Cartographic Generalization in Multi-scale Environment: Case study of Lamu County, Kenya

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Abstract: ***At survey of Kenya (SoK), map generalization is still carried out manually. This results in datasets that are not harmonized; process is slow, large data storage demands, loss of detail in the downscaling and duplication of effort when multiple scales are involved. For a faster generalization of a topographic map at large cartographic scales a generalization workflow was developed in this work that ensures a harmonized and linked multi-scale database using a base data at 1:5,000 containing feature classes to different scales. The main objective of this work is to generalize geospatial data using ArcGIS and QGISs operators. It discusses the process of vector based cartographic generalization using a case study of Lamu, Kenya. The vector dataset used was at basic scale of 1:5,000. The datasets contained the following feature categories: transportation, water features, vegetation boundaries, swamps and other special and unclassified features. General and Survey of Kenya specifications and constraints for each scale of generalization were used to symbolize the layers after generalization. Contour and spot height features were separately regenerated by varying the contour interval and spot height spacing, for each scale, using Global Mapper analysis tools using lamu DEM to create contours and spot heights. Results obtained were compared with old maps and new features for quality assessment. Findings indicated that, cartographic generalization using GIS softwares provides a good opportunity to generalize large scale data and this can be possible to generalize up to two steps for optimal results as per the current GIS generalization operators. However, there is a requirement of editing and symbolization to preserve important details and to add other map elements. Results obtained indicate optimal solutions for two steps in the generalization hence further research is recommended to enable more steps of generalization and also explore possibilities and outcomes of change the order of generalization to check for significant variations if any on results.***

Keywords: Cartography, Generalization, GIS, Scale, Symbolization

1. Introduction

Map making includes production of geospatial information at various scales as required by various users. To meet all the needs of various users, one has to shorten production cycles of derived maps and National Mapping Agencies (NMAs) are considering use of fast generalization processes. Generalization is the abstraction of detail, Muller and Wang 1992 [19] while maintaining data layers and display and arrangement for ease of access and even how layers are allocated names to convey meaning. The process of generalization occurs such that some geographic details are emphasized at the expense of others. Survey of Kenya (SoK) is the National Mapping Agency (NMA). One of its mandates is to prepare the national base map [13].

The SoK is in the process of revising specifications and procedures of map making. National Mapping Agencies like SoK annually use and produce enormous amounts of geospatial data that include: geodetic, aerial and manual data entry and scans of analogue data in the production of topographic maps. This data is obtained from different sources and is used to produce a variety of different map products at different scales. In most cases, the data is for public use; especially topographical and administrative boundary maps. Disseminating data to the public is sometimes slow and also makes the customers to acquire data not useful for their applications. Hence, it would be convenient for SoK to adopt a system where customers obtain data they are interested on.

SoK produces geospatial data at various scales to satisfy diverse needs of citizenry. Furthermore, SoK is mandated to define features on a topographical map, which are governed by their presence on the ground and are mapped within the limits of scale. In carrying out the these mandates, standards are required to regulate process of surveying and mapping for quality control through the Kenya survey manual which is yet to be revised as it is dated 1962.

The demand of producing maps automatically has increased and aided by continuous evolution of GIS since 20th century. The paper uses the available generalization tools in the GIS softwares with minimal manual cartographic editing. There is relation between omitting and repressing while, exaggerating and emphasizing on the other. It accompanies all the construction stages of the map, from the conceptual design to the final reproduction. In generalization it is important to ensure good communication of all operators so as to produce consistency results.

The aim of this paper is to develop workflows for generation of geospatial datasets from the basic geospatial dataset at basic scale of 1:5,000 to SoK standard mapping scales. Specifically a linked multi-resolution geo-database was prepared to be used to visualize the generalized data. Then generalization operators were used for detail extraction on the area of study using ArcGIS and QGis generalization platforms. The ArcGIS operators used include aggregate points, aggregate polygons, collapse dual line to centerline, collapse road detail, delineate built-up areas, simplify building, simplify line, simplify polygon and thin road network. QGis operators housed in Sextante toolbox was based on v.generalize plug-in which had simplification and smoothing algorithm. Additional Cartographic symbolization techniques were used to prepare the final products for visualization.

The paper is organized starting from the introduction which introduces the generalization subject, section two presents a review of generalization aspect. Section three presents methodology of generalization adopted, the operators used and the general process of using them in ArcGIS and Qgis platforms to get results. Generalization workflow, data used and how it was manipulated to get the results is presented in section four and finally conclusion and recommendations are placed in the last part.

2. Background on Map generalization

One of the assumptions for geospatial data generalization is that, data points may take any position in the Euclidian plane and their location after generalization is assumed to be scale free. Map generalization at different scales traditionally relies on different datasets at different scales. Generalization can be partly assembled [23], from software codes, written map specifications and one carried out by cartographer using various operations. Generalization operators, in [14] are defined as an abstract or generic representation describing the type of modification that can be used when generalizing while an algorithm is a particular implementation of the operator, [21]. Examples of algorithms in the cartographic practice include the Douglas-Peucker algorithm [6], [11], optimization simplification, optimization simplification, [5], the Visvalingham- Whyatt algorithm, [24], and the modified Visvalingham-Wyatt algorithm, [26]; [3], among many others.

