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Kehinde A. Adewara
eHealth Africa, Kano, Nigeria

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An Evaluation of Open Source Geographic Information Systems Routing Tools inVaccine Delivery in Kano State, Northern Nigeria.

KEHINDE A. ADEWARA,

eHealth Africa, Kano, Nigeria.

ABSTRACT

The recent proliferation of online/desktop/mobileopen source geographic information systems (GIS)routing tools such as qgis road graph plugin (QRG), open street routing machine (OSRM), google maps engine (GME), graphhopper (GH), and OsmAnd has led to the need to provide a method forcomparatively evaluating the strength and weakness of these routing tools. This is crucial in view of its implication on the prospect and otherwise of routing related projects such as supply chain logistics, supply/delivery operations, and emergency services, among others. In this paper, comparative evaluation of these tools has been carried out using drive test survey and desktop routing estimation with respect to routine vaccine delivery in Kano, Nigeria. Kano state being one of the states in Nigeria with huge burden of health challenges with records of 3062 maternal death between 2005 – 2010(Ibrahim, 2014). *Thus vaccine delivery is one of such healthcare delivery programmes used to addressing some of these health challenges. The primary objective of this paper is to demonstrate comparative advantage of using open sourceGIS routing tools to optimize vaccine delivery process such that there would be significant reduction in logistics, manpower and cost associated with routine vaccine delivery. The capacity of the selected open source GIS routing tools was evaluated against this backdrop. Hence drive test survey was used to define the benchmark for determine the best rank among these desktop routing tools. The drive test survey was carried on selected number of delivery routes and the results were compared with values derived from desktop routing estimation using these tools. Two rounds of drive test survey were carried out for the delivery routes and an average was considered in order to minimum possible error associated with possible inconsistent in driving behavior. Significant discrepancies were observed in the outputs derived between desktop (QRG), online (OSRM, GME, GH) and mobile (OsmAnd) routing platforms. OSM vector base map was used across all the routing tools except GME.The overall outcome indicated QRG had the highest cumulative error margin of 67.52km while the lowest was reported for GraphHoper (46.17km) using same OSM base map. This is an indication that the routing algorithm used is not the same. When compared with GME that uses different base map, the cumulative error margin is very close (QRG – 67.52, GME – 55.99), an indication that similar routing algorithm has been used. Drive test outcome may not be sufficient to determine best or otherwise routing tool, it may be appropriate to consider other valuable criteria for the purpose of ranking these tools. Hence, those criteria were not limited to drive test/routing output error margin, others include capacity for multiple routing, base map completeness/content, support for traffic input, routing platform, and alternative routing option. With these considerations, QRG was ranked 1st. while OsmAnd (5) was least ranked. GME and GH had same ranking (2). QRG was ranked above other OSM based routing tools because it uses desktop platform and a capacity to integrate traffic input. It was ranked above GME majorly because of its robust OSM base map compared to google base map.*

1. INTRODUCTION

The need to be objective in the choice of appropriate open source GIS routing tools cannot be over-emphasized in view of its decision making consequence. This may have adverse economic implication on critical service deliveryand supply chain systems. However the need to embrace open sourceGIS routing tools is necessary and crucial in view of high cost associated with proprietary software yet must be embraced with caution in order to avoiddamaging consequent it may have on the decision making as well as the integrity of few other credible ones(Graser, Straub, & Dragaschnig, 2015).

open source GIS routing tools are some of the resources provided by the open source communities (such as open source geospatial foundation - OSGeo) through crowd sourcing initiative to support international efforts in addressing contemporary global challenges in agriculture (climate change, food security, drought, flooding etc.), health care (response to disease outbreak and eradication, wellbeing etc.), emergency (flooding, earth quakes etc.) among others. These efforts have been applauded worldwide most especially the kind of humanitarian support provided to the developing countries in Africa sub-Sahara(MapAction, 2011).

Hence this article took advantage of the enormous benefits of open source resources to addressing some of the basic problems being faced in Northern Nigeria by government in providing avoidable healthcare service delivery to its citizen through routine or periodic immunization. In view of limited fund to address some of these problems, the need to optimize vaccine delivery activities (which is key to the immunization programme) using reliable and credible cost effective open sourcerouting tools cannot be over-emphasized.Bimonthly routine vaccine delivery is a healthcare programme designed to ease access to vaccine supply in order to eliminate vaccine preventable disease. Thus, it is desirable to use open source GIS routing tools to carry out the necessary planning involving budgeting, manpower allocation, delivery schedules among others.

