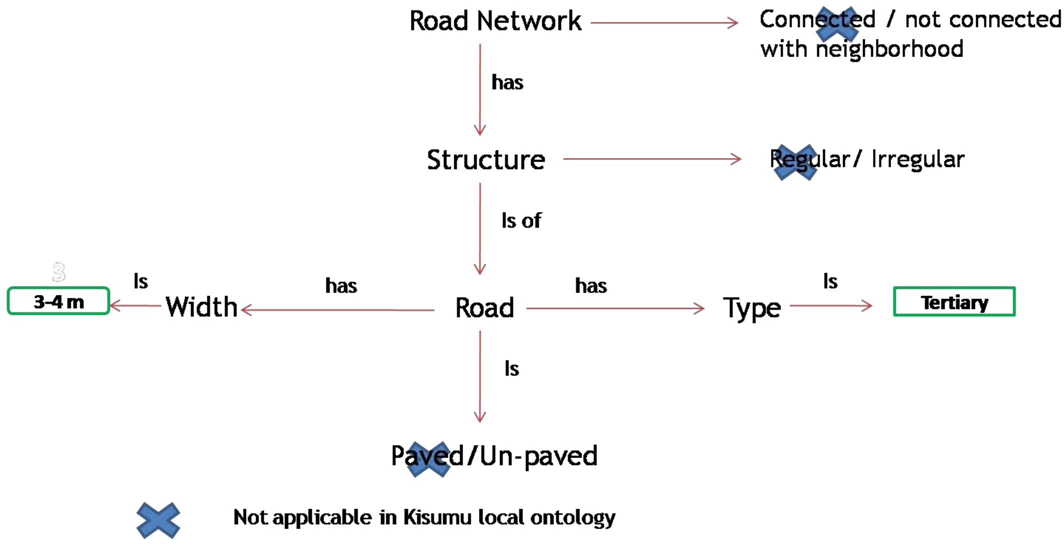

Figure 5-2 Road characteristics

Shape

From the generic definition slums have irregular shape or follow the shape features of roads, railways etc. For Kisumu case the shape is also irregular, some slums are along the major highway and encircle the planned area. As shown in figure 5-3, the slums form a ring shape around the CBD and planned area. The unique characteristic of slums in Kisumu is that it forms a slum belt encircling the central planned area.

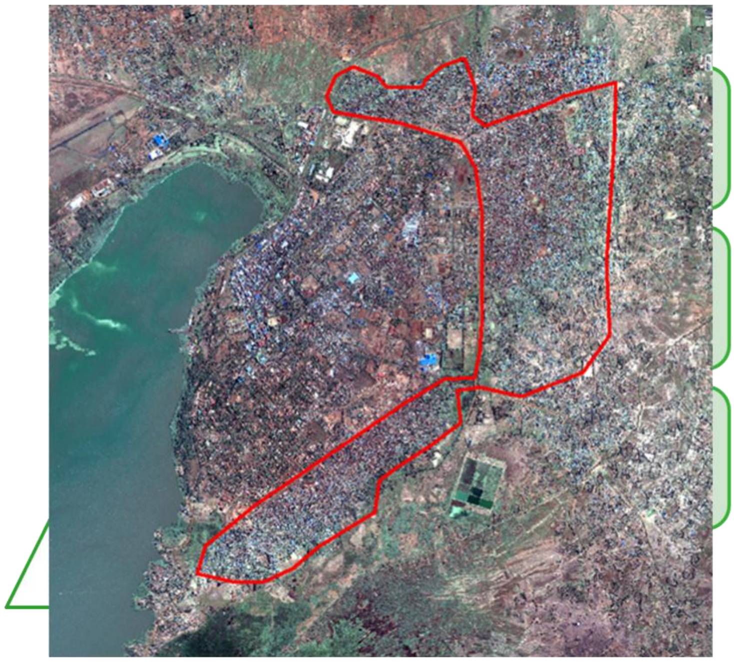

Figure 5-3: Shape of the slums in Kisumu

Density

From the generic definition, slums are very dense with high roof coverage, very low or nil open spaces and vegetation. However, Slums vary enormously in character and huge contrast exists globally. This can be illustrated by an overview of a subset of the study area briefly comparing the pattern of buildings of the Indian slums in Ahmedabad and those of Kisumu.

Figure 5-4: Slums in Ahmedabad, India.(left)Slum areas can be distinguished from planned developments but individual buildings cannot be distinguished.; (right) Slums in Kisumu. Low density unplanned developments. Snapshots from Google earth

In Ahmedabad, the pattern of buildings in the slum area is characterised by irregular highly dense buildings. The buildings are grouped and connected such that the boundary of individual buildings is not visible. Kisumu slums represent an unusual case where slum buildings are fairly widely spaced as compared to how 'normal slums look like. Also the density of Kisumu slums varies hugely in relation to the maturity level of the settlement.

The Environs level is represented by hazardous location and neighbourhood characteristics of the slums.

Location

This describes the physical location of the slum in relation to the surroundings. Slums are mostly located on hazardous locations or land unsuitable for planned development. Slums in Kisumu are characterised by flood zones, swamps, highways, and narrow access roads.

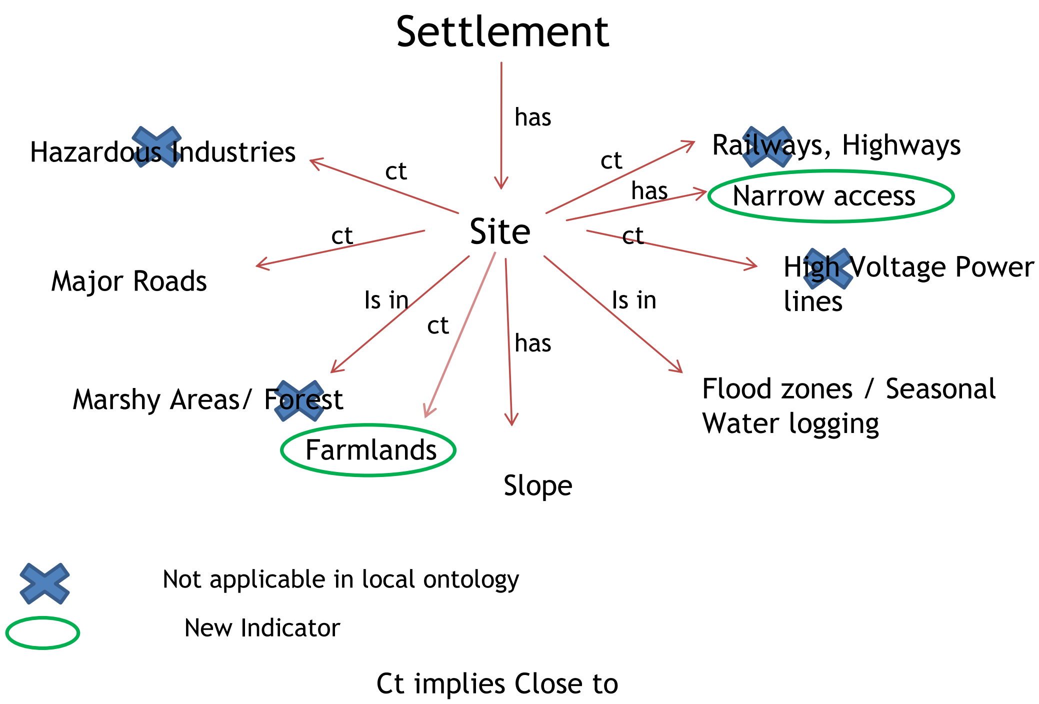

Figure 5-5 Location

Environs

The slums in Kisumu are located around the CBD where people seek employment opportunities. It is also located near other low socio-economic areas and middle to high socio economic areas. However, it has no industrial areas in the vicinity.