The cartographer's objective is to communicate the information present in the map product as simply as possible even after generalization. Presentation of such information can be done through visualizing in vector and / or raster mode generalization. Visualizing in vector mode [16] is by simplification, smoothing, aggregation, amalgamation, merge, collapse, refinement, typification, exaggeration, enhancement and displacement and the vector operators relate to those by [22], [17]. In aggregation a series of point features are fused into areal feature represented by an enclosing boundary. Smoothing can be applied to contour and polygon features to display both displacement as with simplification using displacement vectors and area and changes in the angularity and curvilinearity of any given feature. Likewise, visualizing in raster mode generalization includes such models as those of [9] whereby operators used are of structural, numerical categorization and categorical generalization. In addition, generalization operators are either geometric or semantic. Geometric operators are for reduction in number of discrete features (by geometric selection), reduction in detail of individual line, areal and surface features (reduction in sinuosity) and amalgamation of neighboring features, whether point, line or area. Aerial raster images captured were used for semantic discerning of features in the area of interest only.

2.1 Cartographic Generalization of Geospatial Data Order on generalization and priorities

[20] Presents the constraints of map generalization. In the research constraints were classified as graphic topologic, structural and Gestalt constraints.

Graphical constraints give human graphic perceptions thresholds limits for map objects such as minimal area, minimal distance between two polygons. **Topological constraints** are basics topological relationships like connectivity, adjacency and containment, maintained during generalization. **Structural constraints** can be spatial or semantic. Spatial constraints deal with the preservation of typical shapes of individual map objects or patterns and alignments of a group of map objects. Semantic constraints preserve the logical context of patches. **Gestalt constraints** control aesthetic aspects of patch characteristics while retaining overall visual balance

Parameters for various generalization operators
The parameters used consisted some of those given automatically by the software application, with some editing to suit most of generalization constraints. The steps of generalization include preprocessing, generalization, symbolization and conflict resolution. A concept of generalization like that of [15] can be used to determine why, when and how generalization of geospatial data is done. Cartographic generalization begins from sourcing Digital landscape model with the large scale data, then applying generalization operators while effecting constraint parameters [9].

A grid layer box of varying area of extent using the same paper size is used to define number of feature to be retained. If the same paper size is used of varying extents (as defined by grids) then features will be competing for space from one scale transition to another.

The question of addressing how little is enough, is usually presented using a relationship between generalization scales and usability of the corresponding maps as consistently transmitted. In some cases, some data may be poorly represented and consequently a poor representation of the feature is depicted. In addition, smaller data sizes, a quick response times and possibility of transmission of only relevant details is possible [2] as stated in Fangli Ying et al [8]. For maps containing many polygons and lines, a methodology for determining a globally suitable generalization is necessary. There is also a need to associate the generalized data with quality information using additional derived representations.

Graphic representations of lines for scales of 1:50,000 and 1:100,000 (0.15mm) and minimum sizes of 3mm for (1:50,000 and 1:100,000) and areas of map symbols covering ground distances of 15m side length and 30m and sizes as those of Swiss Society of Cartography as given by [1] cases.

2.2 Multi-scale Mapping

Multi-scale mapping is where each individual layer is generalized for use at a particular range (minimum and maximum range of displays). Multi-relational database (MRDB), offers, for multi-scale mapping, a technical solution for automating map design process, to bring a higher integration of geographic data and map design, easier map updates and a more consistent cartographic design across scales and hence enable the public to view using web mapping services, beyond the "one map" solution [18] in [14]. In open street map and Google maps, one can edit styles across scales hence the question of the degree at which multi-scale mapping choices should be constrained by expert knowledge varies due to cartographic democracy [25]. Multiscale mapping is related to NMA operations, web map service and multiscale representation databases.

Multi-scale mapping operators are based on content, geometry, symbol and label. Multiscale mapping describes the cartographic practice of generating integrated designs of the same geographic extent at multiple (or all) cartographic scales. Multi-scale mapping and generalization are not the same. Generalizations describes the design decisions made for a single scale, with goal of reducing detail as scale is fixed [4] while multi-scale mapping involve use of dynamic maps with multiple scale based data displays.

2.3 Application of Generalization in GIS software: Commercial and Open source

ESRI ArcGIS Generalization toolset used included tools such as aggregate points, aggregate polygons, collapse dual line to centreline, delineate built-up areas, reduce road detail, merge divided roads, simplify building, simplify line, simplify polygon, smooth line, smooth polygon and thin road network [7]. Open source softwares toolset for QuantumGIS (QGIS) ver. 1.8 was found suitable for specific feature classes and types of features class. For example, in the collapse dual lines to centreline tool, the tool derive centreline from dual line (or double line) features, such as road casings, based on specific width tolerances. It was used for regular, near parallel pairs of lines like large scale road casings. Centerlines were also created only between open ended lines and not inside closed lines which are like street blocks. The collapse dual line tool did not simplify multiple lane highways with interchanges, ramps, overpasses and underpasses, or railways with multiple merging tracks as merge divide tool is used instead.

