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# FINAL THESIS

# Application and use of GIS in small Sanitation projects in Developing countries

# ABSTRACT

Sanitation problems are prevalent in many developing countries. Population explosion and climate change cause people to move from their home to cities fueling unemployment, the creation of slums and illegal settlements with which also comes chronic sanitation problems. To solve the problem of personal sanitation and hygiene in areas where the population density is higher than normal, a number of NGOs in Ethiopia had taken the initiative to build group toilets. Group toilets are basically built for a group of households on a certain part of a city.

In the summer of 2009, KeTu, a Finnish NGO, launched the Bahir dar SaWE project which includes a plan to build more sanitation facilities such as toilets, shower rooms and biogas digesters . The project in its infancy also wanted to study the existing sanitation conditions in selected project areas. The study was mainly through a survey that was meant to find out where and at what conditions the existing group toilets were found in.

This report is part of the initial studies of KeTu and it is about how GIS can be applied in assisting decision making in small scale sanitation projects in developing countries. It tries to analyze the data obtained from the baseline survey and shows how simple information can be put to use to make important decisions such as where to build the next group toilets, where are the hot spots and cold spots.

Thus, the key findings of this paper is more than simply identifying the whereabouts of group toilets on maps. But it also shows how GIS can be integrated into small scale sanitation projects in developing countries with limited fund. Thereby, it greatly enhances decision making and the wise use of resources where budget constraint is an issue.

# Foreward

In the summer of 2009, the Bahirdar sanitation, water and energy(SaWE) project was launched by a Finnish NGO called KeTu (an acronym for 'Sustainable future' in Finnish langauge) and an Ethiopian NGO called LEM the environment and development society of Ethiopia. The project was mainly aimed at helping the locals tackle sanitation problems using simpler, cheaper yet workable technologies. These includes the adoption of urban agriculture, construction of biogas digesters and toilets and other sanitation facilities such as shower rooms.

During the actual project implementation, it was decided to carry out a baseline survey at the initial stage. The survey included the study of all group and public toilets in the selected project areas. However, an interesting aspect of the study was the use of Geographic information system elements in the survey. It was done in a manner such that all the toilets were located with a GPS receiver. The incorporation of GIS elements into the study has had several advantages.

Later that year, I was offered by KeTu to write a comprehensive conclusive report on the survey. This paper is part of the project's report on the survey in 2009.


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# Acronyms

| | |
|---|---|
| KeTu | Kestävä Tuulevaisuus ry (Sustainable future association) |
| SaWE | Sanitation Waste and Energy |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| CSA | Central Statistical Authority |
| SQL | Structured Query Language |
| ESRI | Environmental Systems Research Institute |
| FID | Feature ID |
| EPSG | European Petroleum Survey Group |
| UTM | Universal Traverse Mercator |
| ADA | Amhara Development Association |
| UNICEF | United Nations Children's Fund |
| ETB | Ethiopian Birr (Ethiopian Currency) |

# 1. Introduction

The Bahirdar SaWE(Sanitation waste and Energy) project is a pilot project being undertaken by KeTu ry  in the city of Bahirdar, Ethiopia. It constitutes the study of the sanitation conditions in selected areas, urban agriculture and a biogas project. The project was started after a deal was set between the various stakeholders in Ethiopia and Finland . The overall project is funded by the Finnish Foreign ministry. The project in Ethiopia is administered by a local NGO called LEM the environment and development society of Ethiopia and overlooked by the municipality of Bahir dar as part of the city's development program.

The city of Bahir dar is located in the north west of Ethiopia in the Amhara regional state. It is known for hosting *Lake Tana* which is the source of the longest river in the world, *Nile*. The *Blue Nile*, as opposed to the *White Nile* that starts from lake Victoria, contributes to more than 60% of the waters of the Nile serving as an important source of fresh water for many millions of people in various countries along the river course/3/. This makes the project area of some international significance.

Bahir dar city suffers from recurrent seasonal flooding usually from the end of May till September due to the flat terrain that facilitates the accumulation of water over a certain area and due to the overflowing of Lake Tana. This by itself is the cause of serious sanitation problems since the city doesn't have properly built sewerage systems to handle domestic waste. Therefore most of the waste eventually ends in the lake or the river creating a chain of environmental problems.

 The livelihood of many people is directly or indirectly dependent on the well-being of the lake. A large number of people use the lake water for domestic use such as drinking and cooking food, on the other hand, fishery is also another important source of income for a great deal of people living along the lake shore. Tourism also plays an important role in the local and national economy. The diversity of wildlife and vegetation in the area generates a decent amount of income to the city and the region/4/.

## 1.1 Socio-economic problems and sanitation condition

The city has several socio-economic problems. The rapid shift to urbanization and changes in the living style of Bahir dar city is challenging the municipality in providing the necessary services, specifically sanitation and urban waste management [Hinkkanen /4/]. According to the Central

Statistics Agency of the Federal Democratic Republic of Ethiopia 2006 census report, the population of Bahir dar city is estimated to be around 175 185. The population growth rate is about 3% due to migration of people  from rural areas and high birth rate/5/.

The continuous increase in population number has caused a series of problems. To mention few, increase in illegal settlements and slums, poor urban waste management, unemployment and low economic performance. Malaria is prevalent in the area due to the warm climatic condition, the existence of large water body and the poor sanitation condition/4/.

The city's capacity to handle the domestic waste is very limited. As of 2009, the municipality owns only three vacuum trucks to transport sewage from pit latrines to the landfill out of which only one is actively functioning. Residents has to wait for at least 3 months to empty the septic tanks. Therefore, several NGOs over the years has been involved in sanitation work in the city. Among which it includes the building of public and group toilets in slum areas where people cannot afford to build a toilet for themselves.

 A group toilet is a single toilet building consisting of usually 4 to 6 rooms and shared by several households. The households doesn't pay for the service they receive apart from paying for the cost of emptying the septic tank. Meanwhile, public toilets are used by anyone in the city. Unlike group toilets, public toilets aren't free of charge. Users usually pay 0.2ETB to get the service. In addition, most of the working public toilets have been outsourced to a private enterprise and are being run by employed people.

It has also been noted that, local NGOs and youth association has been working in house to house dry waste collection and city cleaning. Decentralized options in sanitation and energy management can offer flexibility, which allows restructuring of the city without large investment and maintenance costs. Besides, decentralized systems can help create micro business opportunities and secure food and water supply as well as empower people to take an active role in the development of their environment [Hinkannen 2009/4/].

## *1.2 What is Geographical infromation system(GIS)?*

Geographic location is an important attribute of activities, policies, strategies, and plans. Geographic information systems are a special class of information systems that keep track of not only events, activities and things, but also of where these events, activities, and things happen or exist [Longley, Goodchild, Maguire, Rhind 2005 /1/].  A geographic information system (GIS)

integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information (ESRI /8/).

Maps which are at the heart of GIS allow us to gain perspective of our surroundings. They enable us to see patterns by reducing the complexity of the surrounding world. Virtually any data that can be spatially referenced can be shown on maps and yet various kinds of data can be represented on a single map. This would give us the chance to analyze the interaction between the different kinds of data and reach at better conclusion than we would have done it otherwise.

## 1.3 Using GIS for decision making

GIS has a broad range of applications. Some of the prominent examples are in urban planning, forestry, climate science, military use, emergency management, public health and epidemiology etc. GIS uses to establish trends within spatially referenced data, make detailed location based analysis, and keep track of events on an area over extended period of time to see how things are changing with time etc /1/. See Figure 1.

Often times, we have to make decisions that require the knowledge about our environment. Our environment is so complex that sometimes we make decisions with incomplete information. Yet GIS enables us to build a model of the complex environment in a much simpler and easier way for us to understand the environment and make decisions about it [Aronoff 1995 /2/].

Visually depicted data  is far more easier to understand than just the raw data itself. In addition to that, GIS makes the interaction between various factors that the data represents to be easily recognized. For example, in planning a new sanitation development project in a certain area one might need to know initially where the existing sanitation facilities are, the condition of the facilities, how sustainable they are, the number of people using them, the number of the under served people and the accessibility to the existing facilities etc.

The acquired data on its own might not be easy to understand or make sense at all to take a comprehensive action towards the new project. Especially, in the case of spatially referenced data such as location, it is virtually impossible to conceive without the help of a diagram. Therefore maps are a key part of the process of turning raw data and experience into usable information, which in turn can build knowledge and even wisdom/7/.  With maps one can have better

imagination of the real world scenario. A large amount of different data becomes more conceivable and easier to understand with maps.
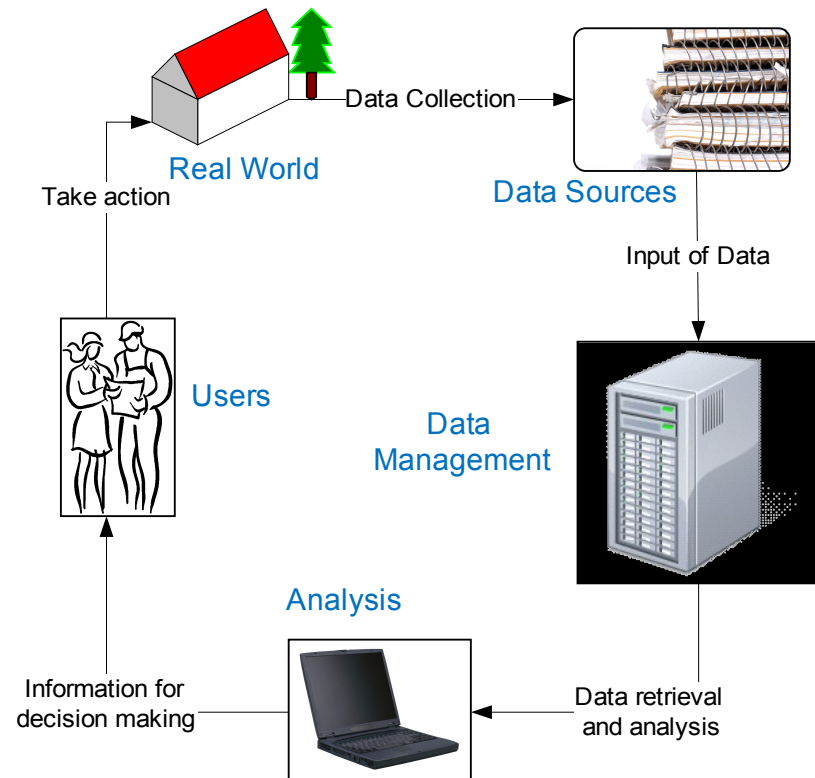