Due to issues associated with recent proliferation of these routing tools in recent time, it is imperative to conduct a comparative evaluation of strength and weakness of prospective open source GIS routing tools before use in order to avoid possible errors in the critical aspects of delivery planning. This effort would undeniably reduce possible revenue loss in the entire process of vaccine delivery system in terms of efficient deployment of manpower and logistics(Yekta, Yalçın, & and Akçay, 2008).

2. DATA AND METHOD

The approach adopted in solving the problem involves comparing outputs from both drive test survey and desktop routing estimation. Drive test output is used to define the benchmark to determine strength and weakness of the open source GIS routing tools as well as providing suitable multi criteria ranking among them.

2.1. Drive Test Survey

Drive test approach is the technique adopted in defining the benchmark for determining the most reliable, credible and efficient GIS routing tools. Such definition is based on the levels of deviation of the GIS routing tools from the drive test output.

Drive test technique seems to be a reliable means of measuring accuracy in this respect because comparing routing outputs from these tools with drive test results is a strategy to avoid conceptual controversies associated with different routing algorithms used in these tools (since any outputs is a manifestation of strength or weakness of its algorithms). Drive test analysis is a technique that has been used in different studies as a control measure depending on study objective and scope. It is widely used in telecommunication studies(Sanders, Linder, Pratt, Dickherber, Floyd, & Pickering, 2004; Boxberger, Lawver, & Smithey, 2010). However it was used in this case as a technique for acquiring baseline information which serves as a benchmark for determining accuracy among different routing outputs.

In view of the fact that it may be practically impossible to conduct drive test survey for all the facilities in the state due to logistic challenge, hence a representative sample size was considered with minimum error of margin. To ensure that that the smallest possible sample size is considered and to ensure it is representative of the entire sample population, proximity/distance coverage (between the state cold store and the farthest facility in each zone) was considered as the sample population.

The sample size was determined at 95% confidence level and narrow confidence interval (CI) of 5. The CI of +/-5 represents the possible narrow margin of error in the sampling(Myles, Douglas, & Eric, 2013). Thus the sample population of 437 km was considered which was the cumulative distances between farthest facilities in each zones and a sample size of 326 km was determined using online calculator (see table 1). The actual distant covered was 411.74 km for 10 facilities (see table 2), which was 85.74 km in excess of the sample size. Drive test exercise and routing estimation were then conducted for the 10 health facilities.

Table 1 - Sample Distribution

Zone	Farthest Distance (km)	Sample Size (km)	Number of facilities served	Distant Covered (km)	Driver
Rano	196	130	2	115.06	A

Bichi	90	73	3	130.4	B
Nassarawa /Wudil	151	123	5	166.28	C
Total	**437**	**326**	**10**	**411.74**	

Table 2–Kano State Primary Health Facilities targeted for Routing Destinations

S/N	PrimaryName	Settlement	Local Government Name
1.	Gwarzo General Hospital	Tudun Burtu	Gwarzo
2.	Shanono Comprehensive Health Center	Unguwar Hakimi	Shanono
3.	Tsanyawa Comprehensive Health Center	Yan Amar	Tsanyawa
4.	Gezawa General Hospital	Kuka	Gezawa
5.	Kunya Primary Health Center	Kunya	Minjibir
6.	Panda Model Primary Health Center	Wudilawa	Albasu
7.	Hungu Primary Health Center	Gidan Tudu Yamma	Albasu
8.	Kachako Primary Health Center	Unguwar Tsamiya	Takai
9.	Falgore Health Post	Tudun Ningi	Doguwa
10.	Dadin Kowa Health Post	Tasha	Doguwa

Hence, drive test was conducted to determine actual travel distant measurement between the state cold store and the 10 selected health facilities. The travel distance and time during the drive test survey was determined using mobile mapping GPS enabled solution called OsmAnd tablet device. The device is a wide screen android based digital tablet preinstalled with OsmAnd app. The device is made up of a detailed base map, navigation tool and a plugin called trip recording. The plugin is the app used for recording distances covered during the drive test survey.

Multiple drive test rounds were conducted for the purpose of improving the quality of the drive test outputs and to adequately compensate for inconsistency in driver behaviors. In order to manage off route driving behavior, the drive test survey considered average of two drive test rounds. Each of the drive test rounds considered optimum delivery routes between the state cold store and the 10 health facilities (fig.1). The delivery routes are the same for the two rounds. During the survey, each driver is supported by a field coordinator who operates the device. The device is used to record the beginning and end of each trip and save accordingly. This is repeated for all the trips, the outputs are saved as gpx files and shared for later download and processing.

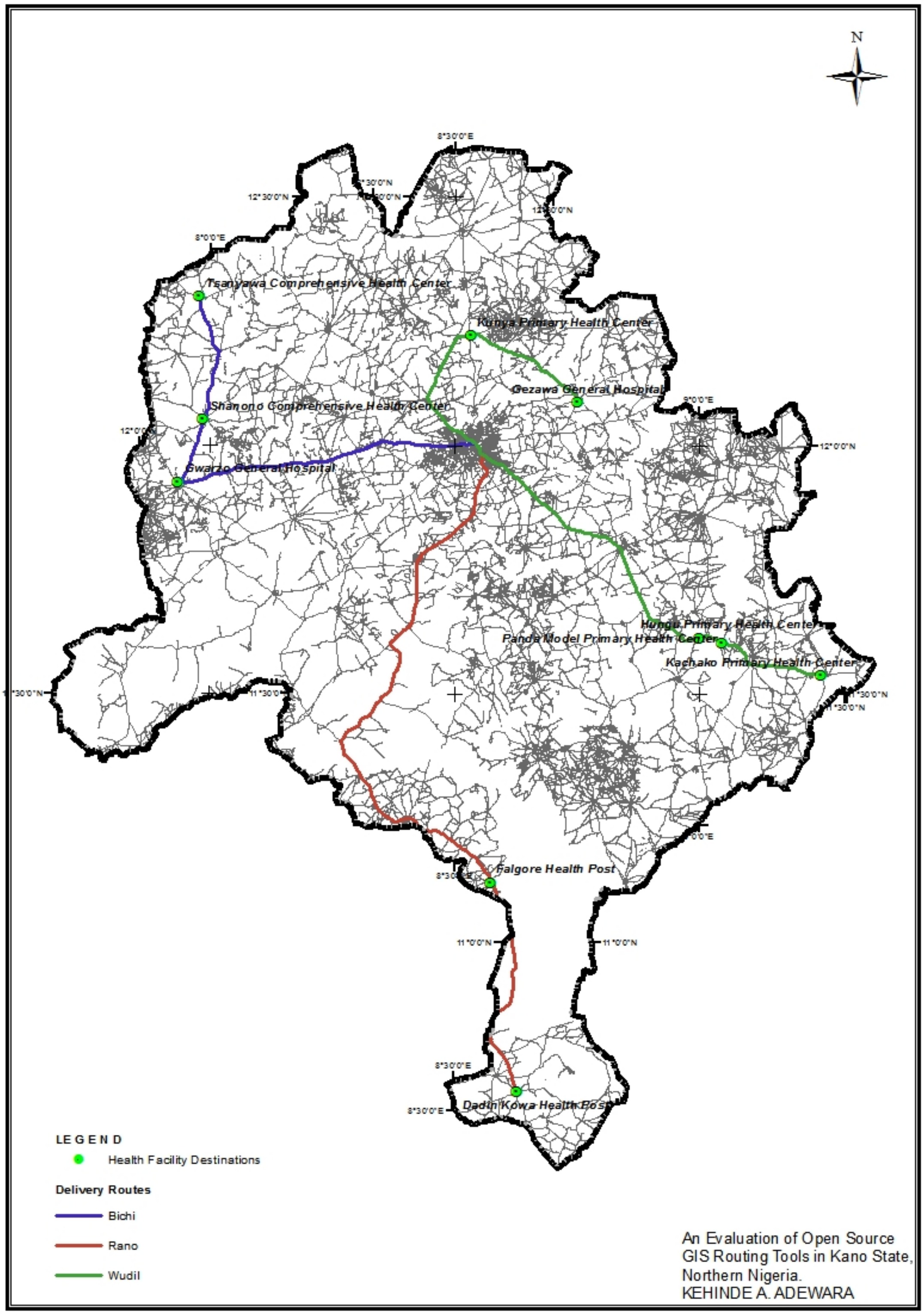

Figure 1 - Health Facility Delivery Routes in Kano State, Nigeria.

Outputs from drive test survey is a control measurement for determining the accuracy of the desktop routing tools because it is the direct measurement of actual distance travelled compared to estimation being conducted during desktop routing exercise. The drive test outputs were derived as gpx file which was later downloaded, converted and integrated with OSM base map to determine distances and travel time (see table 3).

Table 3 - Drive Test Outputs

		DT_Round1		DT_Round2		DT_Average	
Routes (Origin-Destination)	**Drop Order**	**Distance (km)**	**Travel Time (hr)**	**Distance (km)**	**Travel Time (hr)**	**Distance (km)**	**Travel Time (hr)**
State cold store-Gwarzo General Hospital	1	74.34	1.12	74.78	1.55	74.56	1.34
Gwarzo Gen Hosp-Shanono Comprehensive Health Center	2	15.53	0.14	15.45	0.13	15.49	0.14
Shanono CHC-Tsanyawa Comprehensive Health Center	3	79.35	0.58	45.30	1.02	62.33	0.80
State cold store-Kunya Primary Health Center	1	49.12	0.54	45.33	0.47	47.23	0.51
Kunya PHC-Gezawa General Hospital	2	32.91	0.26	30.07	0.19	31.49	0.23
State cold store-Falgore Health Post	1	146.19	1.49	138.79	1.16	142.49	1.33
Falgore HP-Dadin Kowa Health Post	2	54.07	0.36	53.99	0.49	54.03	0.43
State cold store-Hungu Primary Health Center	1	75.81	1.00	75.94	1.02	75.88	1.01
Hungu PHC-Panda Model Primary Health Center	2	5.58	0.05	5.53	0.04	5.56	0.05
Panda MPHC-Kachako Primary Health Center	3	25.73	0.16	25.76	0.18	25.75	0.17

2.2. Desktop RoutingEstimation

The desktop routing estimation was the technique used to compare routing outputs from multiple routing tools(Haklay, 2010). It was conducted for all the delivery routes for the 10 facilities considered during the drive test survey. A number of open source GIS routing tools were used for this purpose, which were primarily classified as online, mobile and desktop routing tools (see table 4).

Table 4 - GIS Routing Tools

S/N	GIS Routing Tool	Platform Type
1	QGIS Road Graph plugin (QRG)	Desktop
2	Open Street Routing Machine (OS RM)	Online
3	Google Maps Engine (GME)	Online
4	GraphHopper (GH)	Online
5	OsmAnd	Mobile

These routing tools use different routing protocols to determine distance and travel time. Speed limit defined for each road class is used as impedance factor in travel time estimation. Hence, speed limit profile for some of these tools are outlined below –

Table 5 - Speed Limit Consideration

Road Class	os rm	GH	QRG
motorway	90	#N/A	#N/A
motorway_link	45	#N/A	#N/A
trunk	85	80	100
trunk_link	40	75	5
primary	65	65	100
primary_link	30	60	5
secondary	55	60	80
secondary_link	25	50	5
tertiary	40	50	60
tertiary_link	20	40	5
unclassified	25	30	30
residential	25	30	30
living_street	10	5	5
service	15	20	5
track	5	15	5
ferry	5	#N/A	#N/A
movable	5	#N/A	#N/A
shuttle_train	10	#N/A	#N/A
default	10	#N/A	#N/A

In carrying out routing estimation, a number of assumptions were made and certain limitations were unresolved. It is assumed that all routing tools consider travel by vehicle (not pedestrian/walking, bicycle) and shortest path option. Limitations include inability to factor in traffic conditions on these delivery routes, as well as inability to consider same routes among all the routing tools due to insufficient base map. Deficiency in base map was as a result of derived error in the base map contents (include digitizing error, geo-referencing errors among others). Hence these errors varied among various routing tools even with those that use same base map. These limitations and other factors such as geo positioning accuracy as well as limitations of inbuilt routing/network model were the reasons for the observed discrepancies in the routing outputs using same base map (see figure 2).

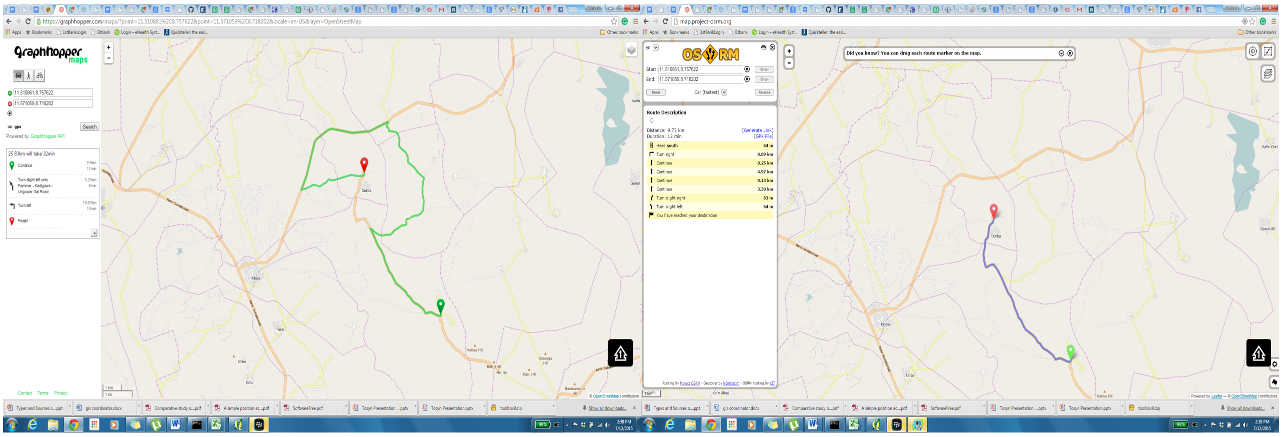

Figure 2 - Different Outputs from Routing Tools using same base map

Hence, each of the routing tools was used to carry out the routing estimation for all the delivery routes considered serving the 10 health facilities. The delivery route is an optimum route (with shortest possible distance) connecting the state cold store to the 10 health facilities across the state (table 6).

Table 6 - Desktop Routing Outputs

Routes	Drop Order	Zone	QRG Distance (km)	GME Distance (km)	GH Distance (km)	OS RM Distance (km)	OsmAnd Distance (km)
State cold store-Gwarzo General Hospital	1	Bichi	69.71	71.00	71.19	71.20	73.70
Gwarzo Gen Hosp-Shanono Comprehensive Health Center	2	Bichi	14.97	15.40	15.63	15.60	15.60
Shanono CHC-Tsanyawa Comprehensive Health Center	3	Bichi	30.41	32.00	46.96	30.60	23.90
State cold store-Kunya Primary Health Center	1	Nassarawa	35.90	36.00	36.08	36.10	36.00
Kunya PHC-Gezawa General Hospital	2	Nassarawa	29.51	29.40	29.56	29.60	29.50
State cold store-Falgore Health Post	1	Rano	132.51	135.00	135.00	143.00	143.00
Falgore HP-Dadin Kowa Health Post	2	Rano	52.77	58.80	52.62	52.60	53.00

State cold store-Hungu Primary Health Center	1	Wudil	70.54	70.60	70.65	70.70	70.30
Hungu PHC-Panda Model Primary Health Center	2	Wudil	5.55	5.40	5.54	5.54	5.53
Panda MPHC-Kachako Primary Health Center	3	Wudil	25.39	25.20	25.39	25.40	25.30
Total			**467.26**	**478.80**	**488.62**	**480.34**	**475.83**

The outcomes of both drive test survey and desktop routing estimation were analyzed to identify peculiar trend for further investigation. Thus, the nature of discrepancies or inconsistency in the outcomes was reported prior to multi-criteria ranking.

There were significant discrepancies in both desktop routing outputs and the drive test outcome. These discrepancies were based on the variation between the drive test average and routing outputs and were reported as error margin (table 7).

Table 7–Comparative Discrepancy Outcomes

			QRG	**GME**	**GH**	**OS RM**	**OsmAnd**
Routes (Origin-Destination)	**Drop Order**	**Zone**	Error Margin (km)	Error Margin (km)	Error Margin (km)	Error Margin (km)	Error Margin (km)
State cold store-Gwarzo General Hospital	1	Bichi	4.85	3.56	3.37	3.36	0.86
Gwarzo Gen Hosp-Shanono Comprehensive Health Center	2	Bichi	0.52	0.09	-0.14	-0.11	-0.11
Shanono CHC-Tsanyawa Comprehensive Health Center	3	Bichi	31.92	30.33	15.37	31.73	38.43
State cold store-Kunya Primary Health Center	1	Nassarawa	11.33	11.23	11.15	11.13	11.23
Kunya PHC-Gezawa General Hospital	2	Nassarawa	1.98	2.09	1.93	1.89	1.99
State cold store-Falgore Health Post	1	Rano	9.98	7.49	7.49	-0.51	-0.51
Falgore HP-Dadin Kowa Health Post	2	Rano	1.26	-4.77	1.41	1.43	1.03
State cold store-Hungu Primary Health Center	1	Wudil	5.33	5.28	5.22	5.18	5.58
Hungu PHC-Panda Model Primary Health Center	2	Wudil	0.00	0.15	0.01	0.01	0.02

Panda MPHC-Kachako Primary Health Center	3	Wudil	0.36	0.55	0.36	0.35	0.45
Sum Total			**67.52**	**55.99**	**46.17**	**54.45**	**58.96**

The error margins reported in table 7 and figure 3 were largely as a result of road quality in the rural area and traffic condition in the urban area, which affected drivers driving behaviors with respect to choice of routes. The cumulative margin of error ranges between 67.52 km to 46.17km. The maximum error margin was reported for QRG routing tool while the minimum was reported for GH both using OSM base map. In this case, choice of different routes must have being considered as a result of different routing algorithms used (a case for future investigation). When the cumulative error margin of a routing tool using different base map (GME) is considered with QRG, the difference is very close (QRG – 67.52, GME – 55.99), an indication that similar algorithm has been used.

In view of the degree of error margin reported, it is not enough to draw conclusion on the best or otherwise routing tools based on this evident. Hence it is imperative to consider other valuable parameters which will be used as criteria for subsequent ranking of these routing tools.

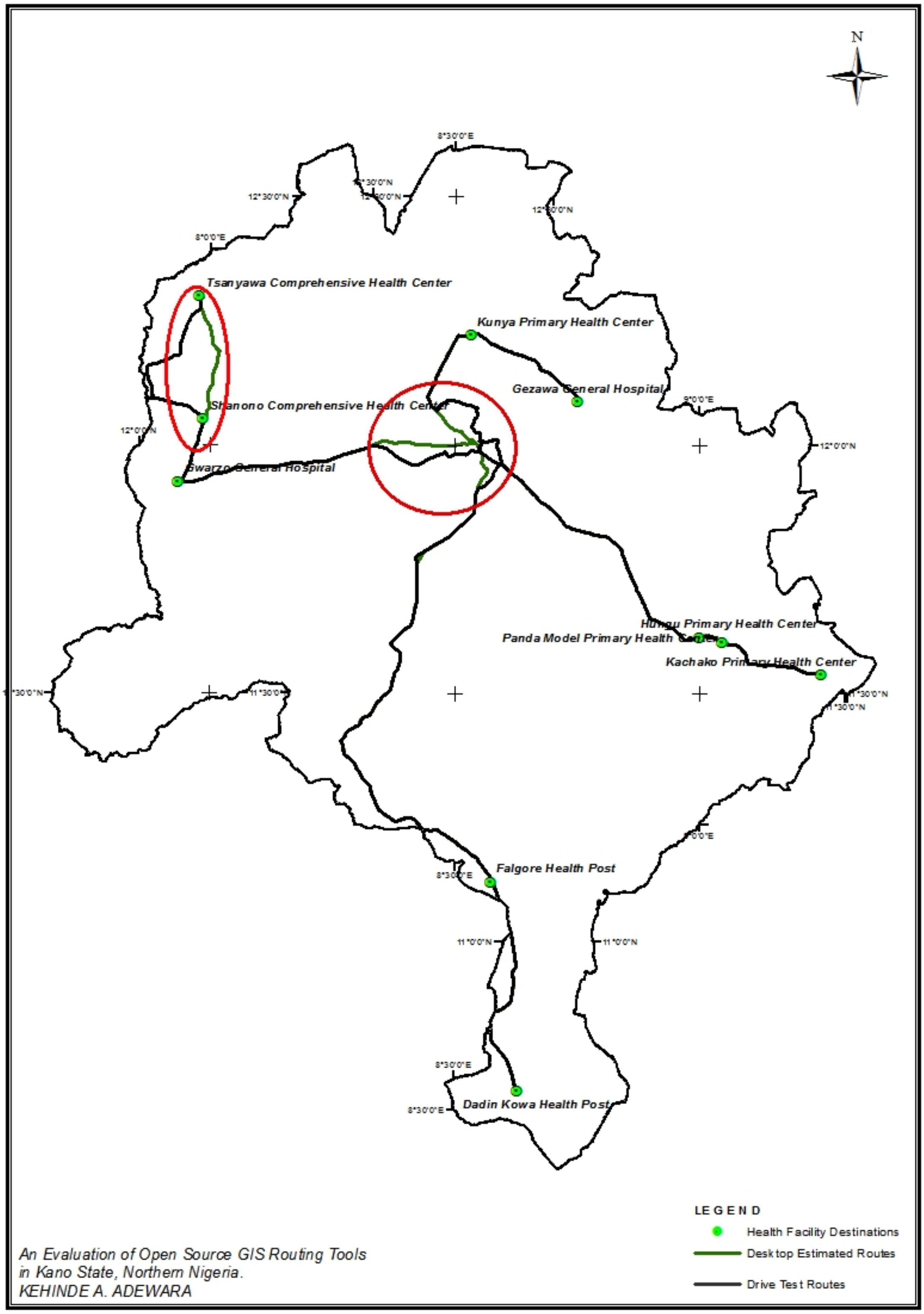

Figure 3 - Comparing Discrepancy in Drive Test Survey and Desktop Routing Estimation

2.3. MultiCriteria Ranking

In view of the limitation associated with using error margin condition as a sole factor for determining best routing tools, it is imperative to consider other 'win and loose' advantages associated with these tools. Thus, it may be appropriate to consider these other factors in providing overall ranking of the evaluated GIS routing tools. Hence multi criteria ranking technique was adopted(Tofallis, 2014). These factors/criteria for ranking may include the following –

1. Routing Output/Drive Test Error margin
2. Capacity For Multiple Routing
3. Base-Map content/completeness
4. Support For Traffic Input
5. Routing Platform
6. Alternative Route Option

The measure of these criteria are provided in the table below -

Table 8 - Definition of Ranking Criteria

Criteria	Measurement	Unit
1. Routing Output/Drive Test Error margin	Cumulative margin of error between drive test and routing outputs.	meters
2. Base map content/completeness	Analysis of % coverage of vector base map compared with imagery, considering average of five clusters each in urban and rural areas (Haklay, 2010).	%
3. Capacity For Multiple Routing	The capacity to support multiple routing was determine by the options provided by the app designed feature.	Yes or no
4. Support For Traffic Input	Determine by onboard designed feature that support traffic modeling	Yes or no
5. Routing Platform	Designed platform for implementation	Mobile, desktop, online/web
6. Alternative Route Option	Provision for choice of alternatives	Yes or no

Hence, a multi-criteria ranking technique was adopted to provide suitable ranking to these routing tools. There are several methods of conducting such ranking well documented in the literature,most common is the additiveweighing factor approach(Tofallis, 2014). This involves assigning certain weights to these criteria and normalizes values reported in different units. This approach is often constrained by non-uniform way of normalizing data which often results in different outcomes(Sagar & Najam, 1998; Tofallis, 2014). But the multiplicative weighing score was able to overcome this limitation and it is commonly used in the decision making hierarchy of world leading organizations such as United Nations Development Programme (UNDP) in developing annual human development index (HDI), an instrument used for ranking nations based on human per capita income, life expectancy and education(UNDP, 2010).

2.3.1. Threshold Definition and Weighing

The range of values that were derived for these criteria were given in different units of measurement, hence the thresholds for each of the criteria were defined and ordinal weights assigned (table 9).The threshold for the drive test/routing error margin was determined using a median (56.62) of the cumulative error margin (46.17 – 67.52) as the threshold. Thus any error margin greater than 58.75 is assigned 0 and less than is assigned 1. Threshold for base map completeness was derived from average consensus option expressed in percentage for both five sample clusters in rural and urban. The threshold values for rural and urban clusters were determined as 50% and 70% respectively by consensus. Hence the average (60%) of the two was used for assigning weight of 1 for greater than 60% and 0 for less than. Consensus opinion was used to assign threshold of 1 for desktop routing platform and 0 for others. For other criteria, ordinal values of 1 and 0 were assigned for yes and no responses accordingly.

Table 9 - Normalized Thresholds

Criteria	Value Range	Threshold condition	Assigned Weight s
1. Routing Output/Drive Test Cumulative Error margin	46.17 – 67.52 km	>56.62 <56.62	0 1
2. Base map content/completenes s	0 - 100%	≤ 60 ≥ 60	0 1
3. Capacity For Multiple Routing	Yes/No	No Yes	0 1
4. Support For Traffic Input	Yes/No	No Yes	0 1
5. Routing Platform	Mobile, desktop, online/web	Mobile/Online Desktop	0 1
6. Alternative Route Option	Yes/No	No Yes	0 1

2.3.2. Scoring/Ranking

In view of this outcome (table 10), scoring was derived based on frequency of 1 occurrence while the highest frequency of 4 was ranked 1st and least score of 1 was ranked 4th.

Table 10 - Normalization Outcome

Ranking Criteria	QRG	GME	GH	OS RM	OsmAnd

1. Routing Output/Drive Test Error margin	0	1	1	1	0
2. Capacity For Multiple Routing	1	1	1	0	0
3. Base map content/completeness	1	0	1	1	1
4. Support For Traffic Input	1	0	0	0	0
5. Routing Platform	1	0	0	0	0
6. Alternative Route Option	0	1	0	0	0
Score	**4**	**3**	**3**	**2**	**1**

Table 11- Ranking Outcome

Routing Tools	Score	Rank
QRG	4	1
GME	3	2
GH	3	2
OS RM	2	3
OsmAnd	1	4

3. RESEARCH FINDINGS, CONCLUSION AND RECOMMENDATIONS

It is not surprising to find distant variation in the routing outputs of routing tools using different base maps (OSM and google) because different choice of routes are chosen. But to discover a significant variation in routing outputs of routing tools using same OSM base map is worrisome. It is an indication that there is an inconsistency in the routing algorithm used. The outcome of drive test clearly shown that GH tool has a better routing algorithm with lowest cumulative error margin. Future research is hereby encouraged to investigate how road graph plugin of QRG would integrate GH routing algorithm for better performance.

It is important to emphasize that the GME better drive test performance over QRG was just because the selected delivery routes were largely within urban area where GME base map content is relatively good. It is thus recommended that outstanding GME features such as alternative routing option should be considered for QRG integration.

Scheduling delivery and routing within Kano metropolis was largely constrained by lack of traffic details, hence the routing outputs which considered speed limit as an input for travel time estimation was not consistent with travel time output derived from drive test survey. Thus it is anticipated that future research would consider investigating metropolitan traffic. Speed limit consideration is still valid for interstate and rural areas.

QRG is at the moment constrained by inability to handle batch routing. All the routing tools considered are equally unable to do batch routing. Hence it is expected that future research would focus of developing batch routing component and to integrate other features such as alternative route options.

4. ACKNOWLEDGMENT AND CONTRIBUTIONS

I strongly acknowledge the contributions and selfless support I have received from the Management and staff of eHealth Africa (eHA), such contributions are hereby outlined below (not necessarily in order of important) –

eHA Management	-	For providing the platform and financing the trip
GIS Team	-	For the valuable criticisms
Human Resources	-	For assisting with necessary documents
Monitoring, Research& Evaluation	-	For their immense support from researchperspective.
Health Camps	-	For providing personnel support during the drive test survey
Operations (Reservations)	-	For assisting hotel reservation and flight booking
Operations (Logistics) survey	-	For providing drivers that carried out the drive test
Finance	-	For assisting with necessary documents and fund disbursement

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