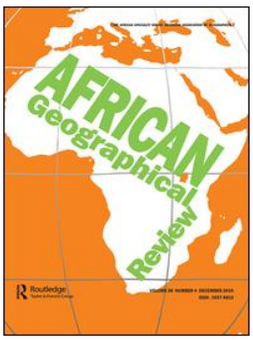

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Maximal Covering Location Problem (MCLP) for the identification of potential optimal COVID-19 testing facility sites in Nigeria

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ABSTRACT

The identification of University Teaching and Research Hospitals (UTRHs) for siting additional National Center for Disease Control Molecular Laboratories (NCDCMLs) for effective coverage of Local Government Areas (LGAs) during the COVID-19 pandemic was accomplished using the Maximal Covering Location Problem (MCLP) method. The maximum number of NCDCMLs required together with the maximum drive time to these identified optimal NCDCMLs were estimated. The NCDCMLs are skewed in favor of the southwestern Nigeria and there is a significant positive correlation between the number of NCDCMLs and the reported COVID-19 infections (r= 0.860, p< 0.001). There are 22.22%, 35.79%, 63.82%, 76.10% and 82.04% of LGAs within 2, 4, 6, 8, and 10hr drive time, respectively, from at least one NCDCML. Addition of five new UTRHs will ensure that 79% of all the LGAs in Nigeria are within 4 hr drive time to at least one NCDCML. Four of the seven proposed new NCNCMLs are optimal while the remaining three are not. Perhaps, this study is the first attempt at evaluating the use of UTRHs as an alternative to none UTRHs NCDCML. The use of the MCLP method allows for the identification of not only the required numbers of NCDCMLs but also the drive time to them.

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Maximal Covering Location Problem (MCLP); National Center for Disease Control Molecular Laboratories (NCDCMLs); Geographic Information System (GIS); Network analysis; University Teaching and Research Hospitals (UTRHs)

1. Introduction

The location and allocation of health facilities and services in many developing countries is largely influenced by political or pragmatic considerations (Agbenyo et al., 2017; Özceylan et al., 2017; Rahman and Smith, 2000; Rushton, 1984). The optimality of such location decision is often challenged during the period of emergency (Rahman & Smith, 1999). To deliver the needed services to humans, the location and allocation of health facilities should be efficient. The location-allocation of health facilities deals with locating these facilities among potential sites to provide efficient and effective services over a wide area with spatially distributed demands (Li et al., 2011). The spatial distribution of health care facilities affects their accessibility and since they provide services which must be socially available, their location should be critically considered (Özceylan et al., 2017). The maximum time or distance separating people from the closest facility is a crucial parameter that can influence utilization most especially emergency service location such as emergency testing laboratories (R. L. Church & ReVelle, 1976). Therefore, for any given location solution, the maximum distance people would have to travel to reach a facility is a reflection of the worst possible performance of the system (R. Church & ReVelle, 1974).

Location-allocation model is a method for finding optimal sites for facility locations and it involves simultaneously selecting a set of locations for facilities and assigning spatially

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distributed sets of demands to these facilities with a view to optimizing some specified criterion (Rahman and Smith, 2000). The diverse interpretations of the goal of maximizing public welfare lead to a number of possible location-allocation models of which the Maximal Covering Location problem (MCLP) is one. The MCLP emerged because of the need to specify the maximum distance or time constraints in formulating a location problem since it has been found that the *p*-median solutions which minimize the weighted travel distance may be inequitable, forcing few people to travel far (Rahman and Smith, 2000). Hakimi (1964) was among the first to use the MCLP. The MCLP seeks to minimize total cost of transport and facilities while maximizing the number of people served. The Maximal Covering Location Problem (MCLP) seeks to maximize the population covered within a desired service distance by locating a fixed number of facilities, provide opportunities to resolve the questions raised. The MCLP is used to identify the minimum number of facilities necessary to achieve coverage within the maximum distance. This MCLP has been used for locating kidney dialysis machines, a form of treatment for which the patient must make frequent (Eben-Chaime & Pliskin, 1992; Rahman and Smith, 2000). A measure of the effectiveness of a given public facility location configuration is the amount of population covered or served within a desired service distance (R. L. Church & ReVelle, 1976). Generally, the location-allocation problem has been broadly classified into two. The first category focused on the location and allocation of public goods (hospitals, ambulance, post office, schools) while the second focused on private goods (retail outlets and industries). One of the basic differences between these two location-allocation problems is that while ensuring maximum accessibility and coverage is always the focus in the location-allocation of public goods, minimization of travel distance and cost of movement takes priority in the location-allocation of private goods (ReVelle & Eiselt, 2005). The Network analysis function of GIS has been used extensively to resolve the problem of location-allocation. GIS provides an opportunity to collect and analyze locational data and thus important in obtaining the locational position of health-related facilities. Network analysis has been used to find the shortest routes or to find the service areas of the facilities. Generally, it improves the capacity of health planners to better plan the utilization of available health resources and improving health care delivery (Özceylan et al., 2017).

Nigeria is one of the African countries with a high incidence of COVID-19. The number of reported cases continues to increase astronomically. For example, the number of confirmed cases rose from 46 to 174 (278.26%) between March 25th and April 1st, 2020. Possibly, the actual number of infected persons may be more than the number of confirmed cases due to the limited and clustered pattern of the available NCDCMLs where the test is conducted (Centres for Disease Control and Prevention [CDC], 1998). The limited and clustered nature of the existing NCDCMLs has reduced the actual number of persons that would have effectively tested for the COVID-19. Hence, a large number of asymptomatic COVID-19 patients that should have been isolated are freely roaming the street thereby further spreading the virus. Thus, the lower number of people tested so far is keeping the reported numbers of persons that have tested positive to the virus artificially low (CDC, 1998; Zhao et al., 2020).

The National Centre for Disease Control (NCDC) certified laboratories for the COVID-19 test include the NCDC National Reference Laboratory, Abuja; the Irrua Specialist Teaching Hospital in Edo state; the Virology Laboratory in the Lagos University Teaching Hospital (LUTH); the Nigeria Institute for Medical Research (NIMR), Lagos State; and the African Centre of Excellence for Genomics of Infectious Disease, Osun state. The southwest geopolitical zone hosts three of these NCDCMLs, while there is one each in the South-South and North Central geopolitical zones. Therefore, 32 States in Nigeria do not have NCDCML and thus are at a greater risk of the pandemic. University Teaching and Research Hospitals (UTRHs) are potential sites for the establishment of COVID-19 molecular laboratories. Two out of the five existing test laboratories for COVID-19 are located within existing UTRHs. The distributional pattern of the UTRHs is slightly more evenly distributed compared to that of NCDCMLs (Figure 1).

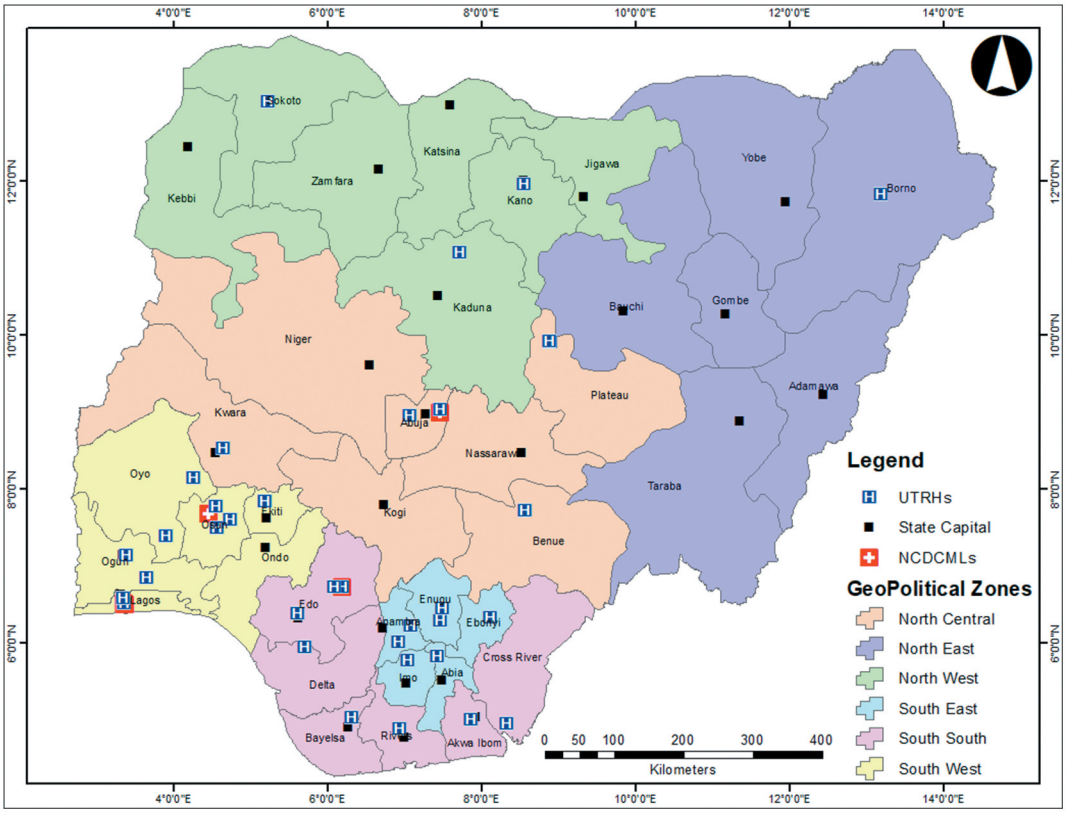

Figure 1. Distribution of existing NCDCMLs and UTRHs in Nigeria.

It is therefore imperative that additional COVID-19 test facilities be established to fast track early diagnosis and subsequent treatment. This raised four typical questions: (a) how many more COVID-19 test laboratories are needed to ensure adequate coverage of the whole country? (b) If the numbers required are known, where should these laboratories be located to ensure accessibility, equity and minimize aggregate travel distance? (c) at what threshold drive time would the proposed number of facilities required to be optimal and ensure adequate coverage of the population? and (d) in the interim, which of the NCDCMLs need to be quickly enhanced to cope with the anticipated increase in the number of persons requiring testing? In this regard, the MCLP was used to minimize the distance to the COVID-19 test centers, while maximizing the number of LGAs that are served by these COVID-19 test centers. The limit of the maximum distance to the nearest COVID-19 test center is imposed to ensure that no more than the specified time period will elapse before each person can access the nearest testing facility (R. L. Church & ReVelle, 1976). The desired solution to this problem locates the minimum number of COVID-19 test centers that satisfies the response-distance requirement. According to R. L. Church and ReVelle (1976), once an upper limit is placed on either cost or distance travel to utilize a service, it is possible to determine the minimum-cost spatial arrangement of service facilities that will adequately serves the entire region. If cost of service is identical in all the possible facility location, then the problem is reduced to the identification of the minimum the total number of service facilities required to meet the distance or time standard for each person. The solution to the problem will indicated both the number and location of the facilities that provide the desired service (Hakimi, 1964, 1965). Due to its pandemic nature, COVID-19 testing facilities is herewith treated as an emergency facility that should serve every one within its demand nodes at a minimum distance. We thus assume that all COVID-19 testing

facilities in Nigeria are offering the same type of service and ensuring their accessibility will reduce mortality from COVID-19.

This study, therefore, focuses on the evaluation of the optimality or otherwise of the existing NCDCMLs to identify existing federal and or state UTRHs as potential sites for NCDCMLs to rapidly meet the challenge posed by a COVID-19. It identifies where new NCDCML facilities should be located to reduce the cost of building new laboratories while improving the equity of access and reducing the population (LGAs) that falls outside the required drive time thresholds. The following objectives were pursued: (a) mapping the locations of the existing network of NCDCMLs and the locations of existing federal and state UTRHs (b) optimally allocating states and LGAs to the NCDCMLs (c) identifying the possible numbers of UTRHs that will ensure maximum coverage of the 774 LGAs at 2, 4, 6, 8 and 10 hr drive time to the nearest NCDCML (existing and suggested); and (d) evaluating the optimality of the newly proposed sites by the NCDC against the identified optimal locations. The choice of 2, 4, 6, 8 and 10 hr was based on the observation of R. Church and ReVelle (1974), that by solving the location set covering problem over a range of values of distance or time, it will possible to develop a cost-effectiveness curve from the pairs of numbers (maximal service distance and minimum number of facilities to cover).

2. Materials and methods

Geographic Information Systems (GIS), linear programming and mathematical models have often been advocated in the MCLP of health-care facilities (R. Church & ReVelle, 1974; Özceylan et al., 2017). The study covered the 774 Local Government Areas (LGAs) in Nigeria, focusing on the evaluation of the optimality of existing NCDCMLs, determination of the required numbers of additional NCDCMLs using the UTRHs as alternative sites, and evaluating the optimality of the seven newly proposed NCDCMLs. Essentially, publicly available spatial data were used in the analysis to ensure transparency most especially in a data-sparse environment like Nigeria (Fredriksson, 2017). tThe MCLP requires precise coordinate of both the demand and supply locations. The coordinates of the demand and supply points were extracted from the Google Earth because of the restriction of movement imposed by the Federal government of Nigeria as a way to stem the rising number of people infected with COVID-19COVID-19. The coordinates of the five NCDCMLs were also obtained from the Google Earth satellite image. The locations of these five laboratories have been indicated on Google Earth; thus, it was easy to obtain their respective coordinates based on the addresses provided by NCDC on its website. Similarly, the list of all the federal and state UTRHs was obtained from the National University Commission's (NUC) website. Their coordinates were subsequently obtained from the Google Earth satellite image. Administrative data such as national road network, administrative state and LGA boundaries were extracted from the Diva-gis.org (https://www.diva-gis.org/gdata).

The coordinates of all the 36 UTRHs and the five NCDCMLs were geocoded using QGIS and ArcGIS software. The *Line to Hub* algorithm in QGIS was used to connect state capitals and LGA headquarters to their nearest NCDCMLs, respectively. The mean and maximum distance between the State capitals, LGA headquarters and the nearest NCDCML were subsequently calculated. State capitals were also allocated to their nearest UTRH since not all the states in Nigeria have UTRH. Using the Network analysis extension in ArcGIS software, the number of LGA headquarters at the different drive time thresholds of 2, 4, 6, 8 and 10 hr to the nearest NCDCMLs was estimated to provide the current baseline drive time situation in the country. R. Church and ReVelle (1974), noted that by solving the location set covering problem over a range of values of distance, it is possible to develop a cost-effectiveness curve from the pairs of numbers (maximal service distance S, minimum number of facilities to cover). Thereafter, an MCLP algorithm was implemented to estimate the number of LGAs at a different drive time with the incremental addition of the optimally selected UTRHs. The Network Analysis tool is based on the well-known Dijkstra's algorithm for finding the shortest paths.

