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Empirical Estimation of Driver Perception Reaction Time (PRT) Based on Distance-Speed Relationship

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Abstract

This research work was carried out to estimate a value of perception reaction time (PRT) for single carriageway roads in Nigeria. This is against the background of the assertion in the literature that different values of PRT exist for different countries in the world, and can thus be established for Nigeria. Data was obtained in a manner considered more direct than previous ways in the literature, in order to reflect a situation that caters for greater number of factors that affect driver behaviour on the road. The data collected was used in developing models relating vehicular space or distance headway to speed (as a variable that affects driver's PRT) data collected on the single carriageway roads selected. Results obtained show that a significant relationship is definable between driver PRT and vehicular speed and distance headway characteristics on the highways. The range of values of PRT obtained is 1.22 to 1.38 seconds and the overall average is 1.30 seconds. While the average PRT value is within the range of values in the literature, as hypothesized for a high accident fatality setting and hence high travel speed setting, the value is on the lower scale of the PRT in the literature. The relatively low value of PRT obtained gives independent empirical credence to the upward review of stopping sight distance in the recently updated Highway Design Manual for Nigeria. Though the speed recorded here is in agreement with the recommendation of the new Highway Design Manual, it is here suggested that further works be done on roads in other areas of the country outside the areas selected for study in this work, to confirm or controvert the findings in this work regarding the perception-reaction time, which will serve as similar verification researches to provide more information for future updating of the Manual.

1.0 Introduction

One of the problems that face traffic and transportation engineers is accommodating the varying skills and perceptual abilities of the driver on a highway in the design of the highways. This could be due to the wide range of people's abilities to hear, see, evaluate, and react to stimuli. Studies have shown that these abilities may also vary in an individual under different conditions, such as influence of alcohol (or drugs), fatigue, and time of the day [1].

Under normal conditions, for instance, in a vehicle accident, it is usually needed to determine the available PRT for a particular driver before one can decide if that driver had the opportunity to avoid the accident. In some cases, an object appears so quickly that there is not enough time to avoid it. In other cases, a driver may be inattentive and not react to the object, even though there was ample time to avoid the accident. Therefore, it is important that perception reaction time selected for design purposes should, however, be large enough to include reaction times for most drivers using the highways. Recommendations made by the American Association of State Highway and Transportation Officials, AASHTO [2] stipulate 2.5 seconds for stopping sight distances, which is said to encompass the decision times for 90 per cent of drivers under most highway conditions. Sohn and Stepleman [3] stated that the major reaction time variable is dependent on the country where the reaction time took place.

In view of the aforementioned findings by various researchers and the fact that work in this area does not seem to have been done in Nigeria, there is the need to engage in research in the area. This work is, therefore intended to estimate perception reaction time on single carriageway roads in Nigeria. This work is done through developing a model relating vehicular space headway to speed (as a variable that affects driver's response time) data collected on some single carriageway roads in Nigeria.

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The work was carried out on three intercity roads emanating from the city of Kano, in the northern part of Nigeria. Roads covered were; Kano-Maiduguri, Kano-Katsina, and Kano-Gwarzo Roads. These roads are shown in Fig. 1. The work concentrated on road links and not intersections. Of the many single carriageway roads that emanate from Kano, these ones are particularly in good condition and seem to carry more traffic in the general area. All data was collected during the day light period (7am to 6pm). Data was collected on traffic volume, vehicular space headway (derived from concentration study data), and time-mean speed (derived from spot speed study data).

2.0 Literature Review

Driver PRT has important consequences for both the design of safe roads for the assessment of liability in court. Although standard organizations have established norms, 2.5 seconds in the United States and 2.0 seconds in Europe [4], these values have sometimes been criticized [5,6]. Many researchers have, therefore, continued to seek a canonical PRT value and investigate the variables that affect it.

In view of the above, studies on estimation of human's PRT or elements considered in ascertaining one's PRT have been carried out by several researchers. One of these was that of Hooper and McGee [5] in which was postulated a model with such components (variables) for braking response time, as perception (latency, eye movement, fixation, and recognition) and initial brake application. Values of 1.50 seconds and 1.24 seconds were recorded for perception and brake application, respectively. Each of the elements they considered was derived from empirical data, and was on the 85th percentile estimate for that aspect of time lag. Based on the doubt that any driver would produce 85th percentile values for each of the individual elements, they stated that 1.5 seconds probably represents an upper limit for a driver's PRT, which is the estimate for the simplest kind of reaction time, with little or no decision making. The driver reacts to the stimulus by lifting his foot from the accelerator and placing it on the brake pedal.

Neuman [7] proposed a perception reaction time for different types of roadways, ranging from 1.5 seconds for low volume roadways to 3.0 seconds for urban highways, on the basis that there are more things happening, and more decisions to be made per unit time on a busy urban facility than on a rural country road. Neuman considered that those added factors increase perception reaction time.

In another work Triggs and Harris [8], studied some situations to assess the response of drivers to a range of static stimuli in which, the situations considered evolved as the study progressed. They found out that the response time depends greatly on the type of situation, the degree of urgency, and the speed of vehicle when the eliciting signal commences. They noted that the 85th percentile times to brake, obtained from several situations varied from 1.26 to 3.60 seconds. Triggs and Harris observed that the results from the investigation cast significant doubt on the appropriateness of the current standard. Hence, they suggested that revision of AASHTO's 2.5 seconds value appears to be warranted.

Triggs and Harris carried out another study to assess the effect of speed of vehicle on driver's response times. The results of the study showed that faster drivers had lower reaction times under otherwise similar conditions.

Khanna and Justo [9] stated that perception-reaction time varies from driver to driver and also depends on other several factors such as speed of the vehicle, distance of object, and other environmental conditions.

According to Dewer [10], there are diverse elements that one must consider when attempting to ascertain one's PRT. Among those he stated are; experience, familiarity with the road and the vehicle, and memory. In his critique of the PRT used in AASHTO design standards for "average" drivers of 1.5s for perception and 1.0s for reacting, Dewer cautions that PRT can increase 30 to 50% in unexpected situations. He also stated that PRT could increase with fatigue, alcohol consumption, age of the driver, and with the speed of the vehicle. The results of his study showed that a driver with average reflexes, eyesight, decisiveness, and sobriety, driving an average car at 60 mph will take almost 3.0 seconds to see and recognize a hazard, and almost 7.0 seconds to decide on a course of action, and almost 4.0 seconds to complete a maneuver.

Hooper and McGee [5] recommended different decision sight distance perception-reaction times for different design speeds. The range of recommended values is from 1.5 to 3.0 seconds. One interpretation of this recommendation is that 2.5 seconds for stopping sight distance situations is near the upper end of this range, and it is only in more complex decision situations, such as intersections and interchanges, that longer perception-reaction times are to be expected. However, there are researchers that obtained values lower than 1.5 seconds. The results of their works are presented in Table 1.

Table 1: Summary of surprise PRT

Study Condition	No. of Observations	Ages	Mean	Std. Dev.	Stimulus
Covert: Gazis et al. [11]	87	Mix	1.12 sec.	-	Unexpected Signal
Sivak et al. [12]	1644	Mix	1.21 sec.	0.63 sec.	Unexpected Signal
Wortman and Matthais [13]	839	Mix	1.30 sec.	0.60 sec.	Unexpected Signal
Chang et al. [14]	579	Mix	1.30 sec.	0.74 sec.	Unexpected Signal
Surprise:	**No. of Observations**	**Ages**	**Mean**	**Std. Dev.**	**Stimulus**
Oslon and Sivak [15]	49	Young	1.10 sec.	0.15 sec.	Unexpected Object
Oslon and Sivak [15]	15	Old	1.06 sec.	0.10 sec.	Unexpected Object
Sivak [16]	1644	Mix	1.21 sec.	0.63 sec.	Unexpected Object
Lerner et al. [17]	56	Mix	1.50 sec.	0.40 sec.	Light, Unexpected Object

Std. Dev. – Standard Deviation

The four studies under the "covert" category were carried out on drivers stopping at traffic signals who had no idea that they were test subjects. The consistency and large sizes associated with the four studies under this category suggest that these findings should be considered a good estimate of PRT for responding to a yellow traffic signal.

The four studies under the "surprise" category were carried out on drivers braking in response to unexpected objects or braking on the roadway. The study by Lerner et al. [17] is considered significant because they compared PRTs for older and younger drivers in stopping sight distance situations. Fifty-nine of 116 subjects reacted to an unexpected object by braking or a combination of braking and steering; the remainder reacted by steering only. For those who braked, the mean PRT was 1.5 sec with a standard deviation of 0.4 sec. The 85th percentile PRT was 1.9 sec, and the longest observed PRT was 2.54 sec. Importantly, there were no significant differences in PRT with respect to age. Although important for SSD situations, the result should not be interpreted to suggest that there is no age-related slowing for more complex driving situations [17].

The present work has not chosen any particular factor per se of those that are mentioned so far, but estimates PRT from the behaviour of traffic, which consists of all kinds of drivers and all manner of driver behaviour. It is therefore considered a very direct way of estimating PRT in any particular weather condition. This being so, it is expected that the results will describe the real situation in life.

3.0 Research Hypotheses

From the foregoing literature review, the major hypothesis put forth for testing in this work is that a PRT value is establishable for the Nigerian setting.

Also from the literature review, it was found that faster drivers have lower reaction time [8]. This implies that PRT value is speed related. Traffic accident being another speed related parameter and Nigeria being on the high side of traffic accident fatality in Africa, the second to South Africa [18], it is also hypothesized that low PRT values compared with those in the literature will be recorded in this work.

For the fact that PRT values for road links are expected to be on the lower side when compared with those in complex decision situations, such as intersections and interchanges [5], a subsidiary hypothesis can be drawn that low PRT values of the order of the average value of 1.15 sec obtained by Fambro et al. [19] are expected in this study.

4.0 Regression Model Formulation

Stopping sight distance (SSD) is the length of the highway visible to driver over which he is required to bring his vehicle to safe stop before reaching an object. It is considered from two perspectives namely: (i) driver and vehicle characteristics, and (ii) road geometrics. It is the first approach that relates to the present work and will be the one to pursue further.

With respect to the driver and vehicle characteristics, stopping sight distance is made up of (a) the distance traveled during the perception time, (b) the distance traveled during the brake reaction time and (c) the distance traveled during braking, i.e., after the application of brakes. These are represented in the SSD formula [20] as follows:

$$SSD = PV + \frac{V^2}{\{2g(f \pm i)\}} \qquad (1)$$

where

V = speed from which stop is made in meter per second

P = perception-reaction time in seconds

f = coefficient of friction (for wet pavement)

i = percent of grade divided by 100 (added for upgrade andsubtracted for down grade)

The first term (PV) is the distance traveled during the perception reaction time. The usual value for perception and brake reaction times are 1.5 and 1.0 seconds, respectively, in most road conditions encountered. The second term is the minimum braking distance where V is in m/s and g is the acceleration due to gravity, i.e., 9.807 m/s^2. The SSD is in metres.

The hypothesis implicit in the regression modeling is that driver perception-reaction time is significantly related to vehicular headway characteristics on the highway.

Where the SSD is the distance between the rear of a downstream vehicle and the front of an upstream vehicle, the headway is the distance between the front bumpers of the vehicles. If L is taken as the length of a vehicle, then the headway can be expressed as

$$H_d = L + PV + \frac{V^2}{\{2g(f \pm i)\}} \qquad (2)$$

On a level road, one with zero incline (i.e., i = 0), equation (2) becomes

$$H_d = L + PV + \frac{V^2}{2gf} \qquad (3)$$

Equation (3) can be written as

$$H = a + bV + cV^2 \qquad (4)$$

The constant a represents vehicle length, while the coefficients b and c represent the PRT and 1/2gf, respectively.

Thus H_d is regressed on V with the regression line passing through an intercept 'a' on the vertical axis. The intercept a represents the length of a vehicle. The value of P (the perception reaction time) is obtained from the coefficient of V(i.e., b).

As mentioned earlier, three roads were used for the study and each traffic direction considered separately. As a result, six models (two models per road, i.e., one per traffic direction) were developed. The models developed are to be evaluated for overall significance (F-test) at 0.05 level of significance.

5.0 Data Collection and Analyses

The study was carried out in two stages; field data collection, and data analysis and development of regression models. With regard to the field data collection, three types of traffic studies were conducted on each of the roads selected. These are; Road link volume study (to determine peak and off-peak periods), Concentration study (to determine average vehicular space headway), and Spot speed study (to determine time-mean speed). The data base for this work is Ibrahim [21].

The field studies were carried out in two phases. The first being the road link volume study and the second phase covered concentration and spot speed studies, which were carried out concurrently. Road link volume study was conducted to serve as a preliminary study in order to assess the nature of traffic volume of the roads, and more importantly to determine the peak and off-peak periods, which are of paramount importance in the second phase of the data collection. Two off-peak and peak hours for both morning and afternoon were determined for each road. These off-peak and peak periods were used for the concentration and spot speed studies.

As stated earlier data collection for the second phase of the study was conducted for off-peak and peak periods for both morning and afternoon. Data for morning off-peak period was collected between 7am – 9am while morning peak period was between 9am – 11am. Data for afternoon off-peak period was collected between 12pm – 2pm while the peak period was collected between 3pm – 5pm.

For the concentration study which is aimed at determining average vehicular space headway, ten observations were taken for each hour and the overall average of the observations recorded as the average space headway for that hour. While for the spot speed study the observation for each hour was made by random sampling. Time-mean speed is then determined from the spot speed data, which is the speed used for the regression model formulation. As mentioned in Transportation Research Board [22] time-mean speed is used in assessing uninterrupted flow, as exists on the road sections studied in this work.

Variables considered in the analysis are; the average space headway, H_d, (as the dependent variable), and time-mean speed, V, (as the independent variables). The resulting models from this analysis were evaluated for overall significance (F-test) at 0.05 level of significance (i.e., 95% level of confidence). The regression was run for each of the roads studied and a model was developed for each traffic direction. The data used for the analysis (i.e., values of H_d and V) is presented in Tables 2 to 4.

Table 2: Variables Used in the Regression Analysis for Kano-Maiduguri Road.

Traffic Direction		**Kano to Maiduguri**		**Maiduguri to Kano**	
Period and Variables		**H_d (m)**	**V(m/s)**	**H_d (m)**	**V (m/s)**
Morning	OPK1	48.88	16.88	50.02	17.15
	OPK2	47.66	16.57	47.40	16.43
	PK1	33.96	12.33	32.61	11.81
	PK2	32.07	11.63	37.31	13.38
Afternoon	OPK1	48.03	16.78	47.02	16.36
	OPK2	49.22	16.98	48.29	16.73
	PK1	35.34	12.75	34.32	12.39
	PK2	36.74	13.21	33.13	12.04

Table 3: Variables Used in the Regression Analysis for Kano-Katsina Road.

Traffic Direction		**Kano to Katsina**		**Katsina to Kano**	
Period and Variables		**H_d (m)**	**V (m/s)**	**H_d (m)**	**V (m/s)**
Morning	OPK1	52.34	17.52	53.49	17.82
	OPK2	50.23	16.93	53.66	17.86
	PK1	42.12	14.60	42.57	14.72
	PK2	40.72	14.17	44.09	15.18
Afternoon	OPK1	48.55	16.48	51.10	17.17
	OPK2	50.69	17.11	52.30	17.59
	PK1	38.36	13.43	45.16	15.49
	PK2	38.97	13.62	41.11	14.28

Table 4: Variables Used in the Regression Analysis for Kano-Gwarzo Road.

Traffic Direction		**Kano to Gwarzo**		**Gwarzo to Kano**	
Period and Variables		**H_d (m)**	**V (m/s)**	**H_d (m)**	**V (m/s)**
Morning	OPK1	49.59	16.66	51.48	17.04
	OPK2	51.04	17.04	49.88	16.65
	PK1	38.56	13.39	40.82	14.03
	PK2	39.36	13.75	39.94	13.79
Afternoon	OPK1	50.92	17.00	51.72	17.15
	OPK2	50.61	16.95	50.71	16.96
	PK1	39.31	13.64	41.42	14.22
	PK2	43.18	14.80	39.78	13.72

LEGEND: OPK1 = 1st Off-peak Period OPK2 = 2nd Off-peak Period
PK1 = 1st Peak Period PK2 = 2nd Peak Period

6.0 Results and Discussion

As stated earlier, a multiple linear regression was carried out relating average space headway, H_d, (as the dependent variable) and time-mean speed, V (as the independent variable).

From the regression analysis, the following models (presented in Table 5) were developed for the three roads studied (i.e., a model per traffic direction).

Table 5: Summary of Results of Models Estimation

Road	**Traffic Direction**	**Equation**	**R^2**	**F-ratio test**		
		$a + bV + cV^2$		**Degree of Freedom**	**F**	**F-Critical**
Kano – Maiduguri	KN-MDGR	$8.19 + 1.28V + 0.0666V^2$	0.9996	2,5	5624.63	5.79
	MDGR-KN	$8.42 + 1.22V + 0.0701V^2$	0.9999	2,5	19,046.56	5.79
Kano – Katsina	KN-KTN	$8.61 + 1.30V + 0.0681V^2$	0.9999	2,5	28,571.57	5.79
	KTN-KN	$8.84 + 1.29V + 0.0679V^2$	0.9995	2,5	5241.04	5.79
Kano - Gwarzo	KN-GWZ	$7.83 + 1.38V + 0.0678V^2$	0.9996	2,5	6094.04	5.79
	GWZ-KN	$8.60 + 1.31V + 0.0701V^2$	0.9994	2,5	4536.31	5.79

LEGEND:KN – KANO MDGR – MAIDUGURI KTN – KATSINA GWZ - GWARZO

The results in Table 5 show that all the models are significant at the 5 percent level at which the study was conducted. This is reflected in much higher values of the calculated variance ratio values, F compared with the critical variance ratio values, F-critical at 95 percent confidence level. In addition to this, the values of the coefficient of determination, R^2 are very high, ranging from 0.9994 to 0.9999.
The important parameters in Table 5 i.e. perception-reaction time, PRT and coefficient of friction, f between the vehicle tyre and the road surface are presented in Table 6 for discussion.

TABLE 6: Estimated PRT and f values from the models

Road	Traffic Direction	PRT	f
Kano – Maiduguri	Kano to Maiduguri	1.28	0.77
	Maiduguri to Kano	1.22	0.73
Kano – Katsina	Kano to Katsina	1.30	0.75
	Katsina to Kano	1.29	0.75
Kano - Gwarzo	Kano to Gwarzo	1.38	0.75
	Gwarzo to Kano	1.31	0.73

From the results presented in Table 6, it can be seen that there seem to be no significant differences between the estimated values of PRTs for all the routes studied. This is the same thing for the lengths of vehicles and the coefficient *c* (or *1/2gf*). These insignificant differences may be due to number of reasons, which include the following:

1. All the roads studied are single carriageway in nature and approximately of the same width.
2. The study was carried out in almost similar field conditions; i.e., same time of the day and same weather conditions.
3. The terrains of the roads are very similar (relatively flat).

The ranges of the average value of the directional (traffic direction) time-mean speeds and space headway are 14.54 m/s (52.34 Km/h) to 16.26 m/s (58.54 Km/h) and 41.26 m to 47.94 m, respectively. Also, the results obtained show that the overall average values of time-mean speeds for each road (for both directions) are 14.59 m/s (52.52 Km/h), 15.87 m/s (51.73 Km/h) and 15.43 m/s (55.53 Km/h) for Kano-Maiduguri Road, Kano-Katsina Road and Kano-Gwarzo Road, respectively.
Similarly, the overall average values of the space headways are 41.38 m, 46.60 m and 45.52 m for Kano-Maiduguri Road, Kano-Katsina Road and Kano-Gwarzo Road, respectively. For these averages, it can be seen that Kano-Maiduguri Road having the least average value of speed has the lowest average space headway which is as expected. As expected also Kano-Katsina Road, which is having the highest average value of speed, has the highest average value of space headway. These rhyme with the trend of the sum of the weekly average hourly traffic volume (pcu) obtained from traffic volume count (preliminary study). These sums are 3991, 2939 and 2732 vehicles for Kano-Maiduguri Road, Kano- Gwarzo Road and Kano-Katsina Road, respectively.
From the models developed the value of the coefficient of friction, *f*, ranged from 0.73 to 0.77 with an overall average of 0.75. The range obtained from this work is higher than the range of 0.06 to 0.12 in the literature, which is for wet pavement condition. The range of *f* value from this work is expected to be higher than the one in the literature because the data collected for this work was for dry condition and more friction is expected in dry condition than the wet one. However, the overall average value of 0.75 for *f* obtained from this work can be considered in order when compared with the nominal value of 0.65 stipulated by AASHTO [2] for dry pavement condition. The deviation of the value obtained from this work from the AASHTO's value may be due to difference in the several factors stated earlier as affecting the PRT value.
The estimated values of PRT range from 1.22 to 1.38 seconds. The overall average is 1.30 seconds. This overall average value is low when compared with the value of 2.50 seconds recommended by AASHTO [2] and those estimated by other researchers. This is as postulated in the subsidiary hypothesis and gives credence to this research effort especially when the 1.30 seconds is within the range of 1.26 to 3.6 seconds estimated by Triggs and Harris [8] from series of studies conducted to assess the response times of drivers to a range of unexpected static stimuli.
One implication of this relatively low value of PRT is that stopping sight distances for highway design in Nigeria may need to be reviewed upwards because of the associated high speeds. The 120km/hr recorded here is higher than the 100km/hr which has been the highest design speed for highway design in Nigeria.
However, this upward review has only recently been done as contained in the recently updated Highway Design Manual for Nigeria [23]. The upward review also includes design speed, the highest value of which is now 130km/hr. The result of this work therefore serves as local (Nigeria-specific) and independent empirical credence to this upward review of stopping sight distance and design speed for highway design in Nigeria, since the upward review (and other changes) in the new manual were made based on international best practices and not necessarily from local empirical evidence. This work provides impetus for further works as similar verification researches to confirm or controvert the changes that have been made in this new Highway Design Manual for Nigeria [23], in preparation for future updating. It is to be noted as mentioned earlier that data for this work was collected in 2007 i.e. as first reported in Ibrahim [21].