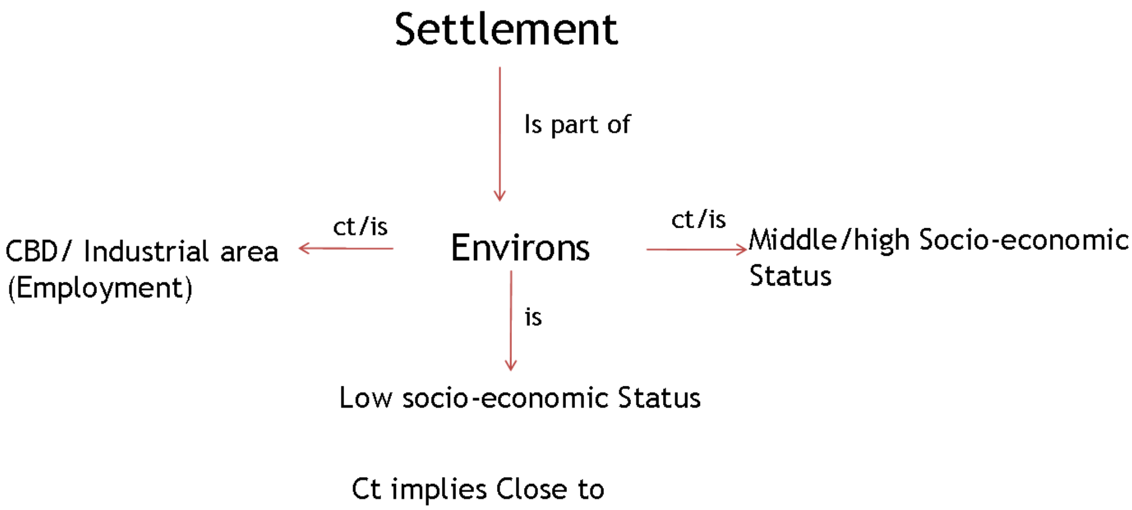

Figure 5-6 Environs

Discussion

The local ontology development requires a more detailed definition of indicators to accurately represent the Kisumu slums.

5.3. Research Objective 3 :Linking Ontology to OOA

This research question shows the results of the steps involved in linking ontology to OOA.

5.3.1. Translating knowledge into OOA based parameters

The results of translation of indicators to image based parameters are represented in table 5-3.

Table 5:3 Translation of indicators to image based parameters

Image observation/ Qualitative Indicators	Knowledge	Quantitative Indicator	Feature values
Most buildings range from bright grey to dark brown, few have bright blue and red. Same building with varying colours	The majority of the roof are constructed from galvanized iron sheet, few are painted with blue and red colour A single building may be made with a mixture of both old and new iron sheets	Spectral	Spectral layer mean values Maximum difference Brightness Spectral difference within the same

			building
Rectangular shape of buildings The size of the buildings range from small to medium Shape of settlement	These are row houses where there are many units in a single building In the slums normally the building sizes are small and they are built so closely together and connected to the adjacent dwelling Some of the slums form a slum belt around the planned area and are along the major roads.	Shape/Geometry	Rectangular fit Elliptic fit Area Roundness
Slums are surrounding the planned areas	There is a clear distinction between the planned and slum areas because of the heterogeneous character of slums	Neighbourhood	Mean difference to planned area.
Irregular patterns of buildings	The buildings are haphazardly built with no order.	Direction	Main direction
Slum buildings are surrounded by: by farmlands swamps unpaved roads Clear shadow in the west of the buildings	Traditional houses/villages are evident which are being choked up by uncontrolled slum development. Some parts of the slum are located in marshy and water logged areas. Ground surface and earth roads are visible between the dwellings. Buildings have height and they cast shadow from the sun's opposite direction	Typology	Distance to farmlands Distance to swamp Distance to earth surface roads Distance to small shadow
Medium density of buildings	Buildings are a little bit sparse but connected to each other at small distance.	Texture	GLCM entropy GLCM contrast GLCM mean GLCM correlation

Discussion

Six main indicators comprising of spectral, shape, typology, direction, texture and neighbourhood characteristics were chosen to translate the qualitative indicators. The quantitative indicators were proposed to connect qualitative indicators to feature values in eCognition software as proposed in Table 5:3. The main spectral features identified to represent the roof indicators were retained to all the spectral features in eCognition software. The main shape features chosen to characterise the shape of the buildings and the slum settlement include rectangular fit, elliptic fit, area and roundness. Neighbourhood feature is used to represent the association between the planned and slum areas. Slum areas are located just next to the slum areas and the central business district because of the employment opportunities. Main direction was chosen to represent the haphazard nature of the slum buildings. The four main texture feature were chosen to represent the high degree of contrast between the slum and the planned areas.

5.3.2. Object oriented Image Analysis

Segmentation and classification

A hierarchical network of image objects was created with the three levels of multi resolution segmentation. On each level, the objects were based on sub-objects from the previous level and merged into super objects into the next level. The result of segmentation for buildings with a scale of 10 with different parameters to the fused image is shown in Figure 5-6. The results of the segmentation show that small scale of the image segments mostly fit well with the buildings. For subset A, roads were next classified with a higher scale of 40. Results are shown in figure 5-7. For subset B a thematic layer of roads was used for classification. There was no available thematic layer in subset A.