It has become imperative to experiment with different scenarios because the Nigerian government does not have a threshold distance goal for health-care accessibility. Therefore, for this study, the distance thresholds of 2, 4, 6, 8 and 10 hr ,respectively, were used (R. L. Church & ReVelle, 1976). The drive time of 60 km/hr was used because it represents the average maximum drive speed on highways. Owoaje et al. (2005) and Oyedepo and Makinde (2010) noted that a vehicle traveling above this speed limit is susceptible to accident. The number of LGAs that are within 2, 4, 6, 8 and 10 hr drive times from the existing NCDCMLs were evaluated as baseline scenarios. Neebe (1988) noted that solving the problem over a wide range of maximum distance values is with a view to showing the trade-off between the maximum distance and the least number of facilities that must be established. Thereafter, these different drive times were evaluated with the addition of 1, 2, 3, 4, and 5 new UTRHs. This becomes imperative because there is no government threshold distance that patients must travel to access such health facility. A 2.0 km (120 minutes) drive time was considered because it represents a relatively close place that can be readily accessed by car (Anderson et al., 2010; Yang & Diez-Roux, 2012). A multiple of this distance was therefore considered to assess the effect of distance on the number of LGAs that are within the specified drive time threshold considered. Research has equally shown that the average distance traveled to a human immunodeficiency virus testing center was about 4.0 km (Eberhart et al., 2015), while an 8.0 km has been established as a close market area of hospital catchment most especially for specialized medical services (Luft et al., 1986).

3. Results and discussion

3.1. Average distance from the existing NCDCMLs in Nigeria

There are five (13.51%) State capitals that are closer to the African Centre of Excellence for Genomics of Infectious Disease (ACEGID) (Figure 2). The closest State capital is the Osun State (15.14 Km), while the Ondo State is the farthest (94.76 km) and the average distance to the ACEGID is 70.51 km±28.96 km. The Irrua Specialist Teaching Hospital, Irrua Edo State (ISTH) is closer to 12 (32.42%) State capitals. Expectedly, Edo State (75.79 km) is the closest, while Cross Rivers (306.65 km) is the farthest and the average distance from all the closest state capitals to ISTH is 177.98 km±68.88 km. The Nigeria Centre For Disease Control Molecular Laboratory (NCDCML), is closer to 18 (48.65%) State capitals. The Federal Capital Territory (19.86 Km) is the closest, while Borno State (699.80 km) is the farthest and the average distance from all the closest states to the NCDCML, Abuja, is 353.13 km±180.88 km. The two NCDCMLs in Lagos State (the Nigeria Institute for Medical Research (NIMR), Yaba, Lagos and the Virology Laboratory at the Lagos University Teaching Hospital (LUTH)) are closer to Ogun State. There were more variations among the states closer to the NCDC reference laboratory in Abuja than elsewhere.

3.2. Distribution of teaching and research hospital in Nigeria

There are 36 UTRHs that are not equitably distributed amongst states in Nigeria. They are affiliated to either federal or state Universities, although States such as Ondo, Kogi, Nassarawa, Niger, Yobe, Gombe, Bauchi, Adamawa, Taraba, Jigawa, Zamfara, Katsina and Kebbi States do not have any UTRHs. The UTRHs are potential candidates for optimizing the coverage of existing NCDCMLs. This is because most of them have an existing molecular laboratory where the COVID-19 testing equipment can be conveniently placed. This is in addition to the likely presence of the required human resource to operate the equipment. Thus, utilizing UTRHs as locations for the rapid placement of the COVID-19 test kits during the emergency period will not only reduce the cost but enhanced operational efficiency of the NCDC and the federal government at large. Realizing the benefits of such placement requires that UTRHs should be optimally selected to ensure maximum

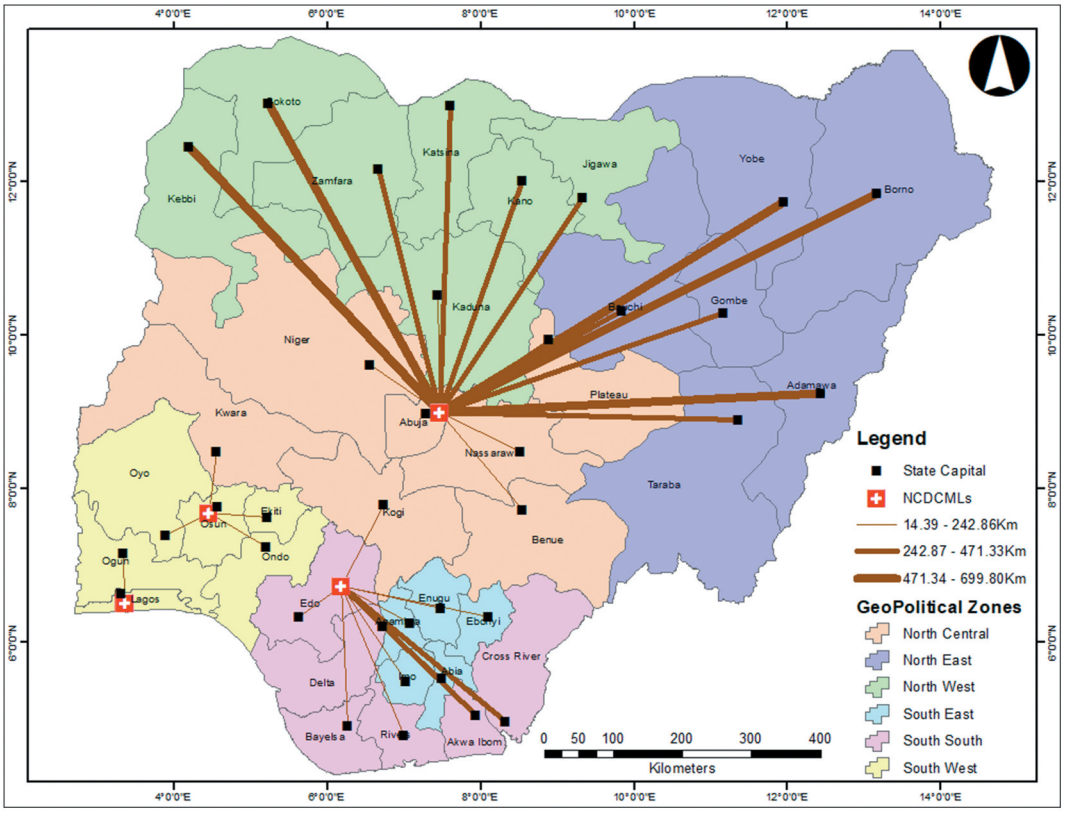

Figure 2. Shortest distance (Km) to existing COVID-19 testing facilities in Nigeria.

coverage of all the LGAs. This would require testing an appropriate combination of existing NCDCMLs with UTRHs that maximize the coverage of LGAs coverage at different travel distance.

The University of Maiduguri Teaching Hospital, Maiduguri, Borno State has the least minimum distances to Yobe (134.46 km) and Adamawa (297.46 km) States, while the Jos University Teaching Hospital, Jos, Plateau State, has the least minimum distances to Bauchi (113.27 km), Gombe (252.96 km) and Taraba (292.75 km) States. The Usmanu Danfodiyo University Teaching Hospital, Sokoto State, has the least distance to Kebbi (128.84 km) State, while the Ahmadu Bello University Teaching Hospital, Zaria, Kaduna State has the least distance to Zamfara (165.15 km) State. The Aminu Kano Teaching Hospital, Kano State, has the least distance to Katsina (154.08 km) and Jigawa (87.13 km) States. The University of Abuja Teaching Hospital, Gwagwalada, Abuja, has the least distance to Niger (92.39 km) and Kogi (132.47 km) States, while the Benue State University, Markurdi, Benue State, has the least distance to Nassarawa (83.73 km) State. The Obafemi Awolowo University Teaching Hospital, Osun State has the least minimum distance to the Ondo (65.08 km) State. Elsewhere, the states have the least distance to their respective UTRHs in their domain (Figure 3).