3. Materials and Methods

3.1 Area of Study

Study area is part of Lamu County. Lamu county has surface area of 6273 km^2 has a population of 101, 539 people as per Kenya Central Bureau of Statistics (2009) census. Lamu County is generally a flat terrain with maximum elevation difference being 79m from the sea level to the highest point in the AOI. The AOI was selected based on presence of density data, as the surrounding areas are either forest land or grassland. Lamu is bounded by geographic coordinates (40.22˚E, 1.70˚S), (41.40˚E, 1.68˚S), (41.40˚E, 2.50˚S) and (40.20˚E, 2.50˚S) decimal degrees, in arc 1960 coordinate system or in projected coordinate system of UTM Zone 37° south, in the North Coast of the Republic of Kenya.

Map of Lamu County
The map shows county boundary and the area of interest bordering the Indian Ocean and an inset of the map of Kenya.

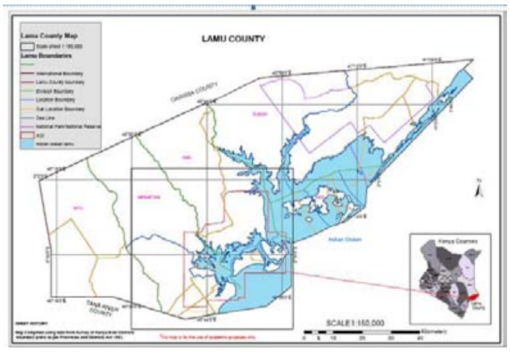


Figure 1: Figure 1: Map of Lamu County showing area of interest bounded in a rectangle

3.2 Methodology

Generalization was carried out on vector data digitized at basic scale of 1:5,000 to SoK standard mapping scales. In some instance some geo-referenced data was overlayed and incorporated such as aerial imagery and topographic map sheet 180/1, 180/2, 180/3 and 180/4 for the area of interest were used.

Methodology flow diagram

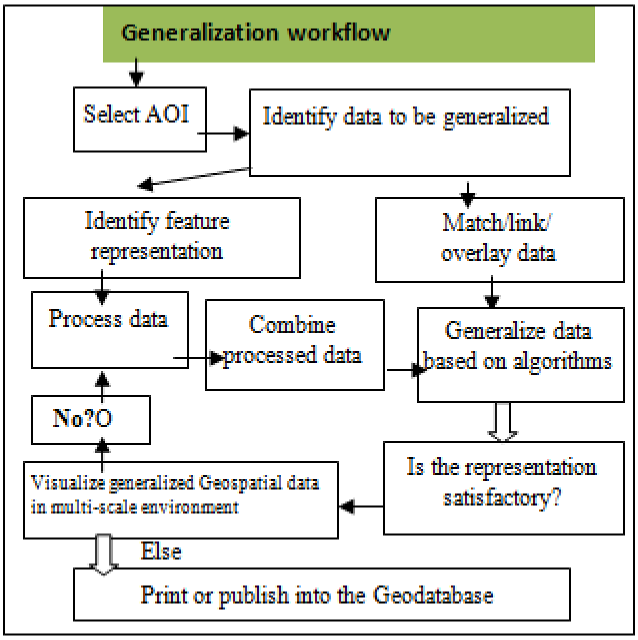


Figure 2: Methodology used

Stages used in generalization process include data preparation, execution of generalization operators and evaluation of result.

3.2.1 Selection of area of interest by use of grid layers
Create fish net tool was used to generate grid layer for all scales of interest using specific cell sizes for each generalization scale, see table 1. The grid layers are scale dependent and can be used to clip the shapes of layers visible, at the data frame properties' settings, in the final stages of map layout content design. They are also used to create index table for the maps sheets reference inset, of adjoining sheet.

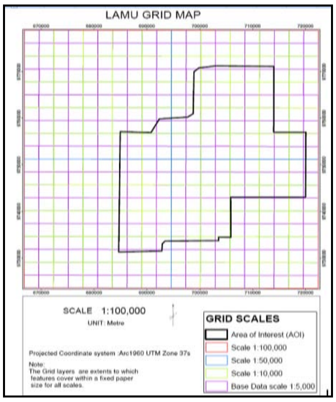


Figure 3: Map of Lamu Grid map showing area of interest bounded in rectangular Grids

Table 1: Table showing scales and grid cell size in metres

	Scale	Grid cell size in Metres (A1 size paper)	Cell size in degrees(arc1960 datum)
1	1:5,000	2775	0.025
2	1:10,000	5550	0.050
3	1:50,000	27750	0.250
4	1:100,000	55500	0.500

Grid cell sizes were used for designing of map layout plans in plotting in A1 size paper for printing.

Due to difficulties in generalizing data successfully from one digital landscape model (DLM) to various cartographic representations data was prepared such that each scale had individual DLM.

What was generalized include polygon, line and point features. Each layer was generalized separately to enable linking of the feature layers in the geodatabase. This was done due to problems associated with multi-linked geodatabase. The order of display of the layers was in such that annotations started on top, followed by points then lines and polygons in that order. Also layer organization can be done separately and conflicts in display can be handled cartographically during manual editing and symbolizing at final stages.

A file geo-database developed was used to store raw and generalized data. Grid index was generated using ArcGIS fishnet so as to encircle area of study only at specific scales. Firstly the data was copied to a folder in a computer, then generalization toolset for ArcGIS and QGis Sextante toolbox. Among the topographic features generalized were features for administration boundaries, buildings, railways, roads, relief, lakes, contours, spot heights, river lines and polygons, coastal feature like shoreline and land cover like swamps and cultivated and uncultivated vegetation. Some features were not generalized such as control points, communication masts, embankments, Airport and water points as these features were scarce. Manual generalization was also incorporated in the GIS software starting with the generation of spot heights, contours, and graticules. Some features were retained and others displaced. Building generalized for 1:10,000, 1:50,000 and 1:100,000 (SoK Standard mapping scales) using deletion by using deletion constraint of 80 m², 400² and 800 m² respectively. The criterion used was based on building area, taking the whole layer or global constraint. Global selection of layer was used in effecting building generalization operation done at Scale: 1:10,000, 1:50,000 and 1:100,000. Operators used include building simplify, simplify polygon, delineate built up area building aggregation and conversion of polygon to point features. Then there was shoreline generalization using bendsimplify as reference baseline at 80, 100 and 100 respectively for scales 1:10,000, 50,000 and 1:100,000. Smooth line generalization was used for tolerance. Roads generalization involved collapse dual line to centre line operator for the SoK mapping scales and thin road network operator was used for 1:10,000 scale only, (using invisibility and hierarchy fields) as there was no new feature created as it was display only. Qgis, v.generalize algorithm using network operator for roads at 1:10,000 scale.

This followed with manual generalization using a DEM to generate contours and spot heights at 4metres, 20metres and 40 meters intervals respectively for the standard scales. Contour generation was also done for flat and undulating areas as proposed by [12] and [10] at contour intervals of 2, 5 and 10 meters for the standard mapping scales respectively. Spot heights were also generated at intervals of 400, 1000 and 2000 meters respectively. Finally a shoreline was generated on 50 meters offset and with bendsimplify algorithms for the SoK mapping scales.

4. Analysis, Results and Discussion

4.1 Vector Feature Generalization Results

In the discussion above, various cartographic generalization tools were used dependent on license capabilities and upgrade or edition type of the software.

The general work flow of the generalization process was carried depending on user requirements; the process can also be applied in different places using different abstraction scales which represent the same area.

In addition creation and keeping of a single DLM for each of the scales in a single geo-database was complex and hence needed a logical framework on the storage locations for each of the datasets and the manipulation processes to be uniquely identified by the software in operation. For this case separate file geo-database was used for deriving each scale datasets before linking them.

Location diagram and Index to adjoining sheets was prepared for The SoK mapping scales and the associated data for generalization was superimposed with Lamu County area of interest.

4.2 Building Generalization Results

Building generalization was applied by selecting building layers to be generalized followed by choosing **o**perator algorithms such as aggregation and simplification. Building generalization for the scale of 1:10,000, using aggregation operation at 5m is shown in figure 5.

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611

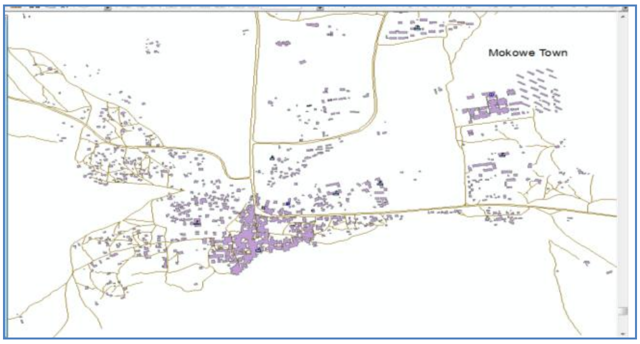


Figure 5: Building aggregation at 5metres

It was noted that buildings after generalization do not retain normal true area extent; they have some aggregation on geometry as buildings are combined, irrespective of type. Also building simplification was carried at 10 meters and the result looks similar as previous example.

Building generalization by simplifies building operation was not done at the scale 1:100,000 because of inability to preserve areal size of features. Combining or converting to points looks as shown below and makes it necessary to select which type of buildings to show at the scale.

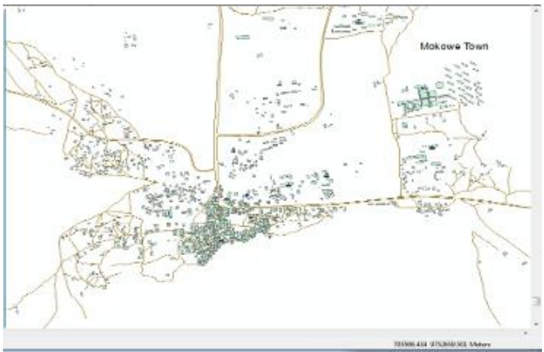


Figure 6: Building Simplify at 10 meters

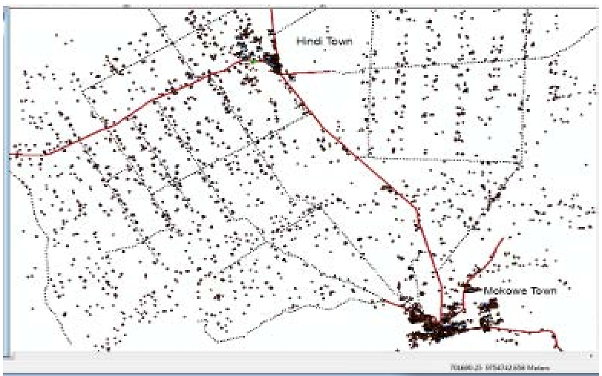


Figure 7: Building conversion to point using Polygon to point conversion tool.

Further, some of the points were eliminated by putting a constraint that a building less than 400 meter squared to be removed and the others are retained. Figure 8 show building point generalization.

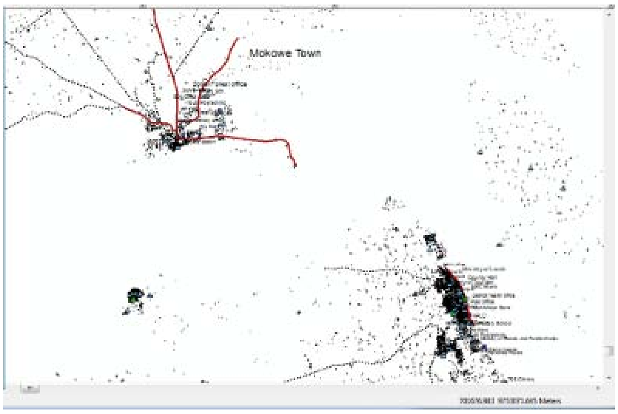


Figure 8: Building point generalization

Figure 8 shows that individual building recognition becomes difficult as one reduces scale, unless the map is made thematic.

Building Generalization at 1:100,000 scale by aggregation at 20 metres

Only a few buildings were drawn, by choice of name depending on density of features at the point of its location, otherwise point symbols are used and large areal buildings emerge.

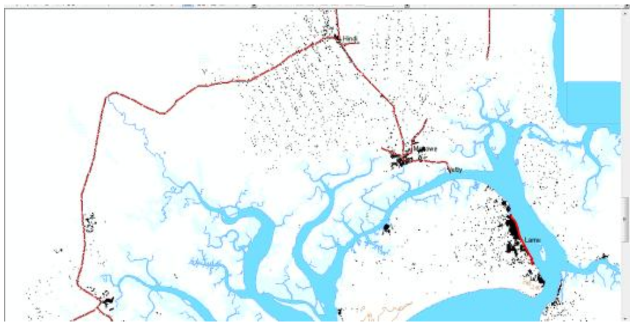


Figure 9: Buildings at scale before generalization 1:100,000

Buildings symbols sizes were kept the same size for all scales generalized. After buildings were aggregated they were further exaggerated, modified while some excluded from display especially those near the road. Combination of the resulting features was done, at the scale of 1:100,000. After, aggregation, point buildings occupying space for built up areas, were erased using erase point tool by using the aggregated arrears showing built up areas as input features and contained inside as the operation.

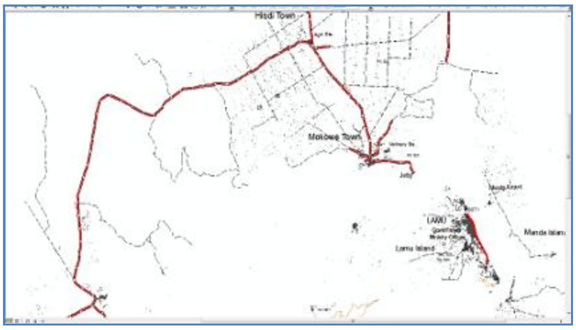


Figure 10: Buildings at scale of 1:100,000 after generalization

The one delineating built up areas at 20 meters is shown in figure 11 with few clusters of irregular polygons created.