*Fig. 1: The modern planning process in GIS(Aronoff 1995/2/)*

One of the most interesting and earliest examples of GIS and spatial analysis is the study on the outbreak of cholera in the 1850s in London. When cholera was poorly understood, there were large scale outbreak at the time of the industrial revolution. One approach to studying the causes of cholera was based on maps which was done by John Snow. Dr. Snow noticed that the outbreak appeared to be centered on public water pump in Broad Street and he thought that the cause of cholera might have been due to the contaminated water contrary to the then belief of people that cholera is due to polluted air. He then tried to establish trends between the supposedly polluted water pump and the causalities who drank from the pump. Upon his investigation it was discovered that among the deaths of people situated farther from the Broad Street pump, half of the deceased preferred the water from the Broad Street pump to their nearer pump, and another third attended school near the Broad Street pump/9/.  After presenting his findings to the community leaders, the handle of the Broad Street  pump was removed, and the epidemic diminished. Later it was found

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out that a sewer pipe underground was leaking raw sewage into the drinking water of the Broad Street pump. In the process of his discovery Dr. Snow thought that a map would be a useful tool to his report. Figure 2 shows one of Snow's original maps.



*Fig. 2: Map of Cholera deaths in London by John Snow /9/*
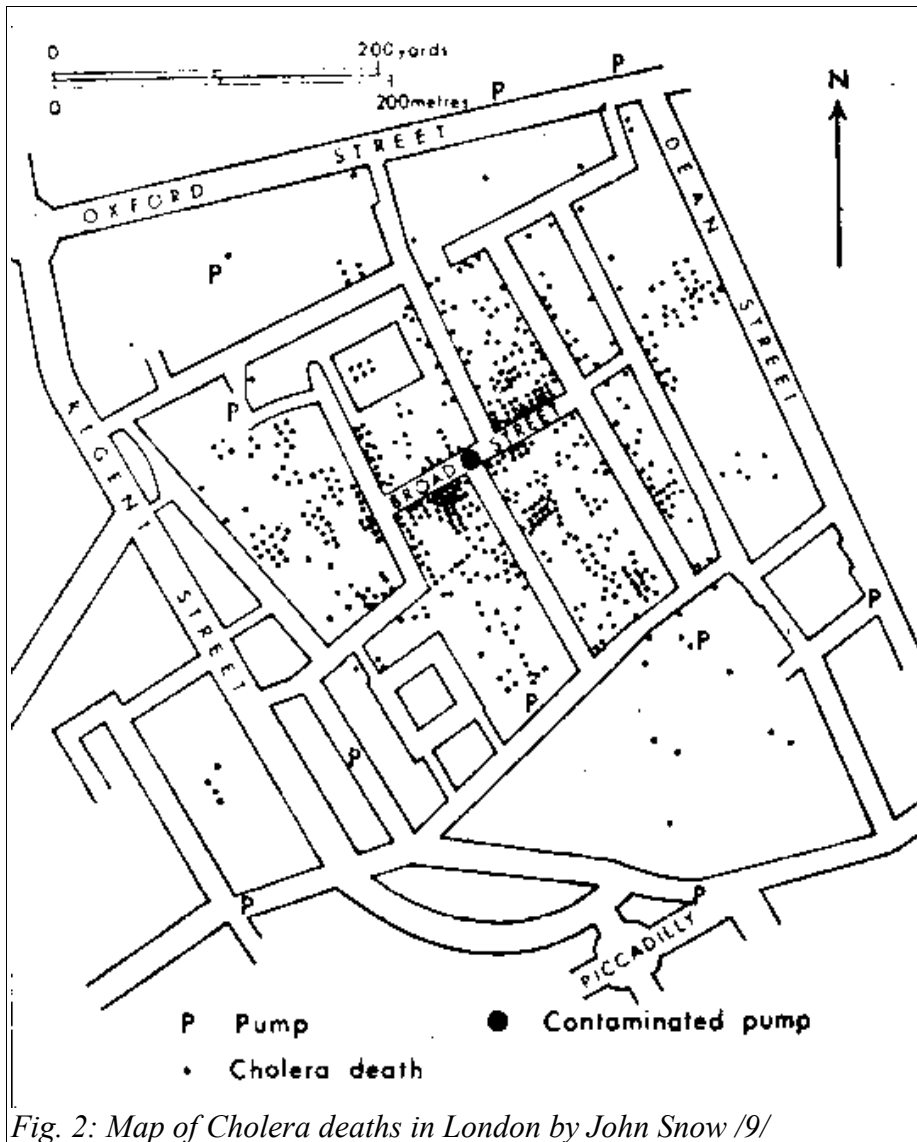
## 2. Getting the relevant data

One of the significant challenges in GIS work is obtaining relevant data. After all, the data lies at the heart of geographical information system. The data used in GIS represents something about the real world at some point in time. They are always an abstraction of reality because we don't need or want every bit of data, just the ones we think would be useful[Aronof 1995/2/]. The data that we consider relevant is the first constraint on the capabilities of the GIS. This in fact means that ultimately the result depends on the quality of the data.

The most  important aspects of data quality are accuracy, precision, time, currency, and completeness.  Accuracy is about how often, by  how much, and the predictability of the correctness of the data. Precision indicates the fineness of the scale with which the data was described. The time indicates the interval at which the data was taken or the point when the data was taken. Time can usually affect the quality of data critically. Yet currency tells about how recently the data was collected. And completeness refers to the portion of the area of interest for which data is available [Aronof 1995 /2/].

Data quality is always costly to achieve. In fact, there is an inverse relation ship between data quality and data cost. The following figure shows the relation ship between the data quality and cost.
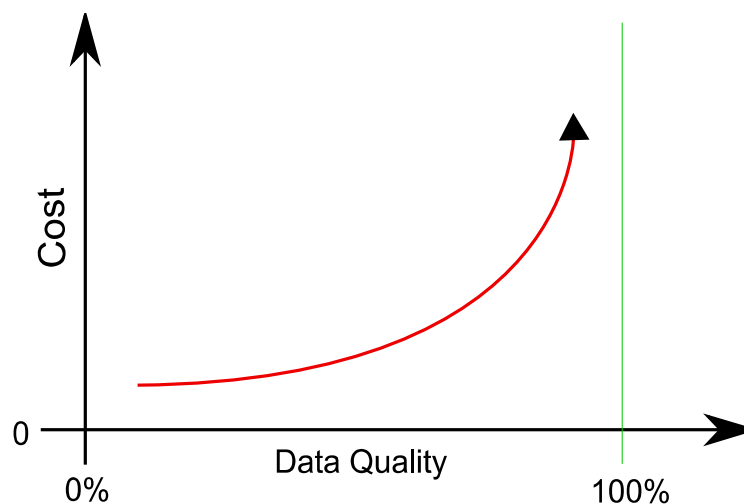


*Fig. 3: The relationship of data quality and data cost (Adapted from Aronof 1995 /2/)*

## 2.1 Organization of data

Data organization is another important factor that needs to be done for a good use of GIS. There are several spatial data models to take care of data organization. Some of the traditional data models are:

1.  Coverages (sometimes referred to as layers or themes/11/) are one of the basic spatial data models. It is a georelational data model that stores vector data. Coverages contain spatial

information representing location and and an attribute data for geographic features[ESRI / 12/].

2. Shapefiles: is one of the most common spatial data model for ArcGIS. A shapefile stores nontopological geometry and attribute information for the spatial features in a data set. In other words, a set of vector coordinates are used to store the geometries of a feature as a shape. Shapefiles  are easier to read and write and requires less disk space. In addition, they have advantages over other data models in such a way that they have faster drawing speed and edit ability/10/. A shapefile in ArcGIS consists of three file systems. These are main file, index file and a dBase table. The main file is a direct access, variable-record-length file in which each record describes a shape with a list of its vertices. In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file. The dBASE table contains feature attributes with one record per feature. The naming convention suggests that all the files have the same name and the name must start with alphanumeric characters (a–Z, 0–9), followed by zero or up to seven characters (a–Z, 0–9, _, -)[ESRI, /10/ ]. For example a Toilet shape file would look like the following.

- ✔ Main file: toilets.shp
- ✔ Index file: toilets.shx
- ✔ dBase table: toilets.dbf

It should be noted that an ordinary user doesn't necessarily handle the three files independently since they are automatically generated when the shapefile is created.

3. Librarian: is a traditional format of spatial data model designed  as a solution to  multiple users editing a shared information resource in an enterprise environment. Librarian layers are collections of coverages which are adjacent to each other. The coverages that form the librarian layers are also called tiles/12/.

4. GeoTIFF: is a TIFF file that allows georeferenced information to be embedded in it. It is a basic data model for rasters where each pixel has spatial representation/12/.

 In addition to the afore mentioned traditional data models, there are also relatively  newer sets of spatial data models which are widely applicable in enterprises and multi user environments. These models are based on Relational and Object Relational Database Management systems/12/.

## *2.2 Georeferenced data*

Geographic data is usually composed of two kinds of information. The first and obvious information is the location data on the surface of the earth, i.e. x-coordinate and y-coordinate values or longitude and latitude values. The second is the phenomenon being reported at the given location. For example, the population size at area A1, the public toilets in a given section of a city, height of forest canopy, soil type etc /2/. Additional to the two attributes though, time is also an important component of geographic data. That is because data has a period of validity. A certain geographic data for example may only be valid for a specific period of time. However, the data can be used to trace history of the given location. For instance, a land area with a pine forest may be given for property developers to become a settlement for a group of people. In this regard, the history of this particular place can be traced back by the data before and after the settlement. Geographic data can be represented in maps through points, lines or area features called polygons. See Figure 4.

Points are used to represent features that have insignificant area compared to their surrounding or the scale of the map. For example, houses, trees, even cities on small scale maps can be represented as points. Lines are used to represent ordered set of connected points. For example, boundaries of countries, rivers, roads etc. It should also be noted here that the scale of the map is one of the determining factors as to how to represent features on the map. An area feature is a region enclosed by line feature. Area features are represented by polygons. An area with a curved boundary can be closely approximated by making the line segments of the polygon continuously smaller. These three features are mainly represented using the vector data model /1/.
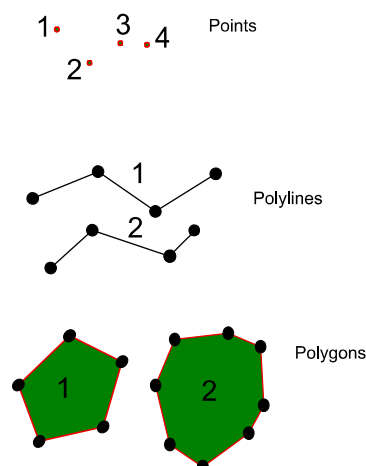


*Fig. 4: Representation of points, lines and polygons*

Several books define georeferenced data in many ways. One definition of it is a unique data where only one location is associated with a given georeference[Longley, Goodchild, Maguire, Rhine 2005 /1/]. For example, a street address with the Zip code refers to only one location on earth and hence is a georeference. Another definition of a georeferenced data is a spatial data that pertains to a location on the earth's surface[Aronof 1995 /2/].

# 3 . Description of the work

## 3.1 The Bahirdar SaWE preliminary survey and mapping

In its planning of the survey, KeTu made a relatively newer approach by integrating GIS components to the survey. That was done by locating every toilet in the area using a GPS receiver device and interviewing the locals who at the time were using the toilets. That way it was possible to make use of spatially referenced data in the process of the study and later in decision making. Since the survey of toilets in the area was the first of its kind, there were no pre-existing identification names for the entire group toilets and public toilets. Thus, it was decided to make use of conventional names which are the names of popular people or place in close proximity to the toilet in question to be able to identify later by name where exactly the toilets are situated.

The GPS receiver device used is called *Garmin GPS III Plus*. In the survey, location precision wasn't given the top priority and thus most of the readings varied between 3m and 30m difference. In the beginning, the device had to be initialized so that it would calculate a fix. The process of initialization consists of multiple stages. At first, the receiver must lock onto satellites. This is shown on the signal strength bars where hollow signal bars represent that the device is trying to establish a connection to a satellite in the horizon. On the other hand, solid signal bars represent that the receiver has collected the necessary data and the satellite is ready for use. Once a fix has been calculated, the GPS III will update the position as long as there are satellites in the horizon /13/.

In addition to the location information, data about the number of people using the toilet, the time when the toilets were built and the emptying frequency from the septic tanks were learned from the interview with the locals. However, for the most part these information were very much based the locals perception and not necessarily the accurate figures. It also included subjective information based on personal observation about the hygiene condition and the state of the building. These data were later classified and further refined into nominal, ordinal and interval data types of fields.

Figure 5 shows the survey form in its original form.

| Id | Conventional Name | Kebele | Belay Zeleke |
|---|---|---|---|
| 1 | Ato Mengesha Gelagay Sefer | Rooms | 4 |

| Coord. | N11o35′07.8″ | E037o23′28.4″ |
|---|---|---|

| Hygien Cond. | - Extremely bad, the toilet floor isn't clean |
|---|---|
| | - Surrounding is filled with litter |
| State of Building | - Deteriorating floor slab |
| | |

**Extra notes:**
- 5 households use a single room
- Toilet is 10 years old
- Septic tank is emptied every 2-3months
- No water

*Fig. 5: Survey form*

## 3.2 Exporting data into ArcGIS

Before exporting the data to ArcGIS, it is necessary to prepare the data to be fed to the Arcmap program in a usable and simpler form. The toilet data was sorted into several column of fields. These fields are the key features of the toilet. They should be able to provide the most important information about the toilets for our study. The longitude and latitude values were converted from degree minute second format to decimal degrees format /14/. On top of that, the large volume of data was condensed using numbers and easily recognizable key terms to facilitate ease of use of the data.

The raw data is a mixture of all kinds of data types[See Appendix A]. For example, the location, number of rooms and number of households are interval data types since the values can be correctly determined. More precisely though, location is a continuous interval data type and thus was represented by a floating point data type or Double data type. On the other hand, number of households or number of rooms are discrete data types and were represented by Short integers.

Nominal data types such as conventional names and kebele names are simple names of places and

were represented by Text or String data types. Finally, ordinal or categorical data types were used to represent the building and hygiene condition of a particular toilet. These kinds of data are described relative to each other. For instance, the condition of the building of one toilet can be described as bad while another toilet's condition of building might be extremely bad. This way of categorical classification would help us to know subjectively which toilets are in really bad condition and which are better of.

*Table 1: Toilet data field and description*

| Field name | Description | Data Type |
|---|---|---|
| X | Longitude value e.g. E037º23'28.4" | Double |
| Y | Latitude value e.g. N11º35'07.8" | Double |
| kebele | The kebele where the particular toilet is found in | Text |
| building_c | The condition of the building. e.g. failing roof, failing wall, | Text |
| rooms | No of rooms in a single toilet building | Short Integer |
| users_room | No of households that own a key of a single room ( No. of households per one room) | Short Integer |
| emp_freq_y | How often the septic tank is emptied in one year | Short Integer |
| conven_nam | Conventional name is a name of a popular person or place near the toilet. It is used as a conventional way of identifying the toilet within the locals. | Text |
| hygiene_c | The hygiene condition of the toilet. | Text |
| Con_Date | The year the toilet is supposed to have been constructed. | Date or Text |
| built_by | The organ responsible for the construction of that particular toilet | Text |
| type | If the toilet is group or public toilet. | Text |

In addition to the above listed fields, arcmap will also add few columns of fields by default. One of these is the FID which is the object ID and guarantees a unique ID for each row in the table. Key functions, such as scrolling and displaying selection sets, depend on the presence of this field

[ESRI /15/]. In other words, if a table lacks an object ID field, it will not be possible to select features in the layer on the map in anyway. And the other field that is created by default is the SHAPE field with type Geometry. The geometry data type indicates the type of geometry, that is point, line, polygon, multipoint, or multipatch which the table stores.

## *3.3 Coordinate Systems*

In the process of exporting data to ArcGIS, it is also important to understand the underlying coordinate system that the data is based on. There are two main classes of coordinate systems. These are Geographic coordinate system and Projected coordinate system.

### 3.3.1 Geographic coordinate system

It is a method of describing a geographic location on the earth's surface using measure of angles from the center of the sphere to the point on the surface. The method mainly uses the longitudes and latitudes to locate a point on the surface of the earth. See Figure 6.
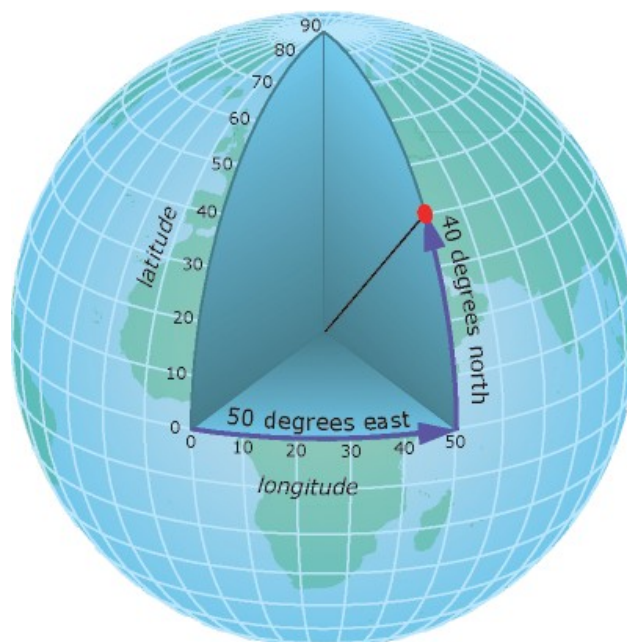


*Fig. 6: Using the latitude and longitude to locate a point on the surface of the earth[Source: ESRI /16/]*

In the geographic coordinate system, the sphere is divided into equal parts which are called degrees. Each degree is subdivided into 60 minutes, with each minute subdivided into 60 seconds. The longitude which runs between north and south measures angles from -180º to +180º east or west

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from the prime meridian. And latitudes run between east and west and measure angles between -90 to +90 north or south of the equator.

Users with global datasets often use geographic coordinates to store and manage their data on a global framework but project the data into a local planar coordinate system for editing and analysis / 16/. The GPS uses the geographic coordinate system to locate points on the ground.

## 3.3.2 Projected Coordinate system

A projected coordinate system is a flat, two-dimensional representation of the earth. It is based on the geographic coordinate system that mainly models the spheroid. However, it uses linear units of measure for coordinates to simplify area and distance calculations. In projected coordinate system, the latitude and longitudes are converted to X and Y coordinates on a flat projection. ESRI suggests that when working with data in a geographic coordinate system, it is sometimes useful to equate the longitude values with the X axis and the latitude values with the Y axis.

The three-dimensional geographic coordinate system therefore is transformed into a flat two dimensional coordinate system using mathematical formulas and the process is called map projection. See Figure 7.
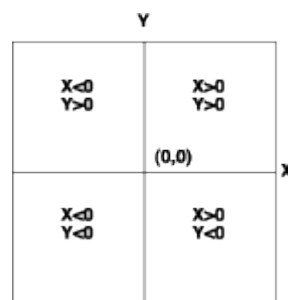


*Fig. 7: Simple representation of projected coordinate system[Source:ESRI /17/]*

According to the EPSG's geodetic parameter registry, Bahirdar under the projected coordinate system lies in the Adindan UTM Zone 37N. The underlying polygon kebele layers and the kebele boundary layers were produced in this coordinate system. However, the toilet locations which were read from the GPS receiver were under the geographic coordinate system. In importing data to ArcGIS, it should be made sure that the two coordinate systems are compatible and the toilets are

represented at the correct places. To handle this kind of coordinate system incompatibility, ArcGIS has a function that is capable of making conversions of Geographic coordinate systems into any form of projected coordinate systems.

## 3.4 Selecting features and SQL expressions

Selection is a very common operation in GIS. We often need to select a group of features from a large data. It enables us to build relationships within the data and make classifications of the large data into finer and simpler groups. There are several kinds of selection techniques in ArcGIS. I would only discuss here about selection by attributes using SQL expressions.

SQL (Structured Query Language) is a standard computer language for managing data in relational databases. A SQL query is a request for data from a database using a SQL expression.

Selection by attributes is one such prominent feature of ArcGIS that is handy when it comes to selecting features using their attributes from a layer. For example, from all Toilets, one may be interested in the toilets that were built four or more years ago and had never been emptied. Using the Select by attribute feature of ArcGIS we can write a SQL expression to retrieve the toilets that were built before 2006 and never been emptied.

**SELECT * FROM** toilets **WHERE**:

"Con_Date" <= '2006' **AND** "emp_freq_y" = 0 **AND** ( "building_c" = 'bad' **OR** "building_c" = 'extremely bad' **OR** "building_c" = 'good' **OR** "building_c" = 'tolerable' **OR** "building_c" = 'very good' )

What the above SQL expression does is, from the TOILETS layer it selects the toilets where the attributes are such that "construction date is in 2006 or before 2006" with "zero emptying frequency" and those toilets that are operational. In other words, the building condition "building_c" can have all values except 'closed'.

After selection, we can export the selected features to a separate shapefile that can be added as a new layer into the map. Such functionality is very handy when dealing with a large bulk of data and when a separate analysis of the portion of the data is required.

The other kinds of selection techniques includes, selecting interactively which is by clicking a feature on the map and selecting that particular feature. Select by location also has a lot more advanced capability to determine spatial relationships.

# 4. Results

## *4.1 Geographic patterns spatial statistical analysis*

Geographic patterns are essential to decision making. Knowing if there is a pattern in a large amount of data is useful to get a better understanding of a geographic phenomenon, to monitor conditions on the ground, compare patterns and track changes /18/.Geographic patterns could be completely clustered or they can be randomly dispersed. Clusters might be statistically significant phenomena to analyze. Whenever clusters exist, it might imply that there is a cause for the clusters in which we can be interested in. For example, a cluster of group toilets is one such example. Why do we have more group toilets in one part of the city than in the other? This might lead us to the cause of the clusters which in our case could be individual's income level or education etc. On the
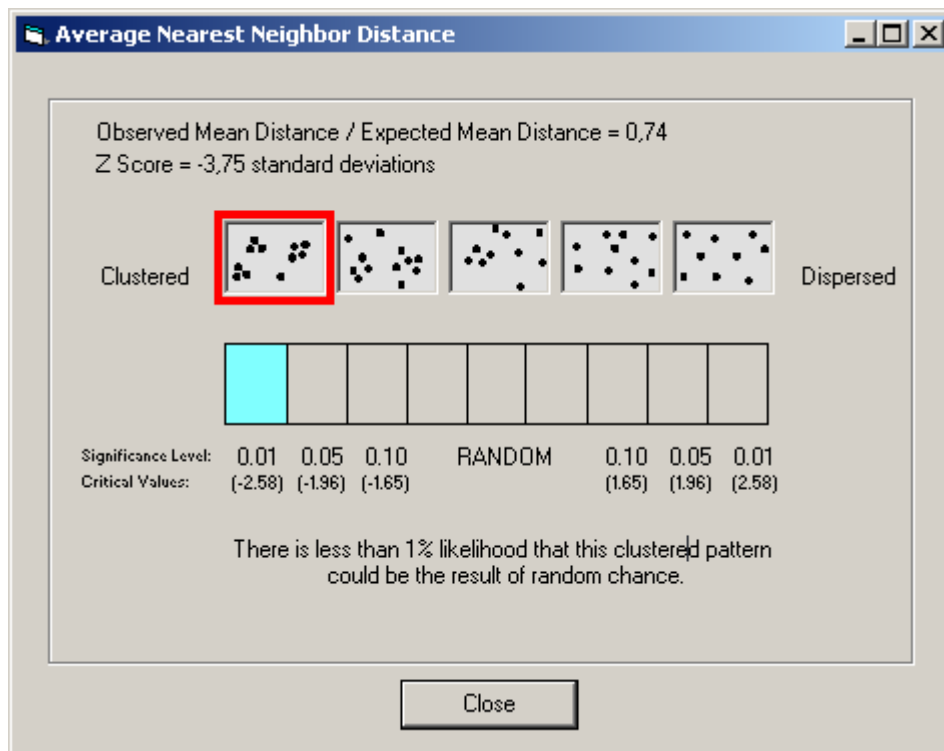


*Fig. 8: Screenshot of the Average Nearest Neighbor distance analysis result for group toilets (ArcGIS Desktop 9.3)*

other hand, for a retail company, study of the clusters of customers would help them to know where to build their supermarkets.  For the toilets data, it might be necessary to examine if the group toilets data and the number of households tend to be clustered or dispersed. ArcGIS has the average nearest neighbor distance tool to  test geometric clustering. That means, without taking the attribute values of the data into account, it will only measure the distance between each feature and its nearest neighbor. It then calculates the mean for all these distances and compares it to a hypothetical

random distribution /19/.

And the result as shown in figure 8 says, there is less than 1% likelihood that this clustered pattern could be the result of random chance. Therefore, we can conclude that the group toilets are geometrically clustered.

However, in the above analysis we didn't take into account the important attribute of the group toilets data which is the number of households using the toilets. Therefore we also need to check if the number of households using the toilets are indeed clustered or not. The High/Low Clustering tool indicates if either high or low values tend to be clustered within the data. In figure 9, The higher the General G value is, the more clustered the high values are in the data. The lower the General G value is, the more clustered the low values are in the data. The Z Score shows the strength of the association. If the Z Score is very high (or very low), there is a strong association. If the Z Score is near 0, it indicates that there is no apparent clustering within the data /19/.
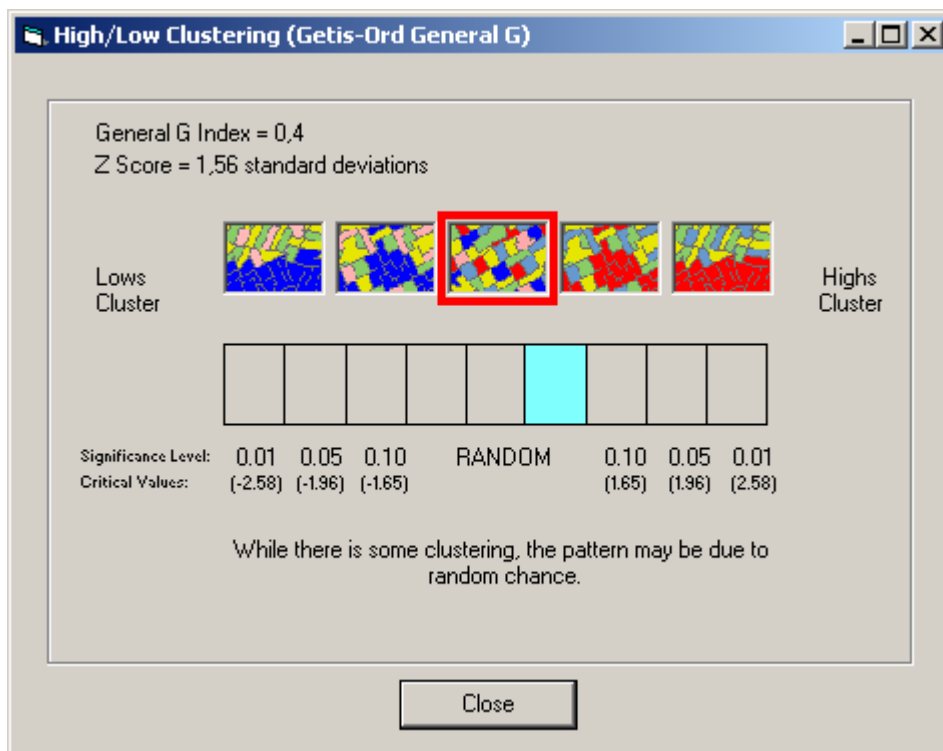


*Fig. 9: High/Low Clustering tool result for number of households in working group toilets[ArcGIS Desktop 9.3]*

The result shows that the number of households within the data are random while there may be some clustering towards the high values.