Patients present in any of the UTRHs can be referred to the nearest NCDCML for COVID-19 test. Based on this, patients from eight of the UTRHs can be referred to NCDCML at the ACEGID. The closest UTRH to this test center is the Ladoke, Akintola Teaching Hospital (14.73 km), while the farthest is the University of Ilorin Teaching Hospital (96.73 km). The average distances from these UTRHs to the ACEGID is 56.99 ± 28.75 km. The ISTH is closer to 15 UTRHs. The closest of the UTRHs is the Ambrose Alli University, Ekpoma (11.92 km), while the farthest is the University of Calabar Teaching Hospital (306.25 km). The average distance from these UTRHs is

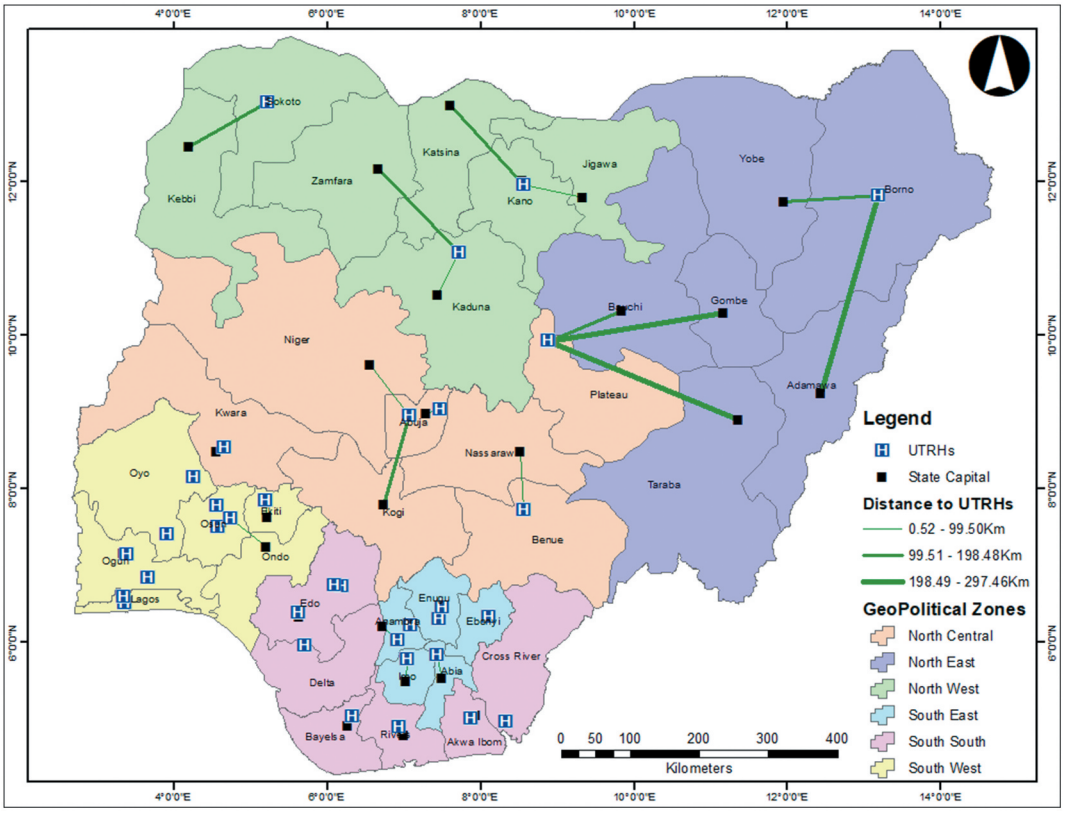

Figure 3. Potential service hospital for the states without any teaching and research hospitals.

147.56 ± 82.12 km. The NCDC reference laboratory is closer to nine UTRHs mainly from the North-West, North-Central and North-East geopolitical zones. These geopolitical zones account for the highest drive time to existing NCDCMLs in Nigeria. The UTRH with the lowest distance is the University of Abuja Teaching Hospital, Gwagwalada, Abuja (4.76 km), while the farthest is the University of Maiduguri Teaching Hospital (700.02 km). The average distance to the testing facility from all the UTRHs is 266.55 ± 208.74 km. The Olabisi Onabanjo University Teaching Hospital is the closest to the NCDCML in the Nigeria Institute for Medical Research (NIMR), Yaba, Lagos, and the Virology Laboratory at the Lagos University Teaching Hospital (LUTH) in Lagos State (see Figure 4).

3.3. Relationship between the number of reported COVID-19 and the number of test equipment

Three of the states with the highest reported COVID-19 incidence as at 6 April 2020 have at least one NCDCML (Table 1). Lagos for example, with 120 confirmed cases have two NCDCML, while Abuja (47), and Osun (20) have one NCDCML each. The higher number of reported COVID-19 from the Osun State has been attributed to the large influx of people from Cote de Ivoire to Ejigbo town in Osun State. Thus, proximity to the Lagos and Osun NCDCMLs could have enhanced the higher testing and reporting. Using the data available from the NCDC, there was a highly positive correlation between the number of confirmed cases and the number of NCDCMLs (r = 0.878, p< 0.001) available in the state. This further strengthens the arguments that the more the number of COVID-19 testing centers, the more likely the numbers that will be reported. Provision of

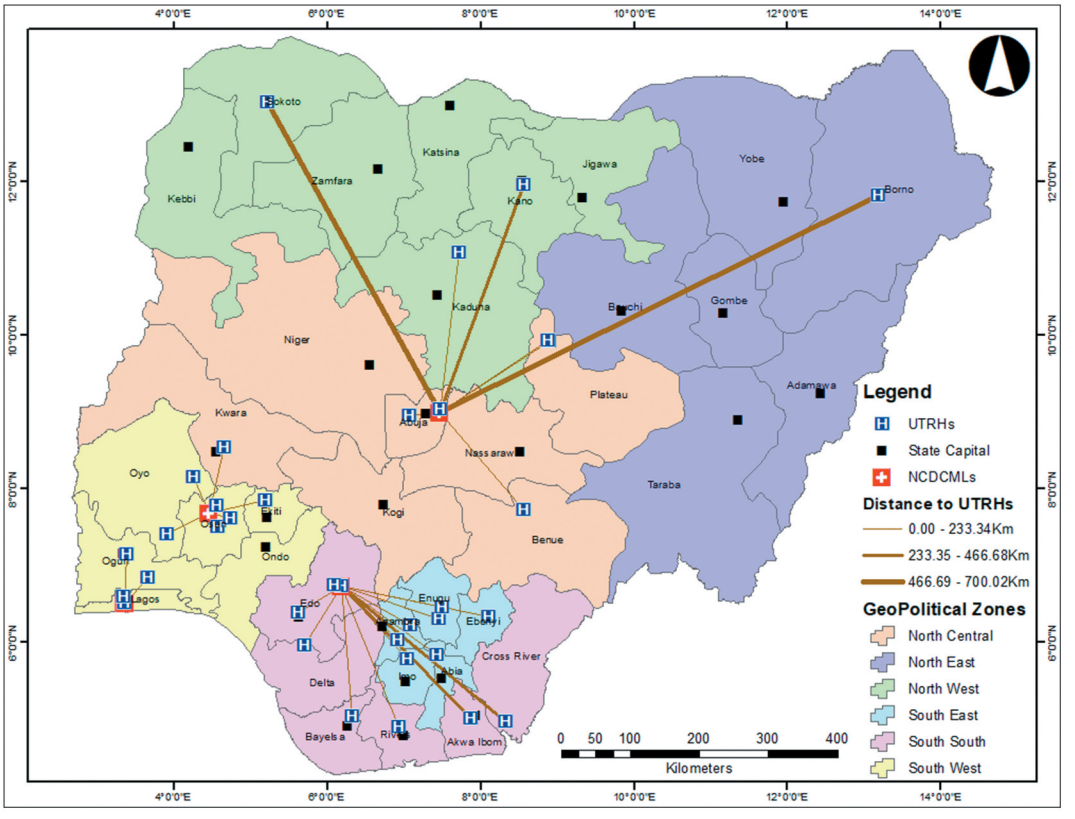

Figure 4. Closest testing center to the existing teaching and research hospital in Nigeria.

Table 1. Reported coronavirus across states in Nigeria (6 April 2020).

State	Confirmed Cases	No of Test Laboratories
Bauchi	6	0
Benue	1	0
Edo	9	1
Ekiti	2	0
Enugu	2	0
FCT	47	1
Kaduna	5	0
Lagos	120	2
Ogun	4	0
Ondo	1	0
Osun	20	1
Oyo	9	0
Awa Ibom	5	0
Rivers	1	0
Total	174	5

Source: NCDC, 6 April 2020.

additional COVID-19 testing centers at accessible locations will most likely encourage more people to present themselves for testing. COVID-19 testing is important to ensure that infected persons are aware of their status and can reduce their risk of transmitting the virus to family and friends.

3.4. Allocation of LGAs to the existing NCDCMLs

The drive time of 120, 240, 360, 480, and 600 minutes to the nearest NCDCMLs was explored. Presently, 22.22%, 35.79%, 63.82%, 76.10% and 82.04% of the LGAs are within 2, 4, 6, 8 and 10 hr drive time, respectively, from the nearest NCDCML (Table 2). The NCDCML at the ACEGID has the largest number of LGAs (93) within the 2hr drive time to the nearest NCDCML. The NCDCML at ISTH has the highest number of LGAs within the 4 hr (117) and 6 hr(207) drive time to the nearest NCDCMLs. The NCDC reference laboratory has the highest number of LGAs within the 8 hr (245) and 10 hr (291) drive time to the nearest NCDCMLs. Thus, the NCDC reference laboratory has the largest number of LGAs at a relatively longer distance than other NCDCMLs.

By increasing the drive time from 2 to 4 hr, there was a 61.05% increase in the number of LGAs within 4 hr drive time from the nearest NCDCML. Similarly, by increasing the drive time from 4 to 6 hr, there was a 78.34% increase in the number of LGAs within 6 hr drive time to the nearest NCDCMLs. There was a 59.11% reduction by increasing the drive time from 6 to 8 hr, while it further declined to 7.81% by further increasing the drive time from 8 to 10 hr. The peak at which the percentage number of LGAs started declining with the increasing drive time (6 hr) could be indicative of diminishing marginal benefits of increasing the threshold distances to the NCDCMLs (Table 2).

3.4.1. Additional one facility at 2, 4 , 6, 8 and 10 hr drive tim

The most optimal UTRH that should be added to the existing NCDCMLs to ensure the highest number of LGAs are within the 2 hr drive time is the Abia State University Teaching Hospital, Uturu, Abia State. Equipping this UTRH for COVID-19 test will increase the number of LGAs within the 2 hr drive time from 172 (without the addition of the Abia State University Teaching Hospital, Uturu, Abia State) to 293 LGAs (70.35%) (Table 3). At 4 hr drive time, the most optimal UTRH in the Aminu Kano University Teaching Hospital, Kano. The addition of this UTRH to the existing NCDCMLs will ensure that 423 LGAs out of the 774 LGAs in Nigeria are within 4 hr drive time to at least one NCDCML (Table 3). The number of LGAs within 4 hr drive time will increase from the present 277 to 423 (52.71%). At 6 hr drive time, the most optimal UTRH for COVID-19 test is the University of Jos Teaching Hospital, Jos, Plateau State. This UTRH will increase the number of LGAs within the 6 hr drive time from the present 494 to 593 (20.04%). Aminu Kano University Teaching Hospital, Kano State is the most optimal UTRH that should be designated as COVID-19 testing center to ensure that the highest number of LGAs are within the 8 and 10 hr drive time, respectively, to the nearest NCDCML. At 8 hr drive time, the number of LGAs that will be within this drive time will increase from the present 480 to 589 (9.68%) while the number that will be within the 10 hr drive time will increase from the present 600 to 635 (2.36%). The percentage of LGAs within the drive times started reducing after the 6 hr threshold distance (Tables 3 and 4).

3.4.2. Additional two UTRHs facility at 2, 4, 6, 8 and 10 hr drive times

The Abia State University Teaching Hospital, Abia State, and the Aminu Kano University Teaching Hospital, Kano State are the two UTRHs to be equipped with the appropriate COVID-19 test equipment to ensure that the maximum numbers of LGAs are within the 2 km drive time to the

Table 2. Distance and baseline number of LGAs with access to NCDCMLs in Nigeria.

Minutes	NCDC	ISTH	LUTH	ACEGID	Total	Percent	% Change
120 (2hrs)	17	39	23	93	172	22.22	
240 (4hrs)	32	117	25	103	277	35.79	61.05%
360 (6hrs)	155	207	25	107	494	63.82	78.34%
480 (8hrs)	245	213	24	107	589	76.10	59.11%
600 (10hrs)	291	212	25	107	635	82.04	7.81%

Table 3. Number of LGAs within the various drive time from existing NCDCMLs and the proposed UTRHs.

	Addition of One UTRH					Addition of Two UTRHs					Addition of Three UTRHs					Addition of Four UTRHs					Addition of Five UTRHs				
UTRHs	120	240	360	480	600	120	240	360	480	600	120	240	360	480	600	120	240	360	480	600	120	240	360	480	600
Abuja	17	34	42	43	43	17	34	91	95	43	17	34	35	89	41	17	34	35	41	41	17	30	35	39	39
Irrua	39	117	200	212	212	39	46	207	212	44	39	46	200	44	44	39	46	44	44	44	39	46	44	44	44
LUTH	23	25	25	25	25	23	25	25	25	25	23	25	25	25	25	23	25	25	25	25	23	25	25	25	25
Osun	93	103	107	107	107	93	103	105	105	107	93	103	105	105	105	93	103	105	105	105	93	103	105	105	105
Abia	121					121				174	121					121		171	174	174	120		171	142	142
Aminu Kano		144		259	263	49	144			257	49	136			203	40	129		153	153	40	113	113	133	133
Jos Hospital			219										153					139				36	54		
Alex Ekwueme							171					171		177			171					170			
Maiduguri								93	104																
Sokoto								109	109		32	54	82	109	58	32	54	82	58	58	32	54	58	58	58
Borno													49	101			39	49	50	50		38	45	50	50
Zaria																36					36				
Enugu																					25				
Benue																								54	54
Total	293	423	593	646	650	342	523	630	650	650	374	569	649	650	476	401	601	650	650	650	425	615	650	650	650

Table 4. The number of LGAs within the different drive time from the optimal NCDCMLs.