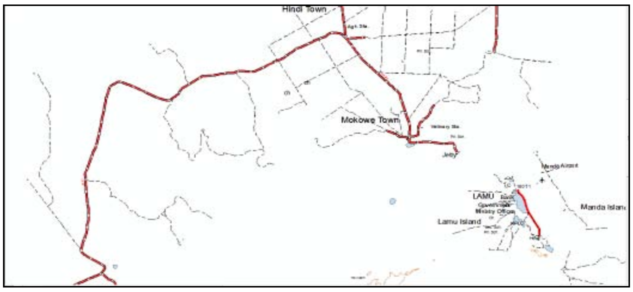


Figure 11: Delineating Built-up areas using 20 meters as tolerance for display at larger scale of 1:50,000 scale after zooming in the display

On comparing the last result with one of manual editing after using aggregate polygon tool gives results in figure 12; which are almost similar with the results in figure 11 of delineating built-up areas at 50 metres.

Figure 12: Delineating built-up areas using 50 meters tolerance for display at smaller scale of 1:100,000.

The two results are of delineation are as shown in figure 32.

Figure 13: Superimposing the layers after aggregation

The results are compared with use of manual editing and built up areas tools for display at scale level 1:100,000. Which can also be shown at a smaller scale of 1:50,000, zoomed as shown below to reflect, the effect of the tool in delineating built up areas.

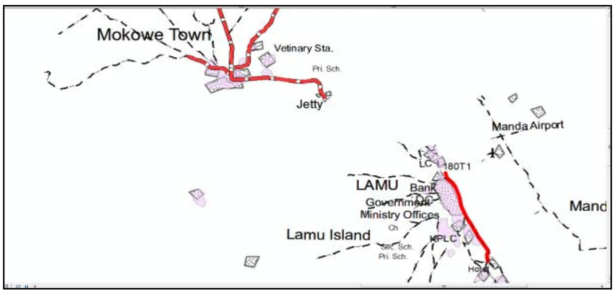


Figure 14: Building generalization by use of delineate built-up area tool

4.2 Road Generalization details

Road generalization was done through deletion or selective pruning or checking or un-checking in the layout or data visualization in the suggested generalization scales of 1:10,000. Most of the foot paths are eliminated from the display using *collapse Dual lines to centreline* generalization tool. It is noticeable that most foot paths are retained where there are junction points unlike where there are no junctions. Generalization result can be assessed in real time, since at the end of the process, the tool responds whether the generalization was successful or not. In cases where it is not successful, tool also responds together with detailed report citing reasons for any eventuality of error.

Collapse Dual lines to centerline tool, the tool generates a feature layer with four new fields which need ranking information on line type; align right or left and polyline ids. The results after applying the collapse Dual line to centre line and zooming in (expanding) the map display to 1:250,000 as shown in figure 15.

Figure 15: result of v.generalize algorithm, using network method of generalization operation in Qgis for representing roads for scale of 1:10,000

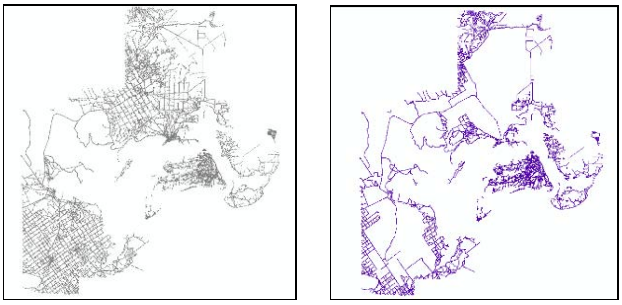


Figure 16(a, b): Before and after applying Collapse Dual Line to centerline tool (zoom 1:250,000)

It can be notice that, not all building footpaths were retained, since some were pruned by collapsing and a layer was created, without symbology. As all layer categories, have one symbol for representation. Results of the generalization at 1:10,000 yields results is shown in figure 17.

Figure 17: Before generalization

Figure 18: After generalization

Comparison of generalized data and original data shows that some footpaths are pruned from view.

Figure 19: Collapse of dual roads to centreline overlay with initial data at scale 1:5,000 for comparison.

Only major road type like tarmac, earth and motorable tracks are retained as foot paths are eliminated. This was done manually to preserve general geometry.

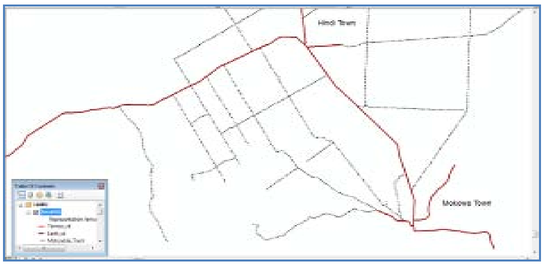


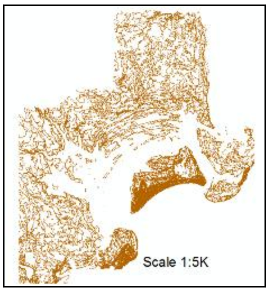
Figure 20: Road Generalization at Scale 1:50,000 and 1:100,000.