Once we have done the cluster analysis, we use the hotspot analysis tool to find where the spatial

clusters of high and low attribute values are located. In hotspot analysis, areas with larger number of households than the average or areas with lower number of households than the average and tend to be found near each other are statistically calculated. Figure 10 shows the results of hotspot analysis of number of households using group toilets in the study area. The hot spots are the points in red with relatively large number of households using a single toilet near each other. And the cold spots are the light blue points which are clusters of households with low number of users.
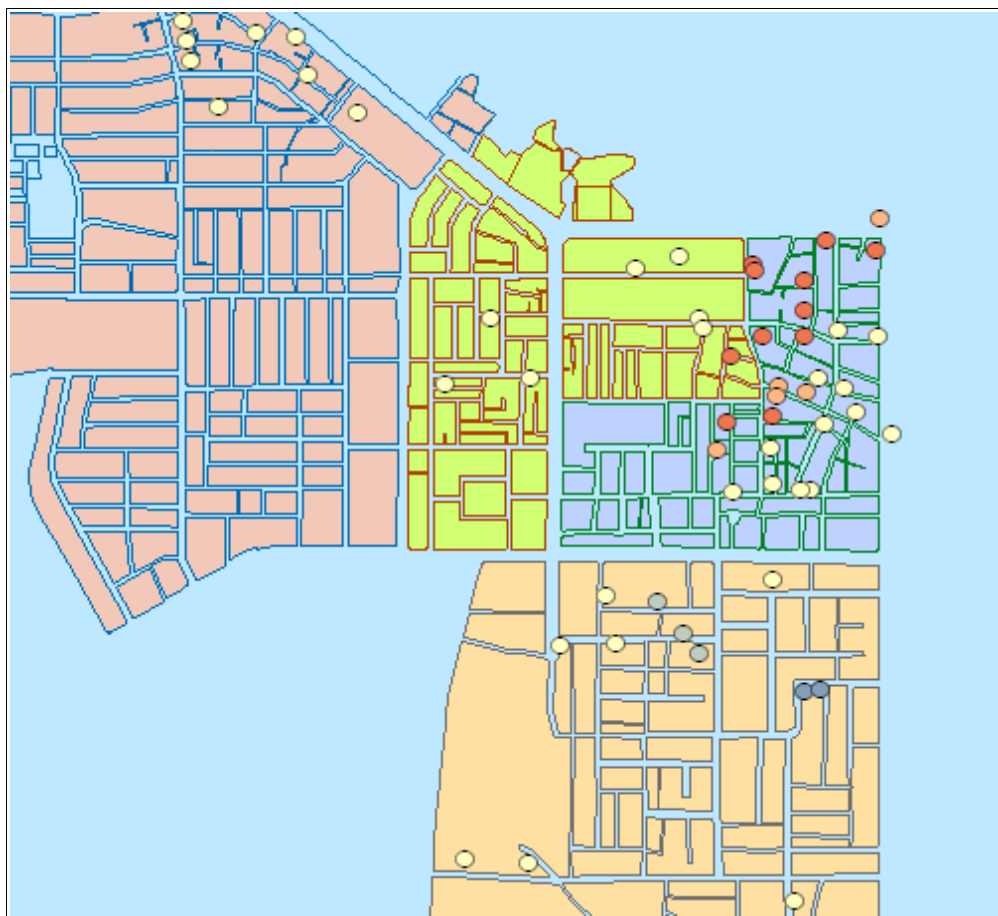


*Fig. 10: Hotspot analysis for number of households using group toilets*

As we see from the above example, hotspot analysis is a very powerful tool in studying spatial patterns. It thus can strongly aid decision making in sanitation projects by showing where the real problems occur and where exactly action is needed /19/.

## 4.2 Challenges in GIS work in developing countries

The application of GIS in developing countries has many challenges. The challenges are diverse and of varying degree. Lack of infrastructures and skilled human power , lack of awareness and fund are some of the key challenges to mention. There is a lot of inter-connectivity between these

challenges. In fact, it is virtually impossible to look at the one with out describing the other.

GIS is a fairly expensive technology to use in developing countries. The cost of data collection, cost of software/ hardware and costs of employing and training GIS staff is beyond what most African countries can do at a local level. Lack of internet connection or its limited speed makes communication and data transfer difficult. However, shortages of staff with the appropriate skills and training is the biggest constraint even above shortages of funding /6/.

Lack of support from institutions and lack of awareness among senior managers of what GIS can actually do to help empower decision makers with a more reliable and simpler model of the real world scenario is by itself another problem. With very little knowledge of the senior managers about GIS, it is virtually impossible to get their support to allocate resources to the development of GIS. Therefore, it is essential to work to raise awareness of the governing bodies to convince them allocate resources towards the development of the technology.

*Table 2: Some of the common factors that have been known to impede the efforts to implement GIS [Adapted from Making GIS work in developing countries: views from practitioners in Africa]*

| Infrastructure | ■ Suitability and security of buildings<br>■ Limited communication and access to information<br>■ Equipment — hardware and software problem |
|---|---|
| Data | ■ Limited availability<br>■ Quality and currentness of data<br>■ Lack of adequate base mapping<br>■ Difficulty in sharing data<br>■ Poor data management — existing data is hard to find |
| Human Resources | ■ Lack of trained staff<br>■ Lack of awareness<br>■ Low priority for staff training<br>■ Poorly developed self-help networks |
| Financial | ■ Limited budget for maintaining the project<br>■ High cost of proprietary software<br>■ Insufficient budget for staff training |
| Institutional | ■ No political or legislative support<br>■ No government policy<br>■ Lack of awareness within the government bodies<br>■ Conflict of interest |

### 4.2.1 Data availability and accessibility

The lack of spatial data infrastructures(SDI) is the biggest challenges to get background materials for the project. Data relevant to the Bahir dar SAWE Project was obtained through surveys and from the Bahir dar cadastre office. These includes, the toilets data which was obtained through a baseline survey conducted by KeTu ry and  kebele boundary and base map from the cadastre office. However, much relevant data such as population number in the kebeles and the income distribution is not available. To make a reasonably good use of GIS in the project there needs to be more physical data collection in different areas of the city.

In addition, there is lack of clear administerial responsibility as to who takes care of the data concerning the conditions of sanitation and other related issues. In principle, it is the responsibility of the Bahirdar water bureau to keep data about the sanitation issues in the city. However, it is impossible to know which department really has the relevant data within the bureau.

### 4.2.2 Data management

The municipality of Bahirdar has no identifiable library for relevant sanitation data in digital form or paper form within the city. And there is no formal way for sharing data and information within the government organizations themselves. Most of the government departments seem not to have active formal information storage systems/7/. The data in question might be available within some people's office shelves or in the hard disk of individual's computer. But in time of need of the material, it is extremely difficult to get hold of the data. Lack of skill in data management software such as Ms Access and Ms Excel adds up to the extent of the problem. Besides, when individual's leave the organization due to retirement or moving to another location, it is very possible that the data is lost.

### 4.2.3 Lack of GIS Skills

Lack of GIS skills perhaps is the most prevalent hinderance to the development and use of maps in managing sanitation projects in Ethiopia. Organizations are not used to using maps in project management. As a matter of fact, there is a very limited use of even the standard packages such as Ms Excel and  Access. Therefore it is very essential to promote the use of GIS and the use of spatial thinking in general within the local administrative organs.

On one side, the lack of of GIS skills of the technicians and lack of fund of the organizations to

build capacity and on the other side, the lack of awareness of the senior management groups to allocate resources, preventing those interested in driving GIS forward to make managers aware of its relevance and potential creates a vicious cycle that goes no where[6].

## *4.3 Sources of error*

In this basic and preliminary work there is expected to be fairly some amount of errors. These errors could be related to the challengers mentioned above. Some of these are:

1. Quality of data: in the Bahir dar SAWE project a calculated risk was taken due to limitations of fund, skilled labor and lack of equipments. For example, the location of the toilets varies between 3m and 30m in the actual sites. This is due to the use of fairly old and simple kind of GPS receiver device and it was decided to go with what we have from the outset than to spend more money to get a better receiver.

2. Survey techniques: During the survey of the entire group and public toilets, the information was obtained by interviewing the locals. And there was no single documented data used from any government office or other non-governmental institutions. In most cases, during the interview, when people were unable to tell what was asked they tend to approximate numbers or guess facts. This would definitely have a consequence in the quality of data obtained. However, this technique has also enabled us to see what exactly peoples need is and what facts lie on the ground.

3. Method of analysis: analyzing the results of the survey is another step where some degree of uncertainties are expected to occur. The structure of the survey itself is such that it consists of several subjective elements. Extracting the most relevant information out of these subjective elements is a difficult task. For example, in defining the conditions of a toilet, one may regard the sanitation condition as 'good'. Another person may call it 'bad'. Therefore, there is lack of uniformity in grading the conditions. This kind of problem is associated with all kinds of ordinal or categorical data types where features are classified as categories.

   On the other hand, in the spatial statistical analysis of the areas, the input feature classes didn't contain projected data. This would have probably caused more uncertainty especially when using the inverse distance conceptualization of spatial relationships which should be used only with projected coordinate systems /20/. In addition, the neighborhood search

threshold or the distance band was set to default. These risks were taken by assuming that the area under investigation was so small and thus the difference in result using the Geographic coordinate system wouldn't be significant.

4. Interpretation of results: In the final interpretation of results, it is necessary to note the combined effect of all other potential sources of uncertainty. The final results are the products of the various factors involved in the study. This includes personnel, data, equipments, methods , and background information used. Each of this factors uniquely influence the results of the analysis.

# 5. Conclusion and discussion

In this essay, the intent was to show how GIS can be put to use in small scale sanitation projects in developing countries especially in the Bahir dar SaWE project. The use of GIS can systematize the decision making process for a proper resource distribution over the project areas. It has also been shown that the integration of GIS can be done without spending a large amount of money. After conducting the study of the sanitation facilities, GIS has enabled us to have a more conceivable picture of the area.

1. The results have shown which areas have the highest density of users per toilet room. This is shown in the hot spot analysis. And it was possible to see which areas are better of compared to the worst toilets. This has the advantage of knowing where to build extra toilets to relieve the problem. In the map[Appendix B], it was shown that the Gishabay kebele is the worst affected in terms of toilet inadequacy. This can actually be subjectively proved from our observation. The Gishabay kebele is one of the oldest kebeles in the city of Bahir dar. It has a population of about 18 973 inhabitants[Hinkkanen 2009]. The chairperson of the kebele, Ato Eyaya Negatu says the kebele  has a lot of small enterprises and a severe sanitation problem. The distribution of toilets compared to the number of people living in the kebele is totally unmatchable. This is mainly because a lot of people live in a small piece of land where the land isn't legally issued to them or by illegally expanding their block of land and with the lacking supervision of the concerned organ from the kebele administration, every open space has been inhabited. In this kebele, more than 95 % of toilets are in real bad condition. It was also noted that most of the toilets were lacking either roof or the floor slab was deteriorating. This on the other hand, raises the issue of safety

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concerns especially for children.

2.  Secondly, the use of maps has explicitly shown us the distribution of public and group toilets, closed and working toilets over the study area. This provides a general picture as to which kebeles have the largest number of group toilets or public toilet. It was also shown which kebeles has 'extremely bad' toilets, 'bad' toilets, 'good' toilets or 'very good' toilets. It is no wonder that this kind of analysis can be done with other kinds of statistical methods. Nevertheless, maps have the advantage of enabling us to know the location in the real world. Maps show us the general picture of the situation more vividly than we could have imagined otherwise.

3.  With maps it is easy to examine trends. Trends are patterns in which entities behave in a certain environment. These patterns could be indicative of some facts on the ground. For example, the fact that there are more group toilets in Gishabay than in any other kebele may suggest that people in Gishabay kebele have low income level or low level of education etc. This presumption might not be correct on its own but it would give us an insight as to why these patterns exist. Thus, further investigation will tell us why indeed there are more group toilets in Gishabay kebele.

    Similarly, it is possible to see if there is any pattern in the location of 'ever unemptied ' toilets. These are toilets that had never been emptied since they were built. At the time of the survey, the interviewees near these toilets responded that the toilets were full during the rainy season and empty during the dry season suggesting infiltration of the sludge into the ground. The pattern here is the tiolets in this particular area had never been emptied which may suggest that the geologic formation of the area is such that sludge can infiltrate through it. Or the construction of the toilets in that area is questionable.

    This may be an interesting phenomenon to look at from protecting the ground water aquifers point of view. Whatever is the correct answer, further investigation will tell what really is happening to the sludge. However, the pattern with regard to the geographic location of these toilets would provide an invaluable information about the underlying soil structure of the area and other related issues.

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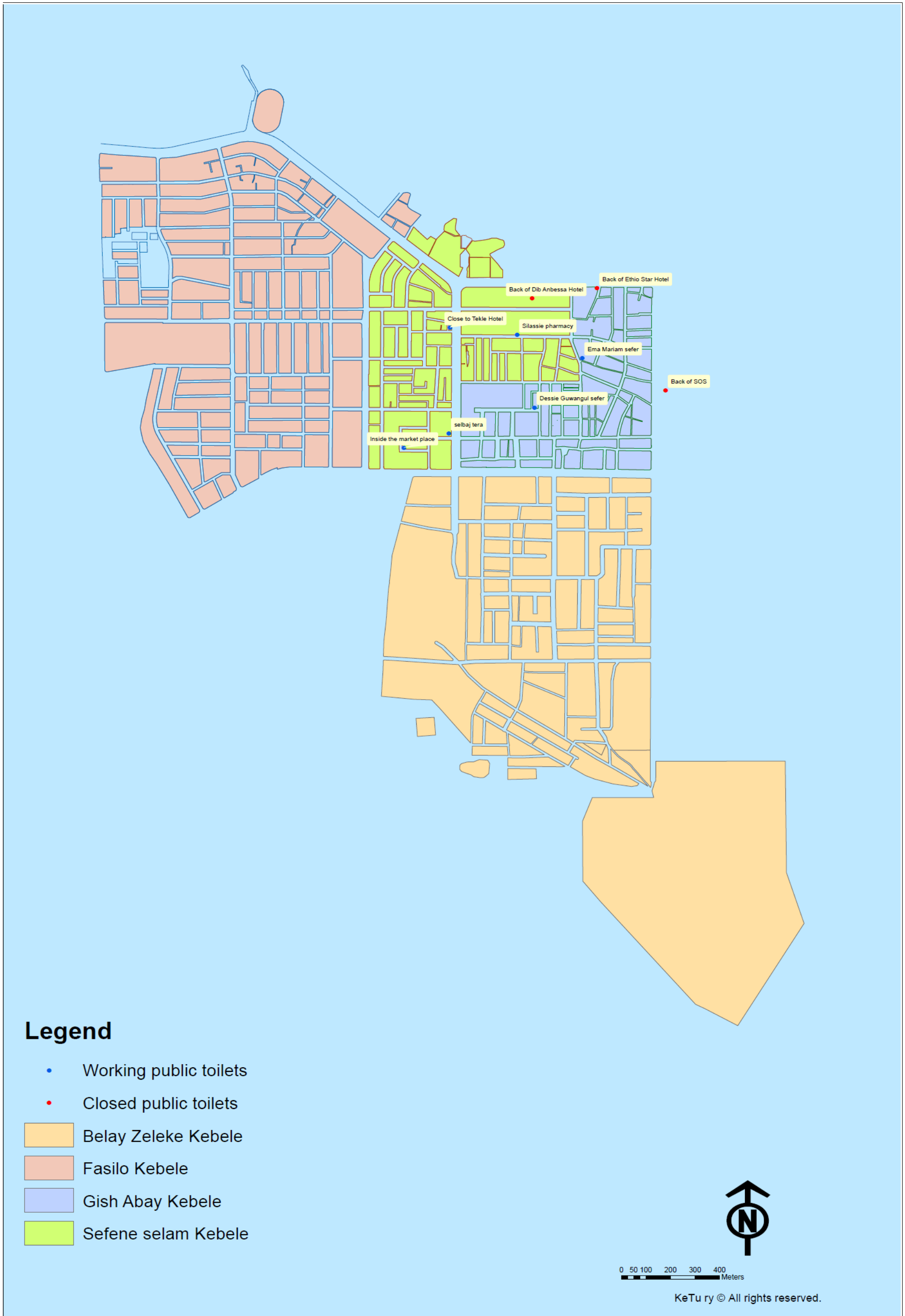
# Appendix

