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Development of Regression Model on the Impact of Rainfall Intensity on Traffic Congestion in Port Harcourt City, Nigeria

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ABSTRACT

Severe weather (rainfall intensity) impacts significantly on transportation network. This research evaluates the impact of precipitation on vehicular congestion in the city of Port Harcourt, Nigeria. Traffic and rainfall data was obtained for the month of June, July and August, 2018 at Location Junction, Port Harcourt. The data was analysed in excel software to understand the trends and patterns, and the rainfall impacts on road traffic through traffic volume and vehicle speed. For the period under study, it was observed that during the month of June, average traffic volume due to rainfall was 2584, while in the month of July, the average traffic volume due to rainfall was 2177, and for the month of August, the average traffic volume was 1446. The gradual decrease in average traffic volume was obviously as a result of increase in rainfall during the study. It also shows that rainfall affects traffic speed as drivers tends to slow down during rainfall, and this was used to develop a regression model that could be used to forecast traffic congestion (with respect to speed) during rainfall condition in the city of Port Harcourt. This model was tested in MATLAB, and the result validated the data analysis which was carried out through statistical tool (excel) which shows that when rainfall intensity increases, traffic volume and traffic speed decrease.

Keywords: Excel Software, MATLAB, Rainfall intensity, Regression model, Traffic congestion.

1.0 INTRODUCTION

During the period from 1912 to 1914, the British colonial administration in Nigeria initiated the establishment of Port-Harcourt City. The geographical coordinates of the location in question are situated within the latitudinal range of 4 degrees 44 minutes 58.8 seconds to 4 degrees 56 minutes 4.6 seconds, and the longitudinal range of 6 degrees 52 minutes 7.2 seconds to 7 degrees 7 minutes 37.7 seconds, with respect to the equator. The geographical location in question is characterized by a relatively low elevation, situated at an altitude of 15.0 meters above mean sea level. Based on the research from [1], it can be observed that the municipality has abundant sunlight and maintains a temperature range of 25° to 28°. According to the data provided by Wikipedia in 2018, the Port Harcourt urban area experienced a notable population growth from an estimated figure of 1,382,592 in 2006 to around 1,865,000 in 2016[2]. The presence of atypical topography in this particular area presents significant obstacles to the progress of road infrastructure. Port Harcourt is characterized by a very little increase in elevation, measuring less than 15.24m. The city is predominantly situated on a coastal plain that is geologically connected to the sedimentary accumulation of the Niger Delta, which is the most recent deposit in the region. The drainage conditions within the research region are characterized by limited effectiveness due to the abundance of bodies of surface water and a high annual precipitation of 2500mm per year [3]. Port Harcourt has a humid semi hot equatorial climate. The temperature is moderately high and would have been higher if not for her closeness to Atlantic Ocean. The mean temperature is about 28o Centigrade. The average relative humidity is approximately 85%; but, during the wet months, particularly in July, August, and September, it exceeded 95%. During the period of low precipitation, particularly in the months of December and January, the relative humidity reaches approximately 80%. Typically, precipitation is observed during the majority of months in accordance with the average data. Nevertheless, there are occasional months within a limited timeframe where precipitation is absent. The average yearly precipitation amounts to approximately 2500mm annually. The rainy season commences in March and concludes in October, with occasional moderate rainfall occurring in the months of February and November, which are often characterized by drier conditions.

Port Harcourt is widely recognized as the primary economic center of Nigeria and plays a significant role in the country's GDP owing to its enormous reserves of oil in the region. The road network serves as the fundamental infrastructure of each urban area. The efficacy and expansion of a city are contingent upon the performance of its road network. Nigeria, particularly the city of Port Harcourt, has been encountering challenges in terms of road performance in recent times. There are several factors contributing to this phenomenon, including population growth, frequent vehicular mobility, and inadequate road infrastructure. However, in the context of urbanized cities, there exists an additional issue that contributes to the subpar performance of roads, namely the inadequate drainage system observed in the instance of Port Harcourt city. The inