Validation of GIS Vector Data during Geo-Spatial Alignment

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Abstract

During GIS modelling, the geometry of objects forming features in geo-spatial datasets are always manipulated in order to get different views and perceptions that help to understand trends that have or taking place on earth's surface to inform the future. In this paper we investigated how the geometry of objects, analysis and modelling capabilities is affected by different geometry adjustment and alignment algorithms and methods when geometry type (point, line, and polygon) and number of objects in dataset are varied. It was found out that features change shape and geometry types during modelling but maintain their relationship and meaning when standard algorithms are used as confirmed using the developed geo-spatial validation framework. The time taken to accomplish adjustment and alignment increases as the number of spatial points increases in point and polyline features but more time is taken for polygons even with fewer points.

1. Introduction

To make location based decisions, geo-spatial datasets are always analyzed to get different meaning, description, explanation, interpretation or to predict geographical phenomena and actions that have or are taking place on earth's surface. For advanced GIS practitioners they go a step further by supplementing the analyses with GIS modelling (geoprocessing, coding, cartographic adjustment, suitability determination, etc.) where features in datasets are transformed, merged and integrated so that they take on different forms that help in understanding likely scenarios of what took place, what was not done well, what could have been done different, and what should be done in future. As geo-spatial datasets are being integrated, in most situations there is need for cartographic modelling to ensure proper geometrical alignment and maintenance of relationship between features formed by either objects or fiat objects (Vogt et al., 2012) following the top-level ontology that distinguishes between bona fide (natural) and fiat (artificial) physical boundaries (Smith, 2000 and Vogt et al., 2012). This brings in geometry adjustment and alignment algorithms and methods to eliminate the openings and overlaps that occur. As adjustment take place, the geo-spatial objects are affected differently and this paper presents a validation and an analysis of how the objects behave and are affected and performance of those approaches on objects forming features during the GIS modelling. As we assessed the impact, we put into consideration relationships among objects during modelling and integration of different geo-spatial datasets and how it is handled on the three dimensions (i) *horizontal* (adjacency), (ii) *vertical* (overlay), and (iii) *temporal* (time) integration (Chrisman, 1990), for example, the relations among buildings and land plots, the relations between poles (point object) and electricity line (line object) (Jiang et al, 2005), etc.

2. Related Literature

2.1 Geo-Spatial Data for Decision Making

GIS has enabled users to model, analyze, and visualize space and geo-oriented data in spatial format. As a result, the interpretation of geo-spatial data has become increasingly simple to understand in a format that almost everyone is comfortable with - spatial visualization with aid of graphics. This has made GIS a good medium for exchange of information among individuals and organizations and it has become one of the bases for spatial decision-making and natural resource planning, distribution, and management. This is because about 80% of information systems are said to have some location aspect (Rajabifard et al, 2005) and spatial datasets are used in all sectors of society due to need for distributed geo-information services (Morales, 2004) to support many location based applications in health care (Busgeeth and Rivett, 2004 and Ogao, 2006) engineering, land use planning and management, market research, and service delivery (Rajabifard et al, 2005), utilizing semi-automatic interpretation of buildings and settlement areas

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(Werder et al., 2010) and Cadastre (Garnero and Ferrante, 2013). With such wide application, coupled with the increase in computing power and distributed geo-processing becoming the norm, the challenge of classifying geo-data and integrating them so that they are shared; has increasingly become critical for spatial information management (SIM) according to many users and applications needs (Sonnen, 2005). This is because they are huge datasets with complex data structures requiring intensive computations and takes a lot of time, effort and other resources to create and store geo-spatial data and most people do not have the resources to create all the geo-spatial data they need. As a result, many individuals and organizations use data from different sources collected by various people and organizations. These datasets are captured at different times, in varying conditions, using different methods, basing on different data models, handled with different information technologies, stored in different formats, and using varying precisions (Evans, 1997, Erdi and Sava, 2005, Musinguzi et al., 2004, Friis-Christensen et al., 2005 and Kilpelainen, 1997); thus the need for alignment.

2.2 Adjustment and Alignment Algorithms and Methods

Geo-spatial data exist in multi-sources, the problem of geometry adjustment and alignment of objects making up features so that integration is achievable cannot be ignored, given the need to take advantage of various geo-spatial datasets in different locations and sources to reduce on the cost and time involved in their production. There are several approaches that have been developed basing on rubber sheeting, stochastical and deterministic algorithms that handle positional accuracy improvement of spatial datasets. To improve on the above approaches, additional efforts are taking place to overcome problems of geo-spatial data adjustment and alignment including.

a) Integration method by Kampshoff (2005) that uses ideas from stochastical and deterministic approaches to come up with an improved geometrical integration model. The model uses sequential and the simultaneous interpolation approaches where spatial interpolation by rubber sheeting and realization of geometrical constraints is performed by least squares adjustment simultaneously:

b) Sester et al., (2007) presented an approach of identification and adjustment of corresponding objects in datasets of different origin using whole objects on a layer where a set of rules are defined that specify how objects have to be altered during the fusion process. The rules control whether one object is representing a "master geometry" to which the objects of the other dataset are adjusted, or alternatively, whether an intermediate geometry between both datasets has to be determined.

c) Kieler et al., (2009) presented a method for matching datasets of systems having objects that represent the same entity in the physical world but were acquired at different scales that Sester et al., (2007) had previously assumed to be on the same scale.

d) Werder et al., (2010) worked on process of utilizing semi-automatic interpretation of buildings and settlement areas in user-generated spatial data to enrich geodatabase. Where they presented an approach that automatically identifies semantic correspondences between object groups of two different geo-spatial datasets by analysis of geometrical characteristics of the objects. To restrict number of correspondences and to improve results; additional geometric criterion in intersection area and object size, are introduced in the analysis

e) Wadembere and Ogao (2010) presented geometrical alignment method that has a set of algorithms that can be used in geo-spatial data updating and adjusting mismatches in thematically same or adjacent spatial datasets. It is based on paradigm that geometrical point primitive can be used to represent all geometrical objects as an avenue to accomplish all geo-spatial geometrical adjustments. By encoding different mismatched geometrical primitives that make up objects in a dataset as points, then establishing the geometry differences followed by changing x-y coordinates using parameters computed from coordinate matrices to align features.

The above approaches have helped in data integration and the need and application of geometrical adjustment and updating can be found even in recent cadastral reforms like in Italy when polygons of objects on the ground identified through Digital Terrain Model (DTM) and Digital Surface Model (DSM) intersected polygons of the buildings in cadastral maps (Garnero and Ferrante, 2013).

3. Geo-Spatial Dataset Validation

As we develop an approach for GIS vector data validation, we have to remember that building valid and credible process models is an important aspect in the representation of the actual system being studied and its accuracy is determined through verification, validation, and credibility (Williams, 2002). Verification is the correctness of model construction i.e. building the system right. Verification checks the translation of the conceptual model (e.g. influence diagrams, flowcharts and assumptions) into a correctly working program or pseudo-code or prototype. Once a model is verified and works correctly, then establish validity through comparing model outcomes to outside data and expectations as validation is the truthfulness of a model with respect to its problem domain i.e. building the right system. Credibility is giving correct or expected and consistent results when used. Therefore, to determine the capabilities/credibility or usefulness of the after geospatial alignment, actual GIS vector datasets were used in testing. Validation helps to determine whether the conceptual model (as opposed to the computer program or model) is an accurate representation of the system under study. If the model is "valid", then the decisions made with the model should be similar to those that would be made by physically experimenting with the system (Williams, 2002).

3.1 Geo-spatial Validation Framework

Geo-spatial features are affected differently during the GIS modelling process that involve transformations like geometry updating, adjusting; and geo-processes. To analyze the effect on objects and features, we developed the geo-spatial validation framework with three main components – (i) Geometrical validation, (ii) Analysis and modelling, and (iii) Performance evaluation. The Geometrical validation component has geometry and attributes checking (Figure 1).

From the figure, the two parts of geometry validation (geometry and attribute checking) are described using the following elements:

Shape relationship: where features are checked for topology to find out if the containment is proper, if there is proper adjacency between features and connectivity between features is true.

Shape location: handling the spatial characteristics that give the location of feature using x, y, and z coordinates.

Shape size: dealing with area, perimeter, and form of the features.

Shape credibility: that handles logical cartographic consistency between objects' geometries (point, polyline, and polygon) by checking for overlaps and openings between features, intersections, closed-holes, fix node ordering, if polygons are closed, have one label for each polygon, no duplicate polylines, and no overshoot polylines (dangles).

Shape Meaning: that verify the primary attribute the handles the meaning of the shape.

Shape description: that includes any other attributes that describe the shape in detail.

After the geometry validation, check for *analysis and modelling* capabilities including:

a) Running queries and spatial operations like network, neighborhood, find, suitability analysis, etc.
b) Checking for minimum objects, nodes, and vertices storage
c) Checking for any difficulty in integrating datasets into one layer due to geometry conflict.

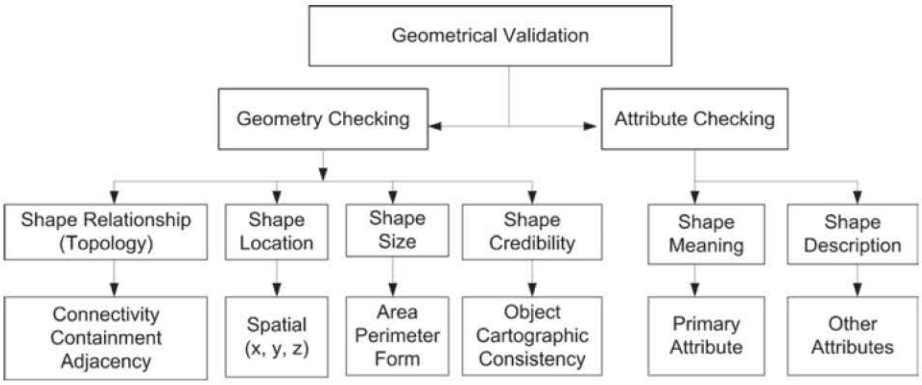

Figure 1: Geo-spatial geometry validation flowchart

The last component of the framework is the *Performance evaluation*, which is about determining the resources and time it takes to solve the GIS geometrical alignment. Detailed explanation, demonstration, and testing of the parts and elements of three components of the geo-spatial validation framework is accomplished in the following sub-sections

3.2 Datasets and Tools used in the Validation Process

To test the impact of geo-spatial geometry adjustment and alignment on objects and the validity of datasets, existing geometry algorithms and methods were applied to update, adjust, and align objects and features in geo-spatial datasets. Aligned vector GIS files were imported into QGIS and geometry checked using fTools and topology checker to find out if it meets the requirements as described in the framework. GIS spatial functions like overlay, merge, connectivity, neighborhood, network, and find operations were utilized to check if dataset performs as expected. This was done using the existing GIS packages (QGIS and ArcGIS) since they provide the required tools to accomplish the different tasks. The datasets used in the testing included districts of Uganda obtained from Uganda Bureau of Statistics (UBOS) as in year 2006. This comprised of Adjustment Dataset (AD) having 80 districts of Uganda as approved by the parliament of the republic of Uganda and became operational in July 2006. Reference Dataset (RD) was the districts of Uganda as approved by the parliament in 2010 and had 120 districts. The dataset having objects (districts) in 2006 data had more details including counties and sub-counties, so there was need to update AD with the district demarcations of 2010 data, but maintain the details of counties and sub-counties as per AD of 2006. The second dataset used was for Kampala city in Uganda that contained the divisions and parishes within Kampala. The divisions are the sub-counties - Kawempe (northern Kampala), Nakawa (eastern Kampala), Lubaga (western Kampala), Makindye (southern Kampala), and Central division. Within those divisions, there are smaller sub-divisions called parishes that make up Kampala. The AD was obtained from Kampala City Council (KCCA) and RD was from department of Lands and Surveys in Entebbe, Uganda. Within the Kampala dataset, we also focused on Nakawa division using UBOS data as the AD and Nakawa population per parish from KCCA as the RD.

3.3 Geometry Validation

Geometry validity was tested on parishes making up Nakawa division (Figure 2) of Kampala city in Uganda. On the right of the figure 1, there is reference dataset (RD) showing the parishes in Nakawa division of Kampala city and on the left, there is the adjustment dataset (AD) with same parishes but varying in geometry for four parishes (Kyanja, Mutungo, Bugolobi, and Luzira Prison)– Kyanja and Mutungo have openings while Luzira and Bugolobi have varying geometry shapes. Running the alignment method on the datasets, it was possible to adjust the geometries of all objects (parishes). We proceeded to check geometry for both topology (relationship between shapes making the features – polygons) and shape validity (proper shape size and definition) and it was proper GIS vector data.

3.4 Topology Validation

To confirm that topology (relationship between objects) was not affected during the adjustment and alignment, we selected some objects from the adjusted dataset, then using QGIS we ran neighborhood analysis. It picked the same neighbors as before adjustment. We also tested the connectivity condition of the two parishes in the Nakawa dataset and it was found to be still present as Ntinda was identified as being near and connected to Bukoto II and Kyambogo. We also used the QGIS topology checker plugin to check for the following on polygons making Nakawa parishes:

- ✓ *Must not have duplicates*: Polygons from the same layer must not have identical geometries and x-y coordinates; those represented twice or more appears in the 'Error' field.
- ✓ *Must not have gaps*: Adjacent polygons should not form gaps between them especially for administrative boundaries like Nakawa parishes.
- ✓ *Must not have invalid geometries*: Checks whether the geometries are valid using rules like Polygon rings must close, Rings that define holes should be inside rings that define exterior boundaries, Rings may not self-intersect (they may neither touch nor cross one another), Rings may not touch other rings, except at a point.
- ✓ *Must not have multi-part geometries*: geometry is actually a collection of simple (single-part) geometries - such geometry is called multi-part geometry. If it contains just one type of simple geometry, it is called multi-point, multi-linestring or multi-polygon. A good example is a country consisting of multiple islands can be represented as a multi-polygon.

- ✓ *Must not overlap*: Adjacent polygons should not share common area.
- ✓ *Must not overlap between layers*: Adjacent polygons from one layer should not share common area with polygons from another layer.

Topology checker for all the above returned zero errors, making Nakawa a true vector GIS datasets that can be used in analysis and modelling processes.

3.5 Shape Credibility

The geometries of the polygons were tested for proper GIS vector shape, size, and credibility by importing the layer into QGIS and using "Check geometry validity" function under geometry tools of fTools plugin, we checked polygons for intersections, closed-holes, closed polygon with a label point, not self-intersecting, had correct node ordering, no dangling nodes on polylines, no slivers and pseudo nodes and lines, polylines/arcs started and ended with a node, intersections had nodes, intermediate points along arcs were vertices.

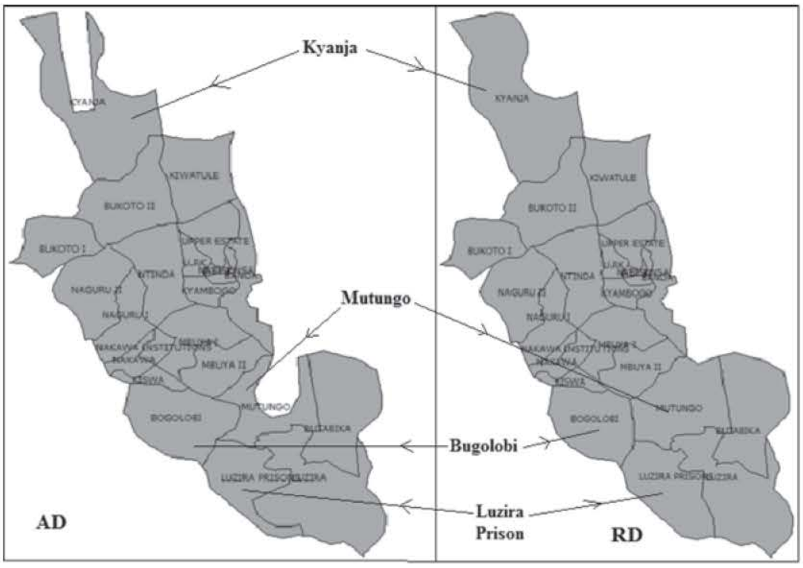

Figure 2: Nakawa adjustment dataset and reference dataset

Figure 3: Verifying Attributes

3.6 Verifying the Attributes

We checked after geometry adjustment and alignment to verify how the attributes of the objects were affected by importing the aligned datasets into QGIS and opening the attributes to compare the attributes before and after alignment (see figure 3 showing attributes superimposed on shapes). The figures shows results of identify function in QGIS used to view the attribute data corresponding to the Kyanja parish geometry shape in Nakawa division of KCCA. We observe the attributes before the alignment (left of the figure above) are the same as the attributes after adjustment of AD with reference to RD (right of the figure above).

3.7 Verifying Analysis and Modeling Capabilities

As geo-spatial datasets are being modeled, in most cases their features' geometry, need to be analyzed. The analysis of geo-spatial objects in datasets is based on validation as it is one of data quality measurement methods used to evaluate relationship (topology) between geometries of objects and the primary attribute (PA) that gives meaning to features. Controlling and knowing geographic data quality can optimize the usage of the data, improve on the GIS market, and also make GIS industry more attracting to four main groups: Data managers, system/software developer, standard organizations, and end user. Geodatabase managers have the responsibility to offer high-quality dataset to the users. Dataset needs validation before being saved, sent and shared. System developer needs the processes of planning, implementation, testing, documenting, deployment and maintenance to develop complete software with planning being one of the most important processes. To check if the adjusted and aligned datasets can be used in any spatial analysis and modelling; we imported into QGIS the Nakawa sub-county dataset having all the parishes and carried out neighborhood analysis. The aim was to check if the parishes were having their neighbors and connected as per the true situation on ground. The focus was put on the parishes of Kyanja, Mutungo, Bugolobi, and Luzira prison and their neighbors Kiwatule, Mbuya II, Kiswa, Luzira, and Butabika since they were involved in the geometry alignment process. The dataset having the parishes that make up Nakawa was used to model the population distribution of the different parishes by importing it into QGIS. We used the size (area) of the polygons that represent the parishes in Nakawa to come up with the population corresponding to those parishes as total population of Nakawa (see Table 1).

Table 1: Population and area of the Parishes in Nakawa

Parish	Population (people)	Area (Sq. M.)	Perimeter (KM)	Population Density	Population Ranking	Area Ranking	Density Ranking
Nakawa Institutions	200	439,681	2,944	2,198	22	21	1
U.P.K	500	494,827	3,244	990	21	20	2
Upper estate	1,700	1,340,506	5,114	789	19	16	3
I.T.E.K	200	141,064	2,011	705	23	23	4
Kyanja	12,100	7,262,590	13,249	600	14	1	5
Naguru I	5,600	1,603,660	6,391	286	17	15	6
Bogolobi	12,700	3,320,254	7,182	261	13	7	7
Luzira Prisons	13,700	3,508,601	8,500	256	10	6	8
Nabisunsa	1,100	273,597	3,231	249	20	22	9
Butabika	17,100	3,916,614	9,280	229	8	4	10
Kyambogo	2,900	646,919	3,811	223	18	17	11
Luzira	22,400	4,953,407	14,012	221	6	2	12
Kiwatule	14,400	2,980,184	7,458	207	9	8	13
Ntinda	13,100	2,657,591	7,685	203	12	10	14
Mbuya II	13,600	1,878,476	6,291	138	11	13	15
Bukoto II	30,100	3,578,569	8,939	119	3	5	16
Banda	17,700	1,764,038	10,280	100	7	14	17
Kiswa	6,500	527,287	4,265	81	16	19	18
Bukoto I	26,100	2,071,014	6,122	79	5	12	19
Mbuya I	27,400	2,088,582	7,897	76	4	11	20
Naguru II	37,900	2,695,330	6,965	71	2	9	21
Nakawa	8,500	562,782	4,544	66	15	18	22
Mutungo	63,200	4,104,302	9,060	65	1	3	23