## A. Background data

| ID | X | Y | Kebele | Building condition | NO. of Rooms | No. Households per room | Emptying freq. Per year | Conventional name | Hygiene condtion | Date of Construction | Built by | TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 37,391222 | 11,585500 | belay_zeleke | extremely bad | 4 | 5 | 2 | Mengesha Gelagay Sefer | extremely bad | 1999 | municipality | group |
| 1 | 37,390889 | 11,585944 | belay_zeleke | tolerable | 4 | 5 | 1 | Bayelign Kase Sefer | tolerable | 2001 | municipality | group |
| 2 | 37,390306 | 11,586639 | belay_zeleke | extremely bad | 4 | 4 | 3 | Agere Dagnew Sefer | extremely bad | 1994 | municipality | group |
| 3 | 37,389194 | 11,586778 | belay_zeleke | tolerable | 4 | 5 | 3 | Asniqa Yigzaw sefer | bad | 2001 | ADA | group |
| 4 | 37,393528 | 11,584694 | belay_zeleke | tolerable | 4 | 3 | 2 | Mesfin Wube sefer | extremely bad | 2001 | ADA | group |
| 5 | 37,393917 | 11,584861 | belay_zeleke | tolerable | 4 | 6 | 2 | Agegne Mucheye sefer | good | 2008 | local people | group |
| 6 | 37,392861 | 11,587139 | belay_zeleke | good | 4 | 1 | 1 | Simegn Gedife sefer | good | 1999 | municipality | group |
| 7 | 37,389389 | 11,585778 | belay_zeleke | tolerable | 4 | 2 | 2 | Worku Dese | bad | 1999 | municipality | group |
| 8 | 37,388028 | 11,585694 | belay_zeleke | tolerable | 4 | 6 | 3 | Sudi sefer | bad | 2001 | ADA | group |
| 9 | 37,387472 | 11,580944 | belay_zeleke | tolerable | 4 | 8 | 0 | cattle market | bad | 2008 | unknown | group |
| 10 | 37,386083 | 11,581028 | belay_zeleke | tolerable | 4 | 10 | 0 | old abattoir | extremely bad | 2007 | municipality | group |
| 11 | 37,388583 | 11,579167 | belay_zeleke | bad | 4 | 3 | 0 | back of cattle market | extremely bad | 2006 | municipality | group |
| 12 | 37,393306 | 11,580083 | belay_zeleke | good | 4 | 4 | 2 | Mobile center area | bad | 2006 | municipality | group |
| 13 | 37,385639 | 11,591417 | sefene_selam | extremely bad | 4 | 5 | 2 | back of kebele office | extremely bad | 1999 | municipality | group |
| 14 | 37,386639 | 11,592833 | sefene_selam | bad | 4 | 4 | 2 | Abeba Mekonen sefer | tolerable | 2001 | ADA | group |
| 15 | 37,387944 | 11,593083 | sefene_selam | tolerable | 6 | 350 | 52 | Close to Tekle Hotel | good | 1991 | municipality | public |
| 16 | 37,387528 | 11,591528 | sefene_selam | bad | 4 | 5 | 1 | Hasabe Melese sefer | extremely bad | 1994 | municipality | group |
| 17 | 37,386028 | 11,588583 | sefene_selam | bad | 8 | 200 | 12 | Inside the market place | extremely bad | 1989 | unknown | public |
| 18 | 37,387750 | 11,589139 | sefene_selam | good | 9 | 350 | 52 | selbaj tera | good | 2005 | municipality | public |
| 19 | 37,389056 | 11,592361 | sefene_selam | closed | 4 | 0 | 0 | Back of Hyper Cinema | not inspected | unknown | unknown | group |
| 20 | 37,390250 | 11,592833 | sefene_selam | extremely bad | 6 | 300 | 52 | Silassie pharmacy | bad | 2002 | municipality | public |
| 21 | 37,391222 | 11,592778 | sefene_selam | extremely bad | 6 | 6 | 2 | Alebachew Tessema sefer | extremely bad | 1989 | unknown | group |
| 22 | 37,391333 | 11,592611 | sefene_selam | good | 4 | 5 | 2 | Brehan Amsalu sefer | tolerable | 2001 | ADA | group |
| 23 | 37,391917 | 11,592000 | sefene_selam | extremely bad | 4 | 6 | 1 | Aba Goshe sefer | extremely bad | 2001 | ADA | group |
| 24 | 37,392639 | 11,591972 | gishabay | bad | 6 | 150 | 12 | Ema Mariam sefer | bad | 1989 | Unknown | public |
| 25 | 37,392611 | 11,592472 | gishabay | tolerable | 4 | 5 | 3 | Enat Kinde sefer | extremely bad | 2001 | ADA | group |
| 26 | 37,389861 | 11,593778 | sefene_selam | extremely bad | 6 | 13 | 3 | koshekosh sefer | extremely bad | 1989 | UNICEF | group |
| 27 | 37,390806 | 11,594194 | sefene_selam | closed | 0 | 300 | 0 | Back of dib anbessa hotel | not inspected | 1993 | unknown | public |
| 28 | 37,392417 | 11,594028 | gishabay | good | 4 | 8 | 3 | Wase Wolde sefer | good | 1999 | unknown | group |
| 29 | 37,392444 | 11,593917 | gishabay | tolerable | 3 | 7 | 4 | Fasil Kasa sefer | bad | 1989 | private people | group |
| 30 | 37,391944 | 11,593972 | sefene_selam | closed | 0 | 25 | 0 | Berhe Neguse sefer | not inspcted | unknown | unknown | group |
| 31 | 37,382444 | 11,599111 | fasilo | bad | 4 | 4 | 1 | Back of Kebele office | extremely bad | 2001 | ADA | group |
| 32 | 37,381222 | 11,599778 | fasilo | good | 4 | 4 | 0 | Ginto sefer | good | 2007 | municipality | group |
| 33 | 37,381500 | 11,599083 | fasilo | tolerable | 4 | 4 | 1 | Enanu Ayalew sefer | bad | 2001 | ADA | group |
| 34 | 37,379889 | 11,599361 | fasilo | good | 4 | 2 | 0 | Ema yidagnu sefer | good | 2007 | municipality | group |
| 35 | 37,380000 | 11,598833 | fasilo | tolerable | 4 | 5 | 3 | Jibril Umer sefer | bad | 2001 | ADA | group |
| 36 | 37,380028 | 11,598472 | fasilo | extremely bad | 4 | 5 | 1 | qes Asmare sefer | extremely bad | 2001 | ADA | group |
| 37 | 37,380667 | 11,597472 | fasilo | good | 4 | 3 | 1 | Menen Tegegn sefer | good | 2001 | ADA | group |
| 38 | 37,382556 | 11,598139 | fasilo | good | 4 | 6 | 0 | Maru Ibrahim sefer | tolerable | 2001 | ADA | group |
| 39 | 37,383722 | 11,597361 | fasilo | tolerable | 4 | 4 | 1 | In front of Sertse school | bad | 2005 | municipality | group |
| 40 | 37,391611 | 11,589944 | gishabay | extremely bad | 6 | 8 | 3 | Mulualem Tadeg sefer | extremely bad | 1997 | municipality | group |
| 41 | 37,391861 | 11,590583 | gishabay | tolerable | 4 | 3 | 0 | Hune Ale sefer | bad | 2001 | JeCCDo | group |
| 42 | 37,390889 | 11,590111 | gishabay | extremely bad | 6 | 200 | 26 | Dessie Guwangul sefer | tolerable | unknown | unknown | public |
| 43 | 37,391972 | 11,589056 | gishabay | extremely bad | 6 | 4 | 1 | Tesfaye Ayo sefer | extremely bad | 1991 | municipality | group |
| 44 | 37,392861 | 11,590000 | gishabay | extremely bad | 4 | 5 | 4 | back of Gojam bakery | extremely bad | 1999 | municipality | group |
| 45 | 37,392833 | 11,590722 | gishabay | extremely bad | 6 | 5 | 3 | Alemitu Biru sefer | extremely bad | 1991 | municipality | group |
| 46 | 37,392944 | 11,591250 | gishabay | tolerable | 4 | 8 | 3 | Gete Mola sefer | tolerable | 2006 | JeCCDo | group |
| 47 | 37,392944 | 11,591167 | gishabay | tolerable | 4 | 8 | 2 | Back of awash bar | tolerable | 2000 | JeCCDo | group |
| 48 | 37,390806 | 11,594194 | sefene_selam | tolerable | 4 | 6 | 0 | - | bad | 2006 | municipality | group |
| 49 | 37,393944 | 11,590528 | gishabay | extremely bad | 4 | 5 | 3 | back of Mulu Tamene | extremely bad | 1997 | municipality | group |
| 50 | 37,394417 | 11,591306 | gishabay | good | 4 | 10 | 0 | In front of Ayalew Belay | bad | 2008 | JeCCDo | group |
| 51 | 37,393833 | 11,591528 | gishabay | tolerable | 4 | 9 | 2 | Kefyalew Muche sefer | tolerable | 2001 | ADA | group |
| 52 | 37,393583 | 11,591250 | gishabay | tolerable | 4 | 8 | 2 | Gebremeskel Gebremariam sefer | bad | 2005 | municipality | group |
| 53 | 37,393556 | 11,592444 | gishabay | extremely bad | 4 | 8 | 2 | Mola Megodat sefer | bad | 1995 | unknown | group |
| 54 | 37,394306 | 11,592583 | gishabay | extremely bad | 6 | 5 | 2 | Back of the kindergarten | extremely bad | 1991 | municipality | group |
| 55 | 37,393556 | 11,593028 | gishabay | bad | 4 | 3 | 3 | Next to Lalibela hotel | extremely bad | 1991 | municipality | group |
| 56 | 37,393556 | 11,593694 | gishabay | tolerable | 4 | 3 | 0 | Salilew furniture | tolerable | 2006 | municipality | group |
| 57 | 37,394028 | 11,594611 | gishabay | bad | 4 | 7 | 2 | Basha Ayalew Assegie sefer | extremely bad | 2005 | municipality | group |
| 58 | 37,393250 | 11,594639 | gishabay | closed | 0 | 0 | 0 | Back of EthioStar Hotel | not inspected | unknown | unknown | public |
| 59 | 37,393667 | 11,589111 | gishabay | extremely bad | 6 | 5 | 2 | Bombolino sefer | extremely bad | 1991 | municipality | group |
| 60 | 37,393444 | 11,588972 | gishabay | good | 4 | 2 | 0 | Bombolino sefer | tolerable | 2006 | municipality | group |
| 61 | 37,392833 | 11,589222 | gishabay | tolerable | 4 | 4 | 2 | Bombolino sefer | bad | 2001 | ADA | group |
| 62 | 37,394694 | 11,590778 | gishabay | very good | 4 | 0 | 0 | Aba Jember sefer | very good | 2009 | JeCCDo | group |
| 63 | 37,394694 | 11,590528 | gishabay | closed | 0 | 0 | 0 | SOS sefer | not inspected | unknown | unknown | group |
| 64 | 37,395444 | 11,590333 | gishabay | good | 4 | 12 | 4 | back of SOS | tolerable | 2005 | municipality | group |
| 65 | 37,395694 | 11,590750 | gishabay | closed | 0 | 0 | 0 | back of SOS | not inspected | unknown | unknown | public |
| 66 | 37,395139 | 11,592444 | gishabay | good | 4 | 16 | 2 | Mantegbosh Kelkay sefer | good | 2007 | municipality | group |
| 67 | 37,395389 | 11,594333 | gishabay | extremely bad | 6 | 5 | 0 | Back of red cross | extremely bad | 1991 | municipality | group |
| 68 | 37,395222 | 11,595028 | gishabay | extremely bad | 4 | 0 | 0 | Geremew Asres sefer | extremely bad | unknown | unknown | group |

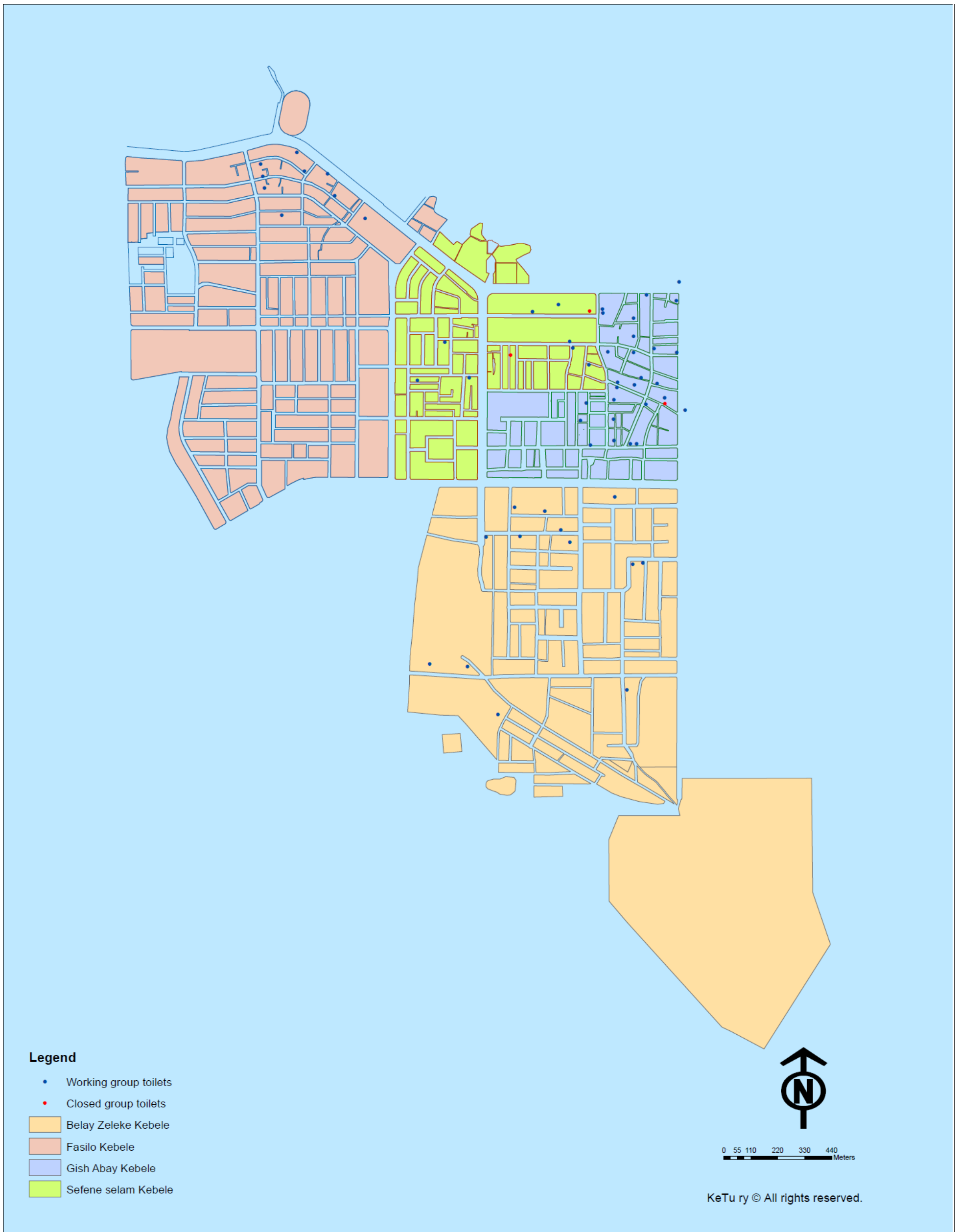## B. Hotspot Analysis result on working group toilets using number of households



Legend

**Working group toilets hotspot analysis by number of households**

Gi Z Score

- • &lt; -2.58 Std. Dev.
- • -2.58 - -1.96 Std. Dev.
- ◦ -1.96 - -1.65 Std. Dev.
- ◦ -1.65 - 1.65 Std. Dev
- • 1.65 - 1.96 Std. Dev.
- • 1.96 - 2.58 Std. Dev.
- • &gt; 2.58 Std. Dev.