Though the speed recorded here is in agreement with the recommendation of the new Highway Manual for Nigeria, it is suggested here that further works be done on roads in other areas of the country to confirm or controvert the findings in this work regarding the perception-reaction time. It is to be noted that other works i.e. Dula Associates [24,25] that have also recorded 120km/hr speed were carried out on roads in the southern part of the country, and one of them actually traversed the full length of the coastal states running from CrossRiver state to Lagos state [24].

7.0 Conclusion

From the investigations carried out in this work, the following conclusions are drawn:

1. As hypothesized, a relationship is definable between driver perception-reaction-time and vehicular headway characteristics on Nigerian highways.
2. The average value of the estimated PRT ranged from 1.22 to 1.38 seconds, with the overall average being recorded as 1.30 seconds.
3. While the average PRT value of 1.30 seconds is within the range of values in the literature, as hypothesized for a high accident fatality setting and hence high travel speed setting, the value is on the lower scale of the PRT values in the literature. This implies the need for an upward review of stopping sight distance for highway design in Nigeria. This review having been done by the Federal Ministry of Works of Nigeria [23], the result of this work therefore serves as an independent empirical credence to this upward review of stopping sight distance for highway design in Nigeria. This work also provides impetus for further works as similar verification researches to confirm or controvert the changes that have been made in this new Highway Design Manual for Nigeria, in preparation for future updating.

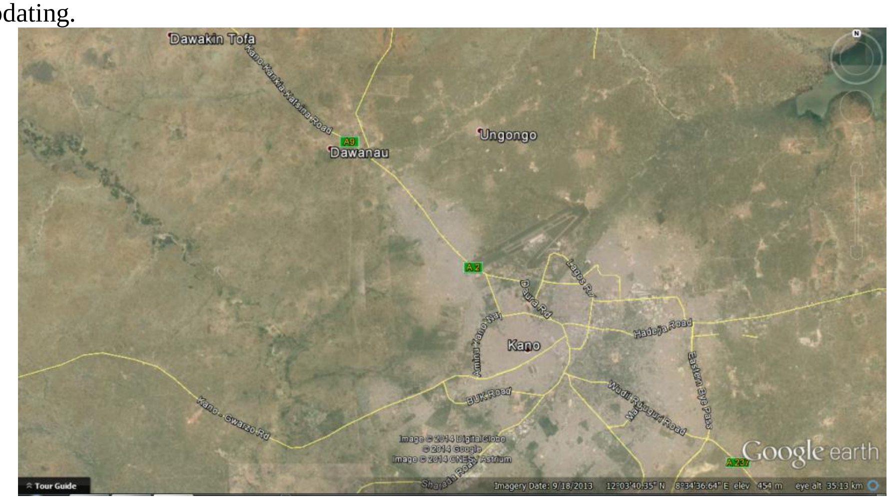

Fig 1: Map of the study roads in Nigeria (*source- Google Earth [26])*.

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