Minutes	Base	1 Facility	2 Facilities	3 Facilities	4 Facilities	5 Facilities
120	172	293 (70.35%)	342 (98.84%)	374 (117.44%)	401 (133.14%)	425 (147.09%)
240	277	423 (52.71%)	523 (88.81%)	569 (105.42%)	601 (116.97%)	615 (122.02%)
360	494	593 (20.04%)	630 (27.53%)	649 (31.38%)	650 (31.58%)	650 (31.58%)
480	589	646 (9.68%)	650 (10.36%)	650 (10.36)	650 (10.36)	650 (10.36)
600	635	650 (2.36%)	650 (2.36%)	650 (2.36%)	650 (2.36%)	650 (2.36%)

nearest NCDCML. The addition of these two UTRHs to the existing five NCDCMLs will increase the number of COVID-19 testing centers to seven. These two UTRHs will ensure that a total of 342 LGAs are within 2 hr drive time from at least one testing center. Thus, 44.19% of LGAs in Nigeria will be within 2 hr drive time from at least one COVID-19 testing center. By increasing the number of UTRHs from one to two, there is a 16.72% increase in the number of LGAs within 2 hr drive time from at least one COVID-19 testing center in Nigeria.

At 4 hr drive time threshold, the two most optimal UTRHs that should be equipped in addition to the existing five NCDCMLs are the Aminu Kano Teaching Hospital, Kano, and the Alex Ekwueme Federal University Teaching Hospital, Abakaliki, Ebonyi State. These two UTRHs will increase the number of LGAs within the 4 hr drive time to the nearest NCDCML from the present 277 to 523 (88.81%) while increasing the percentage number of LGAs that will be covered by 23.64% within the 4 hr drive time. A total of 67.57% of the LGAs would be within 4 hr drive time using these two UTRHs.

University of Maiduguri Teaching Hospital, Maiduguri, Borno State and Usmanu Danfodiyo University Teaching Hospital, Sokoto, Sokoto State are the two most optimal UTRHs that should be equipped for COVID-19 testing to ensure that maximum number of LGAs are within the 6 hr drive time from the nearest NCDCMLs. The two UTRHs will increase the number of LGAs within 6 hr drive time to the nearest test center from the present 494 to 630 (27.53%). There will also be a 6.24% increase in the number of LGAs within the 6 hr drive time from what it was with just one additional single UTRH at this distance. The Jos University Teaching Hospital, Jos, Plateau State which was the most optimal when only one facility was identified did not feature when two new optimal UTRHs were identified. Two entirely new optimal UTRHs were identified. Therefore, the identified optimal facility can change with the drive time used. The two UTRHs identified as optimal using a 6 hr drive time are still the most optimal at 8 hr drive time. These UTRHs will ensure that maximum number of LGAs are within the 8 hr drive time from the nearest testing center. The number of LGAs within 8 hr drive time will increase from the present 589 to 650 LGAs (10.36%) and the percentage of LGAs within this drive time will also increase by 0.62% with the addition of two UTRHs at this distance threshold.

The Abia State University Teaching Hospital and the Aminu Kano University Teaching Hospital, which were the most optimal at the 2 hr drive time are also the most optimal at 10 hr drive time. These two UTRHs will ensure that 431 LGAs are within 10 hr drive time to the nearest NCDCML testing centers. Thus, out of the combined 650 LGAs that both existing and new facilities will ensure are within 10 hr drive time, 66.31% would be accounted for by these two UTRHs. It should be noted that the total number of LGAs that will be served is the same at 8 hr and 10 hr drive time to the nearest COVID-19 testing centers.

3.4.3. *Additional three UTRHs facility with 2, 4, 6, 8, and 10 hr drivetime*

The addition of three UTRHs to the existing NCDCMLs to increase the number of LGAs that are within the 2 hr drive time to the COVID-19 testing facility will involve equipping the Abia State University Teaching Hospital, the Aminu Kano University Teaching Hospital and the Usmanu Danfodiyo University Teaching Hospital, Sokoto with appropriate equipment. However, to ensure that largest number of LGAs are covered within a4 hr drive time, the three UTRHs that will

optimize the coverage of LGAs are the Aminu Kano Teaching Hospital, Kano State, Alex Ekwueme Federal University Teaching Hospital, Abakaliki, Ebonyi State, and the Usmanu Danfodiyo University Teaching Hospital, Sokoto while Jos University Teaching Hospital, Usmanu Danfodiyo University Teaching Hospital and University of Maiduguri Teaching Hospital, will be ideal at a maximum drive time of 6 hr. The existing NCDCML will serve 365 LGAs, the three UTRHs will serve 284 LGAs. At 8 hr drive time to the nearest NCDCML, the Alex Ekwueme Federal University Teaching Hospital, Abakaliki, Ebonyi State, Usmanu Danfodiyo University Teaching Hospital, Sokoto State, and University of Maiduguri Teaching Hospital, Maiduguri are the most optimal. These three UTRHs will ensure that 387 LGAs are within the 8 hr while the existing NCDCMLs will be within 8 hr drive time to 263 LGAs. At a maximum drive time of 10 hr, the Abia State University Teaching Hospital, the Aminu Kano University Teaching Hospital and the Usmanu Danfodiyo University Teaching Hospital, Sokoto State would be the most optimal. The additional of these three UTRHs to the existing network of NCDCMLs will ensure that 650 LGAs are within 10 hr drive time from at least one COVID-19 tests center. Of the 650 LGAs that can be covered by these three UTRHs and five NCDCMLs, 435 LGAs will be within the drive time of 10 hr from the three UTRHs while the NCDCMLs will serve the remaining 215 LGAs.

3.4.4. Additional four UTRHs facility with 2, 4, 6, 8, and 10 hr drivetime

The addition of these four optimally identified UTRHs (the Abia State University Teaching Hospital, the Aminu Kano University Teaching Hospital, the Usmanu Danfodiyo University Teaching Hospital, Sokoto State, and the Ahmadu Bello University Teaching Hospital, Zaria, Kaduna State) to the existing network of NCDCMLs will ensure that a total of 401 out of the 774 (51.81%) LGAs are within a drive time of 2 hr from the nearest COVID-19 test facility. These four UTRHs will be within a 2 hr drive time to 229 LGAs while the remaining 172 LGAs will be served by the existing NCDCMLs. At a maximum of 4 hr drive time to the nearest COVID-19 test facility, the four optimal UTRHs identified are the Aminu Kano University Teaching Hospital, the Alex Ekwueme Federal University Teaching Hospital, Abakaliki, Ebonyi State, the Usmanu Danfodiyo University Teaching Hospital, Sokoto State, and Ahmadu Bello University Teaching Hospital, Zaria, Kaduna State. The existing NCDCMLs would be within a 4 hr drive time from 208 (34.60%) LGAs, while the four added UTRHs will be within a4 hrdrive time from 393 (65.40%) LGAs. There was a 5.63% increase in the number of LGAs within the 4 hr drive by increasing the number of UTRHs within 4 hr drive time from three to four. At a maximum drive time of 6 hr, the four UTRHs that maximize the number of LGAs within this drive time are the Abia State University Teaching Hospital, Jos University Teaching Hospital, Jos, Usmanu Danfodiyo University Teaching Hospital, Sokoto and the University of Maiduguri Teaching Hospital, Maiduguri, Borno state. These four hospitals will ensure that additional 441 LGAs are within 6 hr drive time from at least one COVID-19 test center, while the existing NCDCMLs will be within 6 hr drive time of 209 LGAs. There was a 31.57% increase in the percentage of LGAs that are within 6 hr drive time from at least one test center with the addition on these 4 UTRHs. The increase from 3 to 4 UTRHs at 6 hr drive time will increase the number of LGAs covered by 0.15%.

At8 hr drive time, the four UTRHs that will maximize the number of LGAs served are the Abia State University Teaching Hospital, the Aminu Kano University Teaching Hospital, Usmanu Danfodiyo University Teaching Hospital, Sokoto State, and the University of Maiduguri Teaching Hospital, Maiduguri, Borno state. These UTRHs will increase the numbers of LGAs within the 8 hr drive time from 589 to 650 (10.36%). However, the increase in the number of UTRHs from 3 to 4 at 8 hr drive time will not increase the number of LGAs covered. Also, at 10 hr maximum drive time from the nearest test centers, the four UTRHs that should be added are the Abia State University Teaching Hospital, the Aminu Kano University Teaching Hospital, Usmanu Danfodiyo University Teaching Hospital, Sokoto and University of Maiduguri Teaching Hospital, Maiduguri, Borno state. These UTRHs were the same for 8 hr drive time. It should be noted that

increasing the number of UTRHs from four to five will not increase the number of LGAs served at either 8 and 10 hrdrive time.

3.4.5. Additional five UTRHs facility with 2, 4, 6, 8, and 10 hr drivetime

To ensure that the maximum numbers of LGAs are within the 2 hr drive time from at least one COVID-19 test center, the five optimal UTRHs identified are the Abia State University Teaching Hospital, the Aminu Kano University Teaching Hospital, the Usmanu Danfodiyo University Teaching Hospital, Sokoto State, the Ahmadu Bello University Teaching Hospital, Zaria, Kaduna State and the Enugu State University Teaching Hospital, Enugu State (Table 4). Equipping these five UTRHs with requisite COVID-19 test kits will increase the number of LGAs within the 2 hr drive time from the present 172 to 425 (147.09%), while there will be a 5.99% increase in the number of LGAs that are within the2 hr drive time by using the five identified optimal UTRHs instead of four at the same distance threshold.

At 4 hr maximum drive time to the nearest COVID-19 testing center, the five UTRHs identified are the Aminu Kano University Teaching Hospital, Kano State, the Jos University Teaching Hospital, Jos, Plateau State, the Alex Ekwueme Federal University Teaching Hospital, Abakaliki, Ebonyi State, the Usmanu Danfodiyo University Teaching Hospital, Sokoto, Sokoto State, and the University of Maiduguri Teaching Hospital, Maiduguri, Borno State. The number of LGAs within4 hr drive time to the nearest COVID-19 test center will increase from the present 277 to 615 (122.02%). By increasing from four to five UTRHs, the percentage of LGAs that are within a drive time of4 hrincreased by 2.33%. The existing NCDCMLs will be within a drive time of 4 hr to 204 LGAs, while the five newly identified UTRHs would be within a 4-hr drive time from 411 LGAs. Thus, the existing NCDCMLs and the five newly identified UTRHs will be serving 615 LGAs within a distance of 4 hr drive time to the nearest COVID-19 test center. At a 6 hr maximum drive time, the Abia State University Teaching Hospital, the Aminu Kano University Teaching Hospital, the Jos University Teaching Hospital, Jos, the Usmanu Danfodiyo University Teaching Hospital, Sokoto and the University of Maiduguri Teaching Hospital, Maiduguri, Borno State are the UTRHs that will optimize the number of LGAs served. These five UTRHs will increase the number of LGAs within the 6 hr drive time from the present 494 to 650 (31.58%). However, there is no change in the number of LGAs served by increasing the number of UTRHs from four to five at this distance threshold. At a maximum drive time of 8 and 10 hr, the same UTRHs will optimize the number of LGAs covered. These UTRHs are the Abia State University Teaching Hospital, the Aminu Kano University Teaching Hospital, the Usmanu Danfodiyo University Teaching Hospital, Sokoto, University of Maiduguri Teaching Hospital, Maiduguri, Borno state and Benue State University, Markurdi, Benue State. These UTRHs will increase the number of LGAs within the 8 hr drive time to the nearest COVID-19 test facility from the present 589 to 650 (10.36%) LGAs, while at 10 hr they would increase it from the present 635 to 650 (2.36%). Despite the increase in the number of LGAs that will be within the 8 and 10 hr drive time from the nearest COVID-19 test center; nevertheless, there is no increase in the number of LGAs within the 8 and 10 hrdrive time by increasing the UTRHs from four to five.

3.5. Comparative analysis of the new proposed site and the chosen optimal sites

Following the outbreak of COVID-19 in Nigeria, and the outcry against the uneven distribution of the NCDCMLs, the NCDC indicated its intention to scale up its operation by establishing additional NCDCMLs in seven additional states in Nigeria. The identified states are Sokoto, Borno (Maiduguri), Kano, Kaduna, Plateau (Jos), Ebonyi and Rivers (Port Harcourt). The rationale for the choice of the States and the numbers of the NCDCMLs are not detailed anywhere. It is therefore imperative to understand the number of LGAs that will be served by these seven proposed NCDCMLs. The seven additional UTRHs that will optimize the LGAs coverage at a different drive time were identified and thereafter, identified the seven UTRHs that featured across the

period. The hourly drive time increment was explored until no new LGA was added to the existing LGAs coverage identified. Generally, of the 36 UTRHs, 14 were considered optimal at the different drive times considered. The addition of seven optimally selected UTRHs to the existing NCDCMLs will ensure that 251 (32.43%) LGAs will be within a 1 hr drive time of the COVID-19 testing facility. The existing NCDCMLs will be within a 1 hr drive time from 76 LGAs while the remaining 175 will be within 1 r drive time to the identified UTRHs. The NCDCML at the African Center of Excellence for Genomics of Infectious Disease will have 44 LGAs within its 1 hr drive time followed by the Nnamdi Azikwe University Teaching Hospital with 42 LGAs within its 1 hr drive time. At 2-hr drive time, some of the UTRHs (Nnamdi Azikwe University Teaching Hospital, Alex Ekwueme Federal University Teaching Hospital, Abakaliki, Ebonyi State, Federal Medical Center, Abeokuta, Ogun State, and Federal Teaching Hospital, Ido-Ekiti, Ekiti State) that were optimal at 1 hr were no longer optimal. The identified seven optimal UTRHs will ensure that 457 LGAs will be within 2 hr drive time from at least one NCDCML. A total of 582, 619, 641, and 650 LGAs will be within the 3, 4, 5 and 6 hr, drive time, respectively, to the nearest COVID-19 test facility.

Since there is no official information on the maximum distance threshold that should be traveled to access COVID-19 testing facilities, a simple frequency, based on the number of times that each UTRH was optimal over the drive times considered was used to identify the most reoccurring UTRHs that should be equipped for COVID-19 test in Nigeria (Table 5). Thus, Usmanu Danfodiyo University Teaching Hospital, Sokoto, Aminu Kano Teaching Hospital, Kano, University of Maiduguri Teaching Hospital, Maiduguri, University of Uyo Teaching Hospital Akwa-Ibom State, Abia State University Teaching Hospital, Uturu, Benue State University, Markurdi and Jos University Teaching Hospital, Jos are the most optimal UTRHs that should be equipped with the appropriate COVID-19 testing equipment for easy accessibility by the populace. Four of these optimal UTRHs are in tandem with the proposed COVID-19 testing facilities by the NCDC. Based on this, the proposed site in Kaduna should be relocated to Benue, Ebonyi should be moved to Abia State, while the proposed site in Port Harcourt should be relocated to Akwa Ibom States.