At the scale of 1:10,000, only the Tarmac, Earth and a few motorable tracks type of roads were retained.

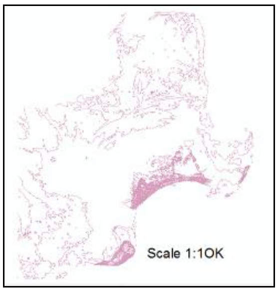
Figure 21: Generalized map with all the layers generalized at the scale of 1:100,000

4.3 Contour Generalization Results

Contour generalization was done through use of reclassification whereby there was variation of contour interval and the number of spot heights coverage selection by automatic selective deletion or distribution in the area of interest. The contours were generalized using reclassification method by using spot heights of the AOI to make a Digital Elevation Model (DEM), whereby contours were manually generated using Global Mapper software. The results are as shown in figure 22. General specifications were used but specific specification suited for flat areas, as proposed by [12] and [10] were adopted to produce the final generalized contours. Contour generalization results were also done for the scales of 1:10,000, 1:50,000 and 1:100,000 as shown in figure 44.

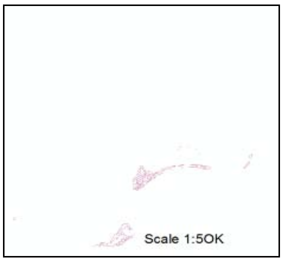


1:5,000 scale

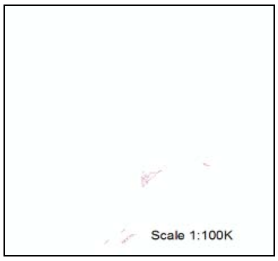


1:10,000 scale

Results of contour generalization based on the SoK general specifications were used to control parameters and minimum dimensions used. Generally for flat terrain, like Lamu area, the contours are visible at the scale of 1:10,000 or larger. Similarly contour generalization at scale of 1:50,000, results to sparse contours and at 1:100,000 almost disappear because of a large contour interval, 40 meters.



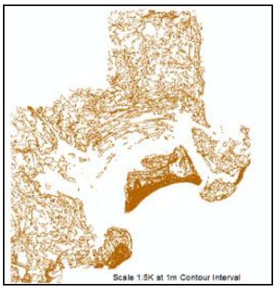
1:50,000 scale



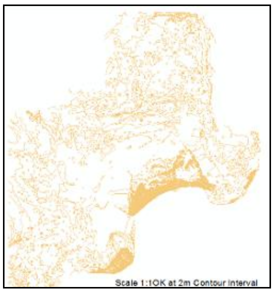
1:100,000 scale

Figure 22(a-d): Contour Generation for smaller scales using general specifications

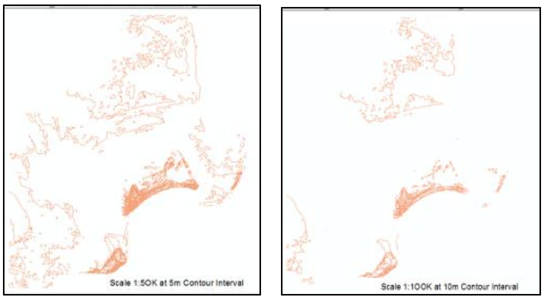
These led to the use of alternative method proposed by [12] and [10], which enables one to get contours at intervals suited for respective flat terrain.



1:5,000 scale



1:10,000 scale



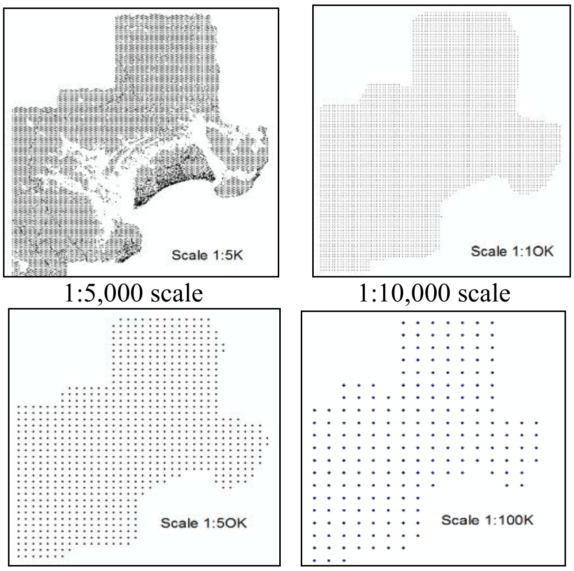
1:50,000 scale 1:100,000 scale

Figure 23(a-d): Contour generation using specification suited for flat areas in contouring, as proposed by [12] and [10]

It can be noted that as one transits from lager scale to smaller scale contours diminish. Other features will be deleted and they include culverts, ditches, piers, any non important details in the smaller scales of 1:50,000 and 1:100,000. Also, other features will be grouped and other re-created or introduced such as spot heights. Other features retain their states and they included swamps, vegetation boundaries and ocean boundaries and what can be changed can be sizes of symbols used to depict the features.