This was aimed to verify if the number of people in each parish was proportion to the size of the parish. From the table, the population and area were analyzed in QGIS using equal intervals of five and the same color schemes (figure 4). From the figure, it can be observed the area is gradually divided into the five equal intervals and the population does not increase gradually nor vary according to area. The modeling and analysis results show that the number of people do not necessary increases as the size of the parish increases as other factors determine the population density. That shows that the datasets can be used in any GIS analysis and modelling process after carrying out geometry alignment.

3.8 Performance Evaluation

The performance of the adjustment and alignment algorithms and methods was carried out on a laptop computer with Intel® Core ™2 Duo CPU T8300 @2.40 GHz and RAM 2GB. The test was done on different datasets with varying geometry type and number of objects (Table 2). From the table, it can be observed that time taken to accomplish the geometry adjustment and alignment increases as the number of points increase as shown on line 1-3 on the table above. For one polyline feature on lines 4 - 7 as the number of points increases, the time taken also increases. The trend is the same for polygons on lines 11 to 15 as points increase the time increases. This can be explained by the fact that as the number of points increase more iteration is needed as each point is handled individually during geometry alignment. The time required running and accomplished geometry alignment on different geometry types increases in order of point, line, and polygons. For example 357 spatial points on line 2, it took 0.63986 seconds but aligning line and polygon geometry with less than 100 points on line 14, it took 1.817050. That means polygons need more time because polygons are made up of lines and points, and any line has a minimum of two points. More time is required to adjust a line than a point as the action will take place on more points that make up the line. Also in polylines, two or more line segments can share a point (node or vertex); which implies that for some points depending on the situation, a point can be adjusted more than once to fill full the topological requirements existing between features in a dataset.