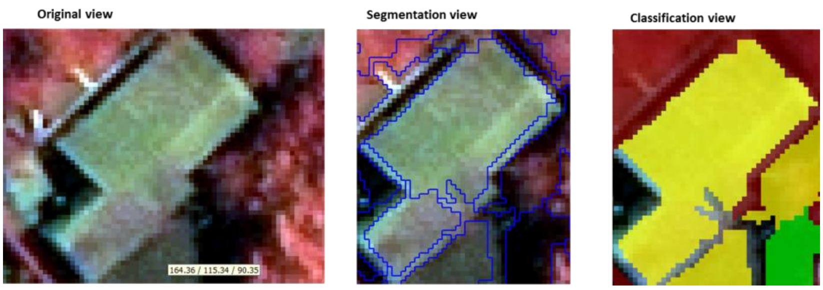

Figure 5-7 Segmentation and classification of buildings

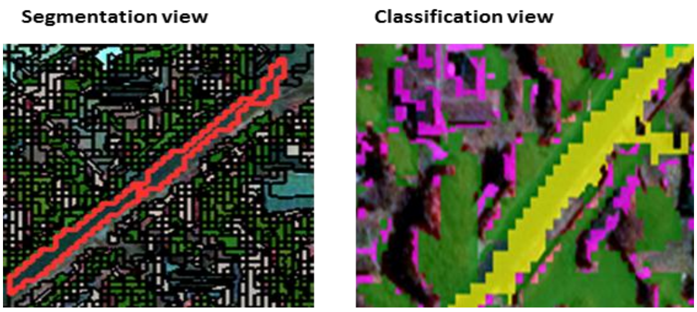

Figure 5-8 Segmentation and classification of roads

Discussion

Segmentation was the basis for classification. Good segmentation should represent accurately features of interest and the aim was not to have image objects from segmentation algorithm that contained more than one feature. However, it was difficult to achieve good segmentation with a one fit all approach for all the target objects as objects were either under segmented or over segmented to accurately represent features of interest. Since object of interest included buildings, roads and settlements it required performing a class hierarchy through multi resolution segmentation to accurately represent different levels of ontology. Segmentation with a small scale ensured there was no mix between the buildings and the bare land. The roads were segmented with a higher scale of 40.

5.4. Research objective 4: Slum Classification linking with the local Ontology

5.4.1. Building characteristics

Characteristics of the slum buildings was perfomed using shadow and by slum roof colour.

- Slum building classification using shadow

The size of the shadow was exploited to detect the slum areas. A library of occurrence of different types of shadow is shown in Table 5:4

Table 5:4 Cases of shadow

Challenge	Screen capture
1. Shadow with one neighbour	
2. Shadow with two edge neighbours in the opposite direction	
3. Shadow with several edge neighbours in different direction	

The result for classification of a building with shadow is presented in figure 5-8. An angle of 270 degrees was used to classify the building. There were a lot of challenges where the shadow exhibited in several ways thus using it for classification was complex.

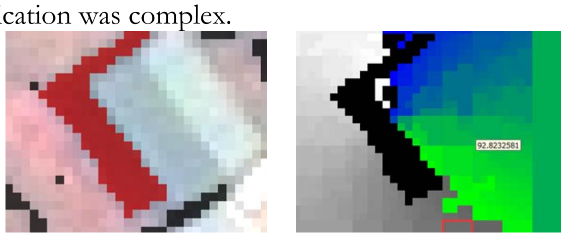

Figure 5-9 classification of buildings with shadow

The classification of the slum buildings using shadow was found not to be to be effective since there were also small buildings in the planned areas.

- Characterisation of slums by roof colour

Housing quality varies across the seven slums settlements mixing traditional and modern type (UN-Habitat, 2005). From the local ontology developed, the colour of the roof ranges from dark brown to bright blue and red. Local ontology informs OOA in the classification of the two types of the roofs. The brown roofs represented in the image as blue represents the worse off slums; while the coloured roof could represent new buildings which are more durable. This shows the linkage between ontology and OOA to characterise and identify the slum areas. The figure shows the results of the classification of the roofs by roof colours. This shows the linkage between ontology and OOA to classify slums.