3.6. Discussion and conclusion

The incorporation of the MCLP methods into the health-care facility planning most especially, during an emergency, such as the COVID-19 will enhance the government response and cut down

Table 5. Number of LGAs that can be covered with additional seven new NCDCML in Nigeria.

	Drive Time						
NCDCML and UTRHs Facility	1hr	2hrs	3hrs	4hrs	5hrs	6hrs	No of Times
Nigeria Center For Disease Control (NCDC) Laboratory, Abuja	8	17	25	13	35	35	6
Irrua Specialist Teaching Hospital, Irrua Edo State	14	39	44	44	44	44	6
Virology Laboratory at the Lagos University Teaching Hospital (LUTH)	10	23	25	25	25	25	6
African Center of Excellence for Genomics of Infectious Disease	44	93	102	103	105	105	6
Usmanu Danfodiyo University Teaching Hospital, Sokoto	10	32	46	54	57	58	6
Aminu Kano Teaching Hospital, Kano	16	40	73	113	113	113	6
University of Maiduguri Teaching Hospital, Maiduguri	-	19	29	38	43	45	5
University of Uyo Teaching Hospital Akwa-Ibom State	39	45	-	-	48	48	4
Abia State University Teaching Hospital, Uturu	-	88	142	-	94	94	4
Benue State University, Markurdi	-	25	32	-	37	38	4
Jos University Teaching Hospital, Jos	-	-	20	36	40	45	4
Alex Ekwueme Federal University Teaching Hospital, Abakaliki, Ebonyi State	22	-	-	72	-	-	2
Ahmadu Bello University Teaching Hospital, Zaria, Kaduna State	-	36	44	-	-	-	2
Nnamdi Azikwe University Teaching Hospital	42	-	-	-	-	-	1
Federal Medical Center, Abeokuta, Ogun State	22	-	-	-	-	-	1
Federal Teaching Hospital, Ido-Ekiti, Ekiti State	24	-	-	-	-	-	1
Imo State University Teaching Hospital, Orlu, Imo State	-	-	-	101	-	-	1
University of Abuja Teaching Hospital, Gwagwalada	-	-	-	20	-	-	1
Total	251	457	582	619	641	650	

expenditures. MCLP analysis has the potential to assist in redressing uneven allocation of health facilities such as that of NCDCMLs in Nigeria. The method and its variants have been found most suitable in the allocation of scarce resources to a large demand center. In a data-scarce country like Nigeria, the availability of freely available coordinates locations of both demand and supply nodes, which can be obtained freely from Google Earth websites can provide the necessary impetus for the utilization of the MCLP method. Freely available data from various sources were compiled in identifying the most optimal UTRHs for siting COVID-19 testing equipment to ensure effective coverage of LGAs in Nigeria. The analysis showed the uneven allocation of the existing NCDCMLs in favor of the southwest geopolitical zone at the expense of other geopolitical zones in the country. The existing NCDCMLs are unevenly distributed with the southwest geopolitical zone having the highest number, leaving the northeastern, northwestern and southeastern geopolitical zones without any NCDCML. Therefore, 33 of the 36 States do not have NCDCML. This may further discourage a large number of people from testing for COVID-19. According to the official population figures, Kano State is the most populous in Nigeria, yet there is no NCDCML in the State. Therefore, the allocation of the existing NCDCMLs in Nigeria may not have been in response to population figures. However, there is a relationship between the number of reported COVID-19 patients and the number of the testing facility. States with a testing facility tend to have a higher reported number of infected persons. Essentially, higher numbers of asymptomatic patients may be unwilling to go for a test due to unavailability of the testing facility within their reach. It is posited that the closer the COVID-19 testing facilities are to people, the more they are likely to go for test.

The use of existing UTRHs as sites for the COVID-19 testing facility is meant to reduce the cost and time of constructing new laboratories. The estimated time for the construction and equipping of such laboratories will likely not be less than 6 months from the day of commissioning such project. In the period of emergency, such luxury of time is not possible because of the high mortality always associated with it. Therefore, using existing UTRHs structures will significantly reduce the cost and time of constructing the COVID-19 laboratory test. Therefore, UTRHs are potentially good sites for siting the NCDCML. It should, however, be noted that not all the States in Nigeria have UTRHs but those without it can be served by States in their immediate vicinity. Thirteen states do not have UTRHs but can be served by adjourning States. Adamawa, Taraba and Gombe States in the northeastern geopolitical zone of the country are among states with the longest drive time to the nearest UTRHs.

A total of 650 (83.98%) LGAs can be effectively served by the available data. Some partsof the south-east and south-south geopolitical zones do not have adequate road network coverage, which could have excluded them from the allocation. Also, none coverage of all the 774 LGAs could have arisen as a result of the drive speed of 60 km/hr used. The 60 km/hr benchmark was used because of the poor quality of most roads, especially intracity roads as well as those roads connecting rural communities to large urban centers (Nwachukwu, 2014). Furthermore, it represents the average maximum drive speed on highways and vehicle traveling above this speed limit is susceptible to accident (Owoaje et al., 2005; Oyedepo & Makinde, 2010).These factors may have limited the number of LGAs within the drive times considered. It should also be noted that the use of actual roadnetwork as opposed to Euclidean distance might also have reduced the number of LGAs within the 60 km/hr drive time. Straight-line (Euclidean) distance is most often used because of the ease of its calculation; however, Boscoe et al. (2012) concluded that for nonemergency travel to hospitals, the added precision offered by the substitution of travel distance, travel time, or both for straight-line distance is largely inconsequential. Different UTRHs becomes optimal at the different drive time thresholds and depending on the number of UTRHs proposed. Furthermore, out of the five existing NCDCMLs, the Irrua Specialist Teaching Hospital, Irrua Edo State and the African Centre of Excellence for Genomics of Infectious Disease, Osun State have the largest number of LGAs within the various drive times considered. Consequently, the capacity of these NCDCMLs should be increased to cope with the large numbers of LGAs within their surroundings. Among the 10 most optimal UTRHs, identified at different drive time thresholds, the Aminu Kano Teaching Hospital,

Kano State, the Usmanu Danfodiyo University Teaching Hospital, Sokoto State, the Abia State University Teaching Hospital, Uturu, Abia State and the University of Maiduguri Teaching Hospital, Maiduguri, Borno State appeared to future as the four most optimal UTRHs with the largest number of LGAs within their various drive times. They, therefore, represent potential UTRHs that optimized travel time and can be equipped with COVID-19 testing kits.

Concerning the appropriate drive time threshold that should be adopted, it was noticed that with one additional UTRH, a maximum of 650 LGAs would be covered at 600 minutes (10 hr) drive time. The addition of either two or three optimal UTRHs will ensure that the 650 LGAs are reached at 480 minutes (8 h). However the addition of third optimal UTRH would ensure that 649 LGAs are within 6-hrdrive time from the nearest COVID-19 test facility compared to 630 LGAs with the addition of two additional UTRHs. With four UTRHs, the 650 LGAs will be covered at 6-hr drive time and the same thing obtained with the addition of five UTRHs. Thus, the addition of four facilities will achieve, what the addition of five will achieve. Even with the seven proposed NCDCMLs, it will still require about 6-hr drive time to reach all the LGAs. Therefore, rather than seven proposed additional new NCDCML, four optimally sited UTRHs will be adequate and there will be cost and time-saving.

Disclosure statement

No potential conflict of interest was reported by the author.

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