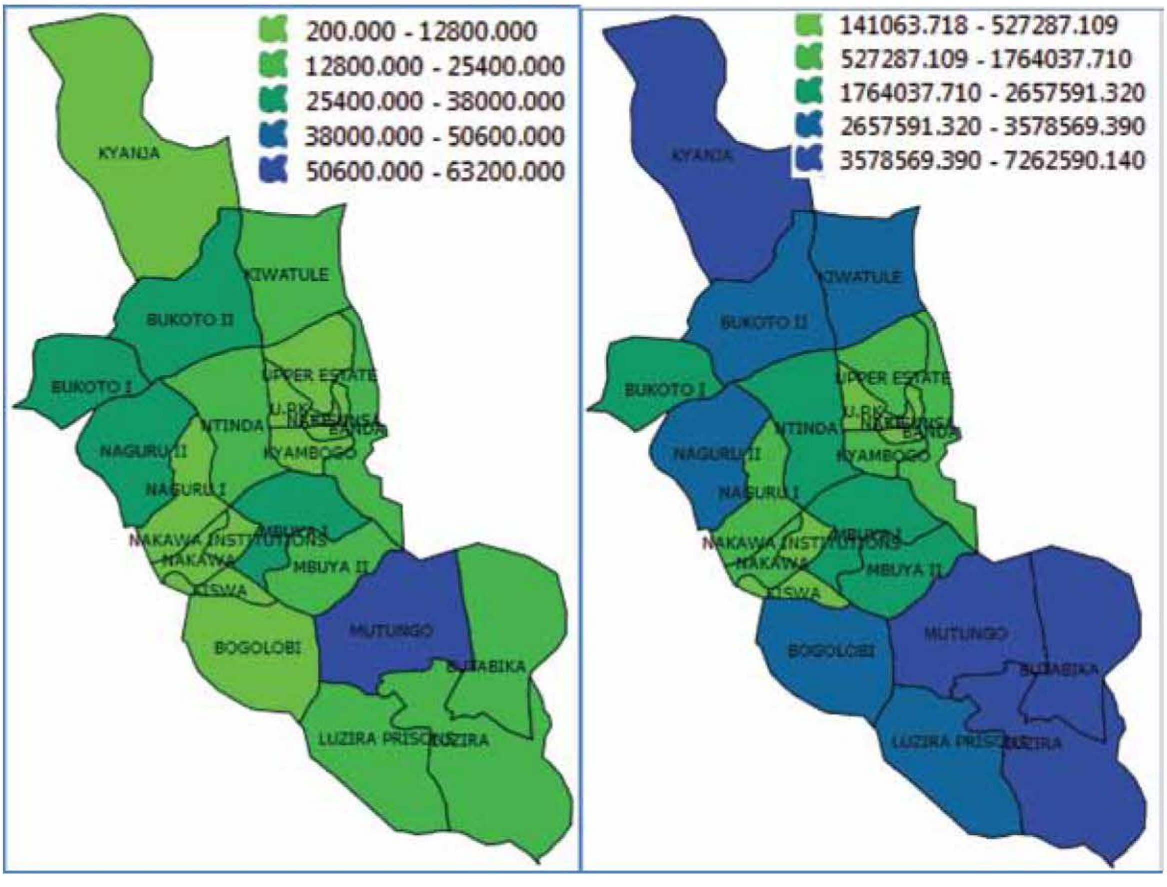

Figure 4: Left is population density of the different parishes in Nakawa and Right is area for each parish

Table 2: Performance Time on different and varying Geometries

Geometry Type	No. of Objects	No. of Points	Time (Seconds)	Line No.
Point	26	26	0.134232	1
	357	357	0.639863	2
	1487	1487	3.791786	3
Line/Polyline/Arc	1	16	0.116660	4
		32	0.140327	5
		55	0.145357	6
		109	0.161362	7
	5		0.201275	8
	30		0.327594	9
	57		0.502892	10
Polygon/Area	1	12	0.123586	11
		22	0.132894	12
		45	0.464927	13
		100	1.817050	14
		185	5.714382	15
	14		0.896085	16
	23		1.355961	17
	34		1.626847	18
	65		2.106925	19

Since the point belongs to two objects and their relationship has to be maintained thus the need to align on points making up polyline more than once to ensure that it satisfies the two objects of which its part. For polygons, they are defined by points and line segments (edges) and adjustment process can act on points or lines that are shared by many polygons and each adjustment on a point or line segment needing many iterations to accomplish geometry change in order to maintain the topological relationship with neighboring polygons as the point or line can belong to more than one polygon. For example line 2 of point geometry type has more points than line 14 for polygon geometry type, but alignment process takes more time on line 14 as each point is handled more than once for each line and polygon it is part of.

4. Conclusion

We developed the geo-spatial validation framework and used it analyze and verify the effect of adjustment and alignment algorithms and methods on geo-spatial objects and if they did not affect the topology and attributes of the objects whose geometry were manipulated. The validity was determined by analyzing if geometry modelling results are proper vector GIS datasets that can be used to compare, identify, determine geometrical differences and analyze and model geo-spatial datasets to match the requirements and if specifications can accomplishes spatial data integration with proper topology and attributes arranged as expected. The result shows that for true vector GIS datasets, performance varies inversely proportional to the number of points that make up the dataset and for the same number of points, the adjustment and alignment algorithms and methods will take more time on polygons, followed by polylines, and finally points. The datasets can be used in any GIS analysis and modelling process after carrying out geometry updating, adjustment, and alignment. This is in line with standard organizations like Spatial Data Infrastructure Secretariat, Open Geo-spatial Consortium, and Federal Geographic Data Committee (Rajabifard, et al, 2005 and FGDC, 2007) as they call for integration of geo-spatial data and its effective management in geo-information systems since they are costly and time consuming to build and process. This paper help to improve on location based decision making since end users who receive dataset from unknown resource and with unknown quality are able to use findings to determine errors in the datasets and how they can correct them before usage.

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