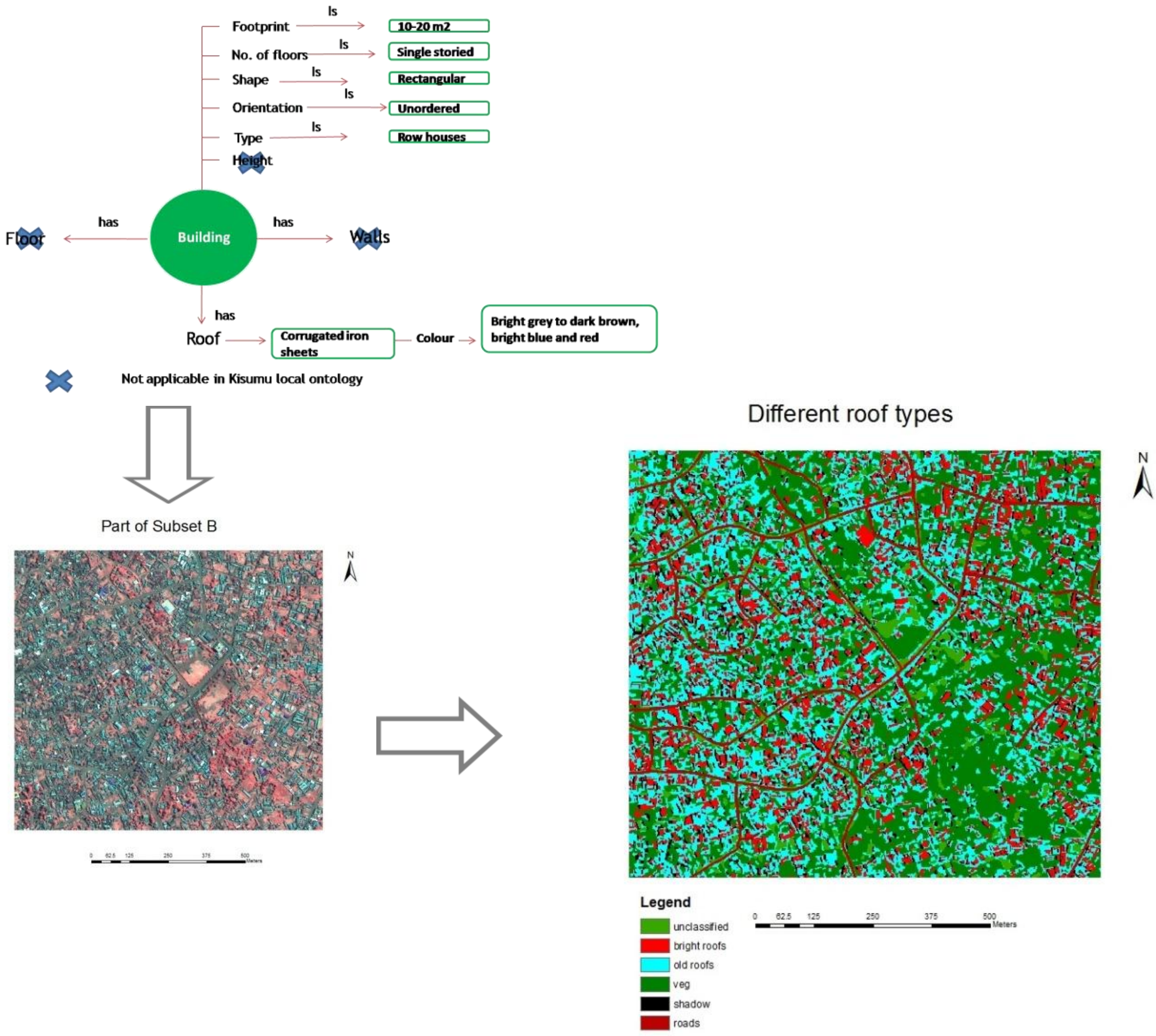

Figure 5-10 Classification of two roof types

5.4.2. By Roads layout

Results

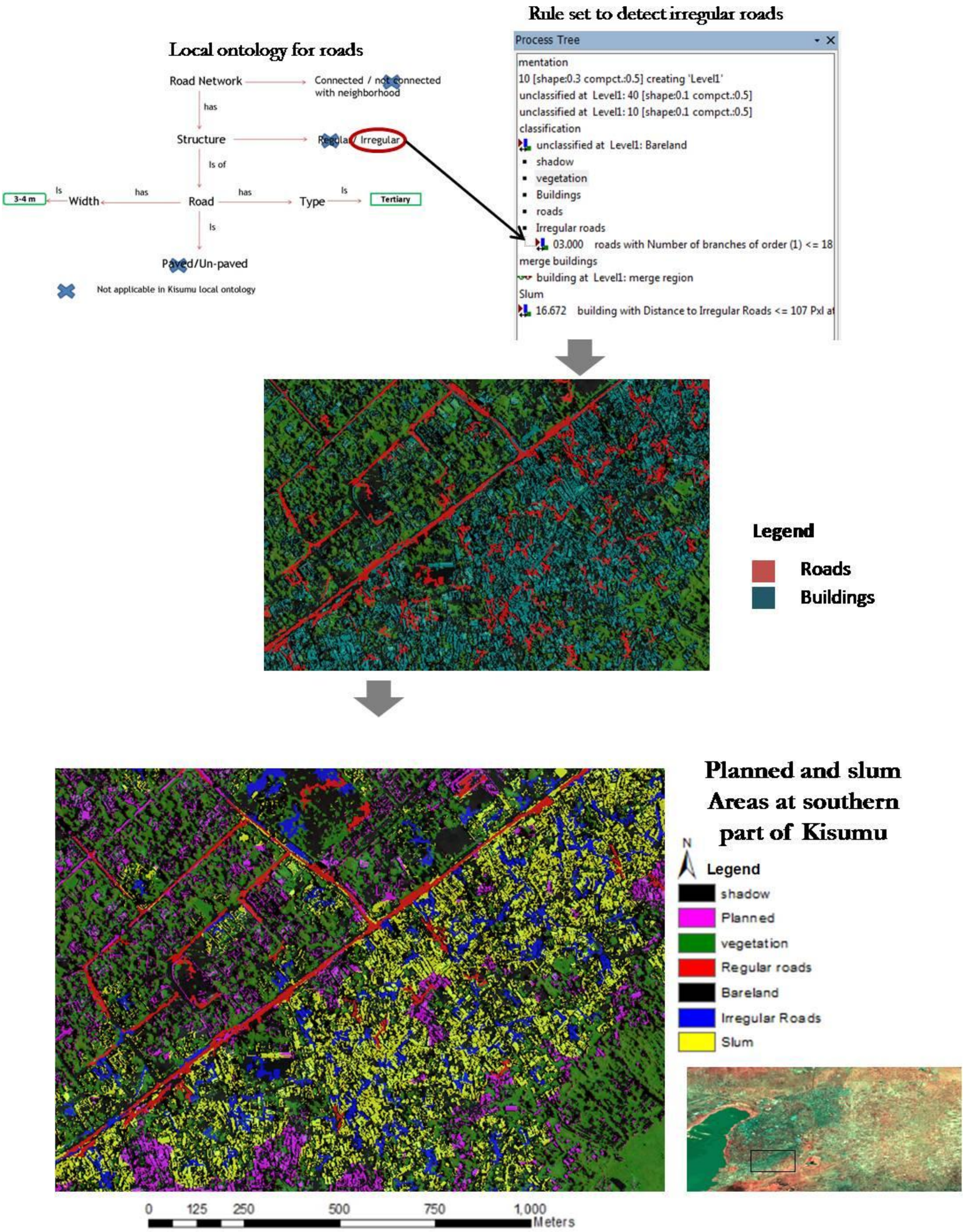

Figure 5-11: Slum classification in Study Site A

The results as shown in Figure 5-10 shows slum classification using ontology concepts. In subset A branches of order (1) less than or equal to 18 was used to classify irregular roads. In subset B, irregular roads were classified with more than or equal to 49. Next, buildings with a distance of less than or equal to 107 were classified as slums in subset A and less than or equal to 369 in subset B.