4.4 Spot height Generalization results

The spot height generalization used intervals in generalization. From the generalization, whereby, results for whole area of interest zoomed at scale of 1:250,000, shows a number of points decreased from 20,827 points with scale. As shown, a number of feature count for each scale is 5234, 833 and 213 points respectively for scales of 1:10,000, 1:50,000 and 1:100,000.



1:5,000 scale 1:10,000 scale

1:50,000 scale 1:10,000 scale

Figure 24(a-d): Spot height generalizations using general observation of distribution.

4.5 Shoreline Generalization details

Shore line simplification was based on 50 meters offset and bend simplify for view at scale of 1:50,000, topographical errors and resolve topographical error options checked or selected. The shoreline so simplified was then smoothened by Bezier interpolation technique.

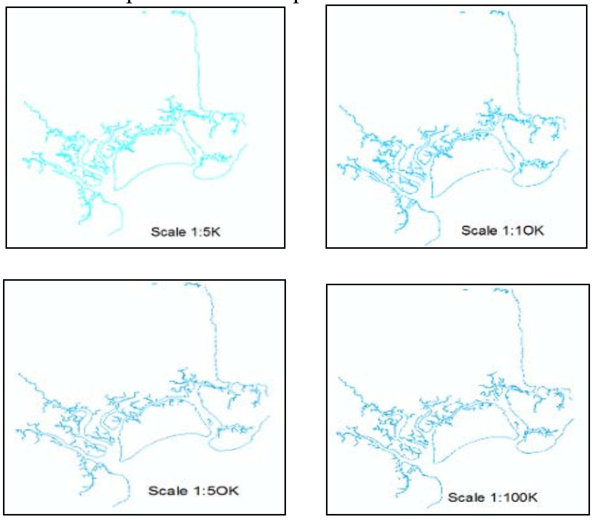


Figure 25(a-d): Shoreline simplifications for scales of 10k, 50k and 100k.

Result of bend simplify simplification algorithm followed by smoothing using Bezier interpolation was used as shown in Figure 26.

Table 2: Generalization operators

	Generalization operator/algorithm	scale
	Aggregation, simplification, collapse dual line to centre line, v.generalize	10,000
	Aggregation, delineate built up areas	50,000
	Conversion/combination, delineate built-up areas	100,000
	Manual generalization	All three scale of generalization

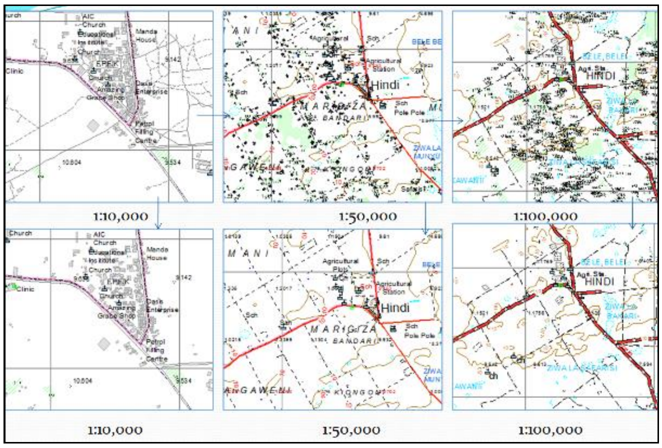


Figure 26: Generalized maps clips at scales of 1:10,000, 1:50,000 and 1:100,000.

4.6 Quality assurance and control on cartographic generalization

Quality analysis after generalization was done cartographically on line size, colour and legibility at the selected scales and a quality summary report generated automatically, using the software tools self checking and carrying out cartographic visualizations such as use of symbolization constraints. Furthermore visual assessment of the results onscreen and prints and referring to minimum sizes is used. It can also be done by use of summary statistics and map contents summary, distribution and density on mapping space and control of generalization process through appropriate tolerances/parameters selection for operators.

5. Conclusion and Recommendations

5.1 Conclusion

Cartographic generalization was successful done up to two times, within the software. The end products were generalized maps at standard mapping scales of SoK produced in a fast, efficient manner to produce detailed updated maps. The process was fast and efficient. Hence there is a need to formalize on how to use GIS generalization techniques for desired scales after combining and harmonizing data.

5.2 Recommendations

There is need for SoK to implement the use of GIS generalization tools. Findings indicate optimal results are obtained only up to two times of generalization. It is recommended to carry out further research so as to go beyond the optimal scales. Also one may opt to change the order of generalization to check if there is any change on generalization results significantly. In addition, more research is needed especially in the design of new symbols for feature description at smaller scale while maintaining minimum size and using constraint considerations to harmonize and achieve desired colour associations and perceptions in map layout design and make decision on what to include or exclude.

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