- ▮ Sefene selam Kebele
- ▮ Gish Abay Kebele
- ▮ Fasilo Kebele
- ▮ Belay Zeleke Kebele
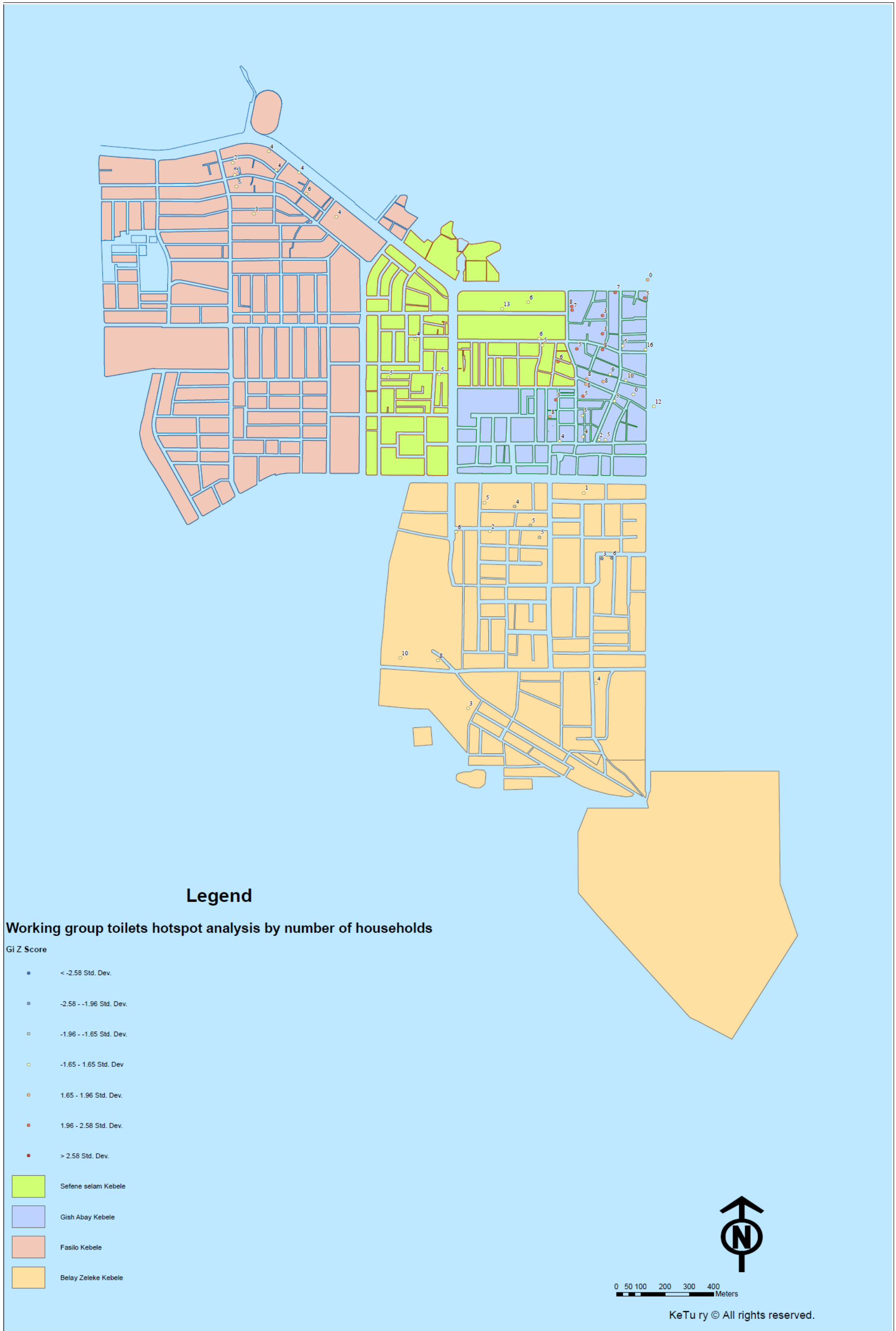
## C. Public toilets – working and closed



Legend

- • Working public toilets
- • Closed public toilets
- Belay Zeleke Kebele
- Fasilo Kebele
- Gish Abay Kebele
- Sefene selam Kebele

Map labels:
- Back of Ethio Star Hotel
- Back of Dib Anbessa Hotel
- Close to Tekle Hotel
- Silassie pharmacy
- Ema Mariam sefer
- Back of SOS
- Dessie Guwangul sefer
- selbaj tera
- Inside the market place

0 50 100 200 300 400 Meters

## D. Group Toilets – Working and Closed



Legend

- • Working group toilets
- • Closed group toilets
- Belay Zeleke Kebele
- Fasilo Kebele
- Gish Abay Kebele
- Sefene selam Kebele

0  55  110      220       330      440
Meters

# E. Unemptied toilets – Toilets built before 2006 and never been emptied
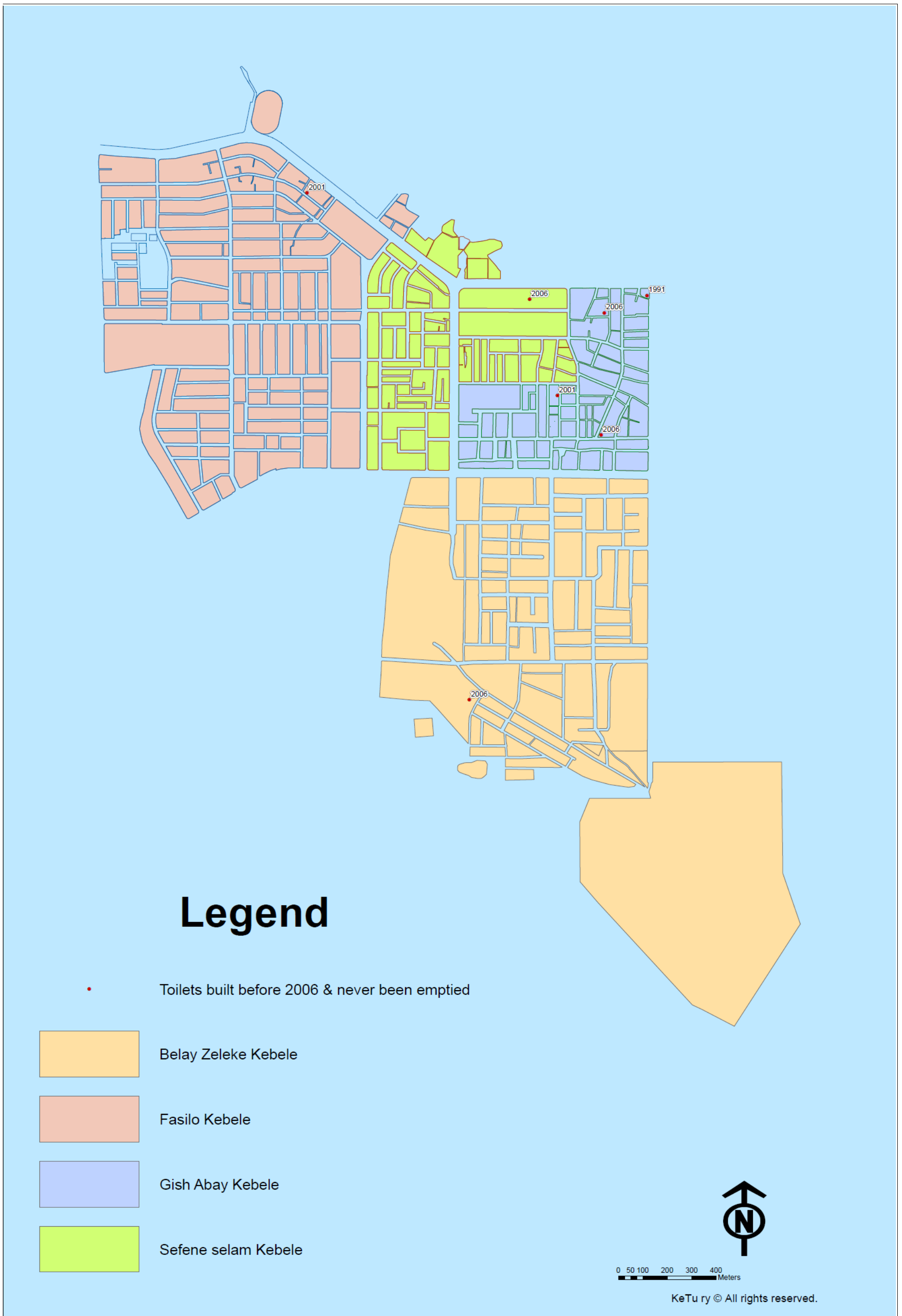


Legend

- **.** Toilets built before 2006 & never been emptied
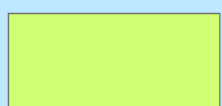- Belay Zeleke Kebele
- Fasilo Kebele
- Gish Abay Kebele
- Sefene selam Kebele