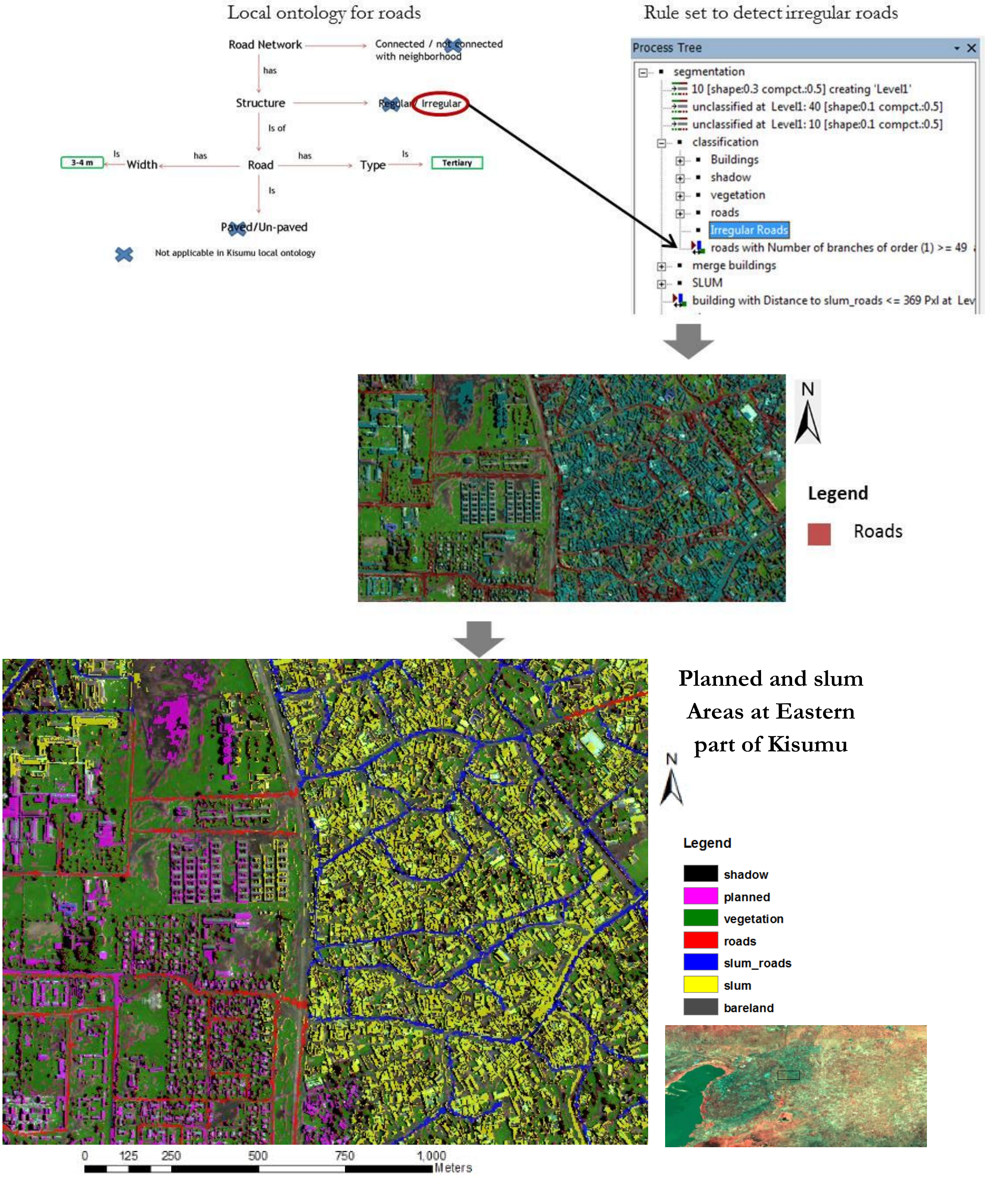

Figure 5-12: Slum classification in Subset B

Discussion

The results indicate how ontology was used as a basis to bring knowledge into OOA. A rule set was developed from the ontology which was then used for classification. This shows that ontology together with OOA can be used to identify the slum areas.

i. Density concept

Density was represented using two major analysis; texture analysis and spatial metrics. The results were validated by use of spatial metrics which showed the overall form and extent of the slums.

By texture

The results indicated areas with a GLCM contrast of less than or equal to 9.Areas less than or equal to 9 were classified in red colour while areas with more than the value of 9 were classified in black colour.

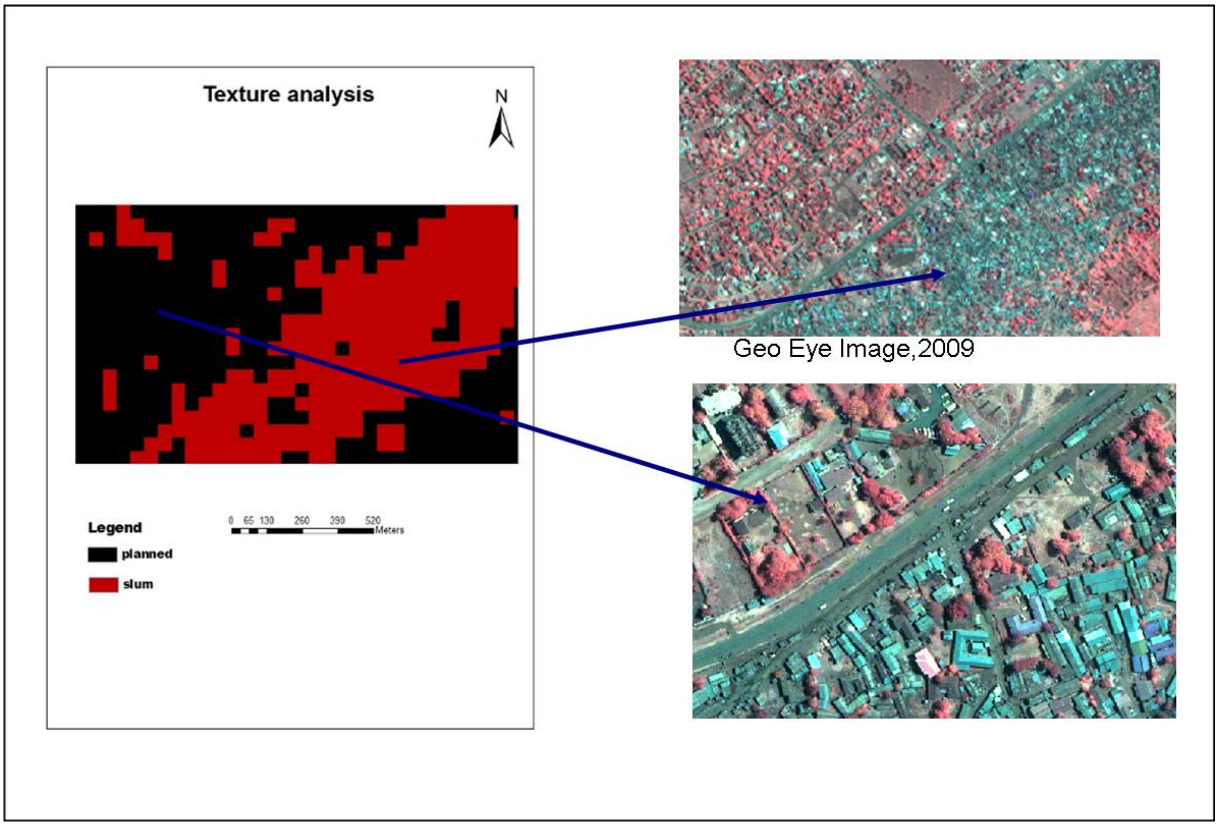

Figure 5-13: Slum detection using texture

The outcome of the results suggested that there is a difference in texture between the planned and the slum areas. The main reason explaining this is the difference in the character of the planned and slum areas. The buildings in the planned areas have a good orientation and appear to be homogeneous in character. In the slums, the buildings are haphazard and heterogeneous in character.

Another reason explaining the difference in texture is the difference in the density of buildings. The planned areas have a low density while the slum areas have high density with clustering of buildings. Areas with low texture were associated with planned areas and areas with high texture were associated to slum areas. This analysis demonstrates that texture is robust enough as regards the detection of the slum areas, despite of some few noise that appeared in the results.

By spatial metrics

Spatial metrics was used to characterise the slums and information was derived about the spatial extent of the slum area. This was to test if the developed ontology in conjuction with spatial metrics could say something about the density of the slums. The results for the selected metrics for both study sites are shown in the following figures 5-13 and 5-14. The largest past index (LPI) results showed a pattern of the highest values in the high density areas of over 86 metres. The values were ranging from low values of 0.05 to high values of 86.972 metres in study site A and from 0.01 to 91.49 metres in study site B. The total edge describes the length of a particular patch type with the highs of 236 and 650 meters in both study areas. The class area (CA) of built up areas showed comparatively similar pattern as with total edge (TE) results in both study areas. It showed highs of 0.03 and 0.15 in the test areas.

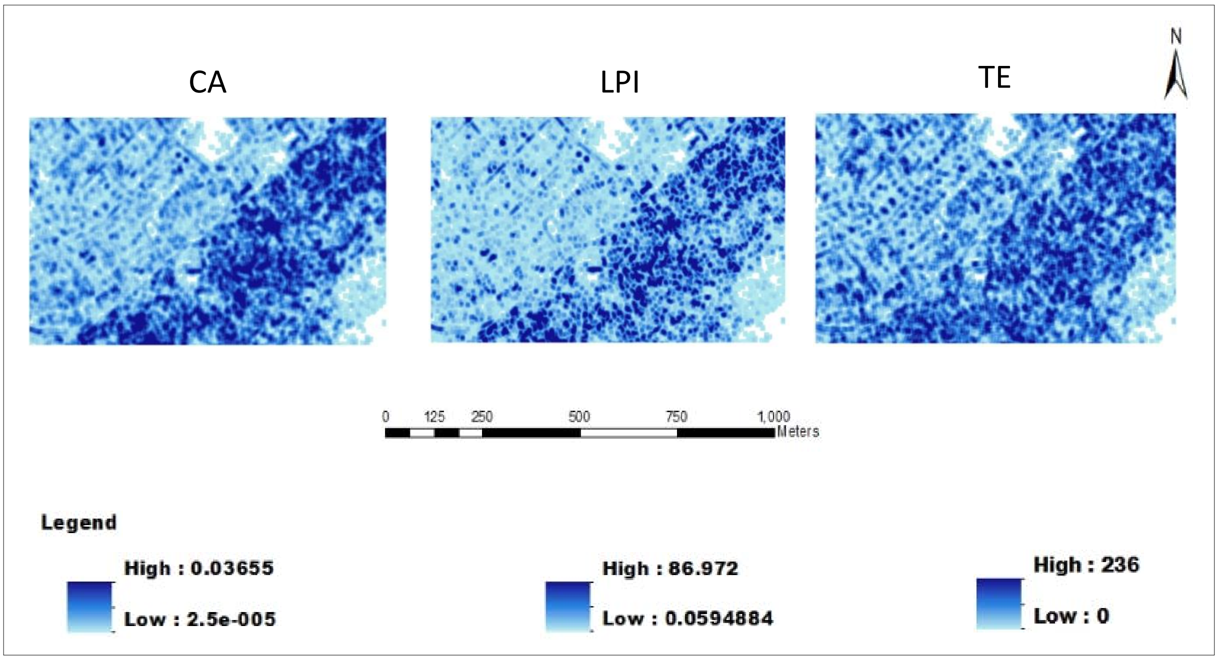

Figure 5-14: Spatial metrics results for test area A

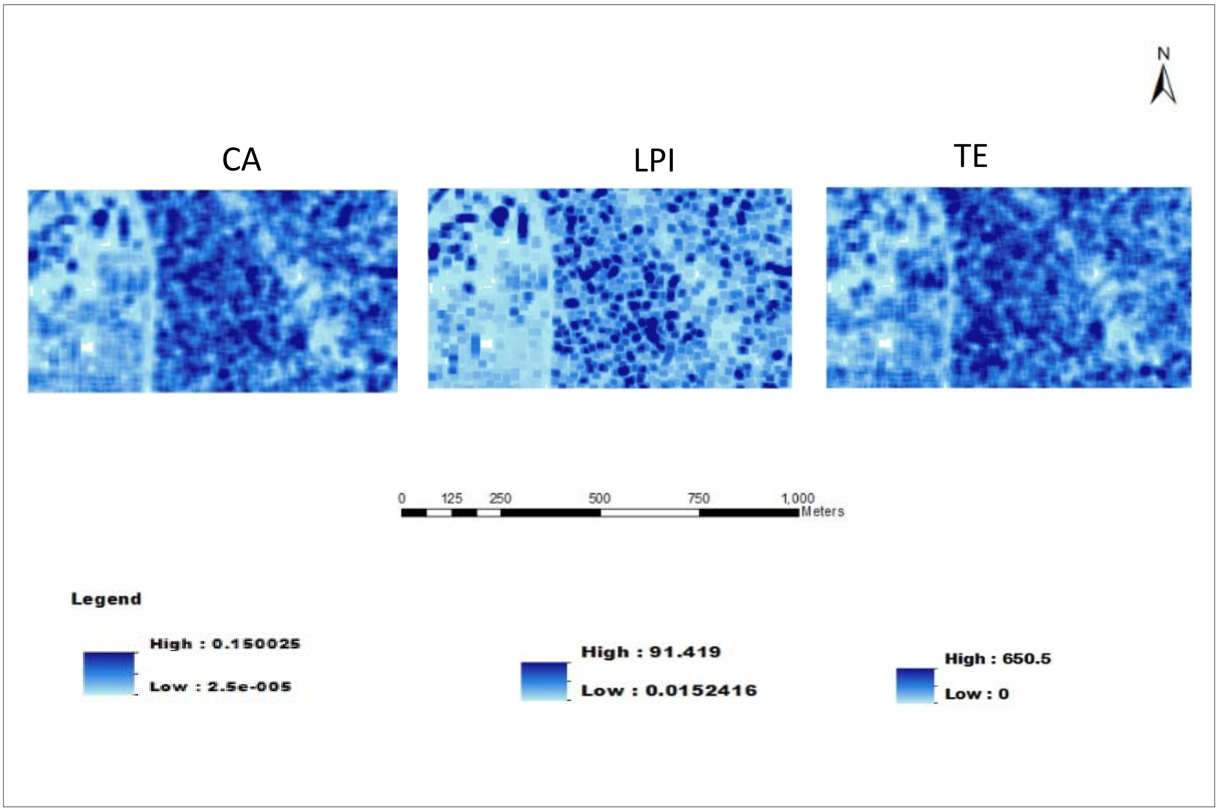

Figure 5-15: Spatial metric results for test area B

Discussion

Spatial metrics proved to be an important measure to distinguish between slum and non-slum areas since the three index metrics shows a similar pattern in the study areas. Largest Patch Index (LPI) index was a clear indicator that the slum area has a high density of buildings forming the largest patch of built up in the area. The high density of the buildings and low amount of non-built areas are reflected by a higher total edge. The more heterogeneous resulted to a higher total edge (TE). The metric results showed spatial arrangement of built up areas and differences can be seen between the planned and the slum areas. This indicates the location of the slum and non-slum areas. The low values indicate the planned areas and the high values of the index metrics indicate the slum areas. This results, however, to make it more objective, further analysis should be performed using other methodology like OOA to confirm or determine the slum locations. This is because a slum is not only defined by the density of the buildings but also other factors as mentioned in the ontology concepts.

The result indicates the delineation of the slum area. The spatial metrics and the irregularity of the roads and texture measures gave similar results of the location of the slum areas. The results showed that there no single parameter can be used to identify a slum area but combinations of parameters are required. The local ontology provides an effective way to breakdown the concepts for slum detection.

6. SUMMARY OF FINDINGS

This section briefly presents a brief summary of the results and discussion. The results of the research have been compared and a synthesis provided to see how far the results has addressed the needs of the stakeholders

6.1. Linking Ontology with OOA

6.1.1. Benefits

In general the generated results show a great potential for the ontology driven slum detection in OOA. The research has shown how ontology concepts such as building characteristics, irregular roads and density through texture description can be used to inform slum detection process. Since ontology is made up of concepts and relations the graphical representations such as Figure 5-4 makes the definition of slums clear. It is important to mention that the generic ontology was flexible enough to extend or remove concepts from it to develop the local ontology. For example it was possible to accommodate more concepts that were found in Kisumu slums. To my opinion, using ontologies helps to integrate knowledge about concepts and enhance detection of complex domains like slums.

6.1.2. Difficulties

One of the challenges was the difficulty in dealing with thresholds to represent the variability in a slum and disparate expert opinions regarding slum conceptualisation.

6.2. Answering the needs of the Stakeholders

The fruits of science continue to shape the nature of our society and influence events which have a world-wide significance- Frank Oppenheimer, 1968

It is vital to bridge the widening gap between science and the societal needs by developing research that attends to society. This research aims at informing the city authorities and other stakeholders of slums about the capability of science in offering solutions to bridge information gap. As mentioned earlier, bodies dealing with slum intervention, rely on out-dated techniques that are time consuming and do not correspond to the dynamic nature of slums.

Different stakeholders are involved in providing range of services to help improve the lives of slum dwellers. The formulation of appropriate policies and intervention programmes for the improvement of slum areas require identifying and understanding the data needs of these stakeholders. These needs can be differentiated and categorized based on requirements of each of the involved bodies. For research oriented in addressing such requirements, the question is 'for the different stakeholders that are concerned with the slum, what are their specific needs ?' or what additional information can research offer to provide solutions to their needs. The requirements can vary in dimensions, scales and time. Comprehensive assessment of various resources like reports and policy documents provided a synoptic view of the current work and a needs catalogue was developed to address these requirements (needs assessment matrix). The model deployed involves using the stakeholders of the slums in developing and carrying out a needs assessment. This helped in gaining a greater knowledge about their needs and the role of the research and its potential to influence decisions.

The results of the needs assessment showed that there were lot of similarities among the requirements of different stakeholders. This shows that once the information is acquired, it can be shared among the different bodies. There were also a lot of data interdependencies. For example, information on development stages, temporal changes, building footprints, size, and density depended on the information on the location of slums.

In needs assessment, the critical requirement is the level of knowledge, that is, the information available. This information requirement starts from a higher scale such as slum location and population estimation. It scales down to more specific information on number of settlement units within a slum, size of each unit, number of people having access to services like roads, water and sanitation. Once the level of information is established, the intervention approach can be planned which may range from additional baseline survey to more specific needs quantification. When the needs are qualified, for example the number of dilapidated units requiring refurbishment, amount of water required etc., it will enhance co-ordinated intervention among the public sector and civil societies. The following subsections shows the information provided by this research

6.2.1. Location of slums

This was the most important need by all the stakeholders. This need was answered as shown in the previous section 5.4.

6.2.2. Boundary delineation of single buildings

Another important need among the stakeholders was to detect the boundaries of the individual buildings to be used as a base layer to attach socio-economic information. Results show that it was not possible to detect all the single buildings in the slum. In test area B the delineated single buildings were more than in test area A. This was because the building density in area A was higher than B. The buildings were so close and clumped and thus, the boundaries of individual buildings could not be identified. Some buildings were connected to each other due to the shadow of tall trees over these buildings; the delineation of most single buildings was difficult.

There were more single boundary building delineation in test area B than in test area A .The reason for this difference was because in test area A the building density was lower. However there were still challenges to extract individual buildings due to the spectral variability within the same building.

As illustrated in Figure 6-1, slum areas were made of different materials and to make it worse, some single building contained different construction materials thus having different spectral reflectance. The spectral reflectance of buildings also overlapped with roads and other open concrete areas. The figure also illustrates the variation in spectral properties of a single building. Direct extraction of buildings lead to other information such as bare land to be included due to the similar spectral responses of brown roofs (old iron sheets) and soil.

Figure 6-1 Photograph showing spectral differences in a single roof. It also shows the similarity of roofs and bare land.

6.2.3. Spatial extent of the slum

After classification at the object level, the connectivity of the single objects is aggregated to a settlement level to generate spatial patterns. The resulting spatial pattern formed the basis for answering to the stakeholders needs such as the area of the slum areas. Spatial metrics in conjunction with the ontology and OOA can be used to identify the spatial extent of the slum.

6.2.4. Sufficiency of living Area

Overcrowding is the proportion of household with more than two persons per room with a minimum standard of 5 square metre floor area per person (UN-Habitat, 2003a). To calculate overcrowding using VHR, information on the number of people and the available living space was required. Social parameters on population should be derived from the census data and integrated with the number of buildings to calculate the number of people living in each house. The following variables are used to calculate sufficiency of living area.

$$Area\ available\ per\ person = \frac{Total\ population}{Area\ of\ buildings}$$

6.2.5. The Different roofing types

Different roof types can be an indicator of variability within the slums and also among different slums. For e.g. the concentration of buildings with rusty roofs can be associated with worse-off slums. Thus, this analysis can be used to prioritize intervention.

6.3. Summary

This section gives the overall verdict of linking ontology to OOA for slum identification. The limitation experienced while undertaking the research is mentioned. The results achieved are assessed against the need information of the stakeholders to show the information provided.

7. CONCLUSION AND RECCOMMENDATIONS

This section presents a summary of the study based on the objectives set at the beginning of the study. The purpose is to reflect on the significant features of the study. Recommendations are also provided based on the findings and limitations with an aim to address the research problem.

7.1. Conclusion

In drawing the conclusion of this study, the main research objective which was to develop a methodology using ontology and OOA for slum mapping in Kisumu, is evaluated.

- **To perform a needs assessment for the stakeholders of Kisumu slums**

Through literature review, stakeholders involved in slums were identified. They included International organisation, NGOs, local government, central government and research institutions in the universities. Their data needs were identified and a matrix table was developed to precisely present their data needs. This objective was important to show the value of this study in contribution to provision of information required by stakeholders for slum intervention.

- **To develop a local ontology for Kisumu slums**

To effectively define Kisumu slums, it required a conceptualisation with an aim of acquiring knowledge by use of ontologies. Generic Ontology was too broad to adequately represent slums at local level and therefore required refinement. Through literature review, visual image interpretation and use of domain experts in remote sensing and slums, knowledge was acquired about Kisumu slums. A list of indicators that represented Kisumu slums were identified. The indicators were used to develop the local ontology by refining the generic ontology to essential elements that represented slums of Kisumu. A local extension and more details were added to integrate disparate expert knowledge.

- **To link ontology to OOA**

The knowledge obtained about Kisumu slums was translated into image based indicators. Six main quantitative indicators comprising of spectral, shape, typology, direction, texture and neighbourhood were proposed to connect qualitative indicators to feature values in eCognition.

- **To map slums based on the ontological concepts in OOA**

The concept of ontology is a fundamental step in OOA .It is a keystone in understanding the specific concepts that characterise a slum through a formal conceptualisation of the knowledge of slums. The methodology is built upon ontology driven slum recognition approach in combination of OOA. The research has shown how ontology concepts such as building characteristics, irregular roads and density through texture description can be used to inform slum detection and characterization process. The results demonstrated the feasibility of the approach. This study advocates the use of ontologies to better inform the recognition of slums in conjunction with OOA.

7.2. Study Limitations

During the research, some limitations were faced due to lack of time and availability of data.

- Limitations on the data

VHR provide high level of spatial information of objects thus increasing the quality and details of information for mapping. It provides latest ground information and is an alternative to the traditional field mapping techniques. However, the study showed that analysis of such VHR was more challenging due to the high spatial and spectral diversity of the object materials. VHR captured well this variability. Large trees planted on the highway or next to a building, covered partially the roof tops and the roads making it difficult to perform classification in getting the whole outline of the objects. Integration of the high resolution imagery and other Geospatial data for example LIDAR would have been useful for accurate classification and mapping of urban features.

The analysis of slum areas, using the location indicator from ontology, required thematic layer for hazardous zones example marshy areas, swamps, agriculture land, hazardous industries. Kisumu slums are mostly located in swamps or flood-prone areas. The GIS layers would have assisted in analysing buildings in proximity to hazard prone areas. However due to lack of GIS layers it was not possible to do the analysis.

7.3. Further Research Reccommendation

Direction for future research are proposed due to limited time could not be carried out

- Further research from methodology

It is recommended for further research on the use of shadow information into slum detection from high resolution satellite imagery. Shadow could offer substantial information about the characteristics of buildings which would be used to identify slums.

- Further research from results

More research should be done on the applicability and the transferability of the conceptual framework of the local ontology and also the rule set developed to another area. Also to the area but using a different image for a different year for spatial temporal analysis.

- Further research on the results of needs assessment.

The stakeholders had varying information needs but due to shortage of time not everything was analysed. To fully assess the UN Habitat definition of a slum, other indicators that were impossible to assess using images were assessed by use of proxy information. Information provided by this research is discussed so as to be used for further research.

Development stages of the slums should be researched further to find out how slums grow over time. Kisumu population is increasing and this leads to overcrowding in the cities prompting the rich in quest for space and well planned areas to move to the outlying suburbs, creating urban sprawls and encroachments of the rural land. Urban sprawl goes hand in hand with slum formation. This is evident in Kisumu where the slums are surrounded by rural land that was incorporated into town boundary (UN-Habitat, 2005). This land provides avenue for slum extension as land owners change use to lucrative provision of cheap slum houses. The development phases of slums include formation of various nuclei, expansion of older nuclei and intensification of the oldest (Agnihotri, 1994). The development phases start with vacant land infancy, by one building, which multiplies, expands, consolidates and reaches a maturity. This is evident in Kisumu where there are clear differences in densities and housing typologies. Understanding the different phases of slum development will help urban authorities to provide policy interventions to prevent their further development (Šliužas, 2004).

Future research should be conducted to explore the temporal changes of slums over time. The analysis should also involve quantifying the changes in different slum settlements so as to identify reasons for the differences in growth in size.

Information of security of tenure was largely a requirement by NGOs and international body. Security of tenure is defined as; proportion of households with formal title deeds to both land and residence; or to either land or residence; proportion of household with any document of proof of a tenure arrangement (UN-Habitat, 2003a). The security of tenure mostly in the slums is different from those of the free hold(International Federation of Surveyors et al., 2010). However, this indicator cannot be considered individually since there are settlements with no title yet they do not have other slum characteristics or vice versa. For example in Kisumu some of the slum dwellers own title deeds. It was difficult to analyse the security of tenure in the images but proxy information can be used to say something about it. A fair assumption was size and shape of the structure as an indicator of the status of the land tenure. In Kisumu, there are several types of buildings that were classified; row houses, large individual houses and village that gave an indication of housing ownership type. Row houses that appeared clumped together indicated commercialisation of houses for rental purposes. So the house occupants could be lacking title deeds. The large individual houses were owner-occupier and indicated security of tenure due to their permanent state. Cadastre information GIS layer can also be integrated with the image during the classification to identify households with no title deeds. Also data on the documents as evidence of secure land tenure should be integrated.

Information on access to sanitation was another data requirement. A settlement has inadequate sanitation if less than 50% of households have improved sanitation (UN-Habitat, 2003a).Sanitation can be explained by the availability of toilet facility, level of uncollected sewage waste and drainage system. If a dwelling is next to an overflowing drainage, septic tank or garbage dump then it could give an indication that it is a slum area. This requires data on the availability of toilet facility and waste disposal systems. It is difficult to know if a household has pour-flush latrine inside the house or connected to a public sewer. This analysis is only possible through field observation and groundtruthing. GIS layers on pit latrines can be integrated during the image classification to identify the toilets. This can give an indication of the sanitation by calculating the distance to the toilet and the number of people it serves. This will depend on the local situation. This research was not able to achieve this since there was no available GIS Layers on pit latrines.

To assess the accessibility of water supply, spatial information on the water taps would be needed to integrate with the classified image of the buildings. Accessibility of water then calculated by analysing the amount of time that each household walk to collect water. A disadvantage of this assessment is the assumption that all piped water is not contaminated and is safe for drinking. Secondly, is that the amount of time spent in the queue to collect water from the communal taps in not catered for. To assess the sufficiency of water, its supply should match with the demand. The slum area, area of single unit, number of single unit, per capita of water consumption variables are required to calculate the water demand. This requires integration of socio-economic data and the results of the image analysis. The slum area, area of single unit and number of single units can be derived from the results of the image classification and spatial metrics. These variables are considered for computation of the water demand which can be compared with water supply to assess the sufficiency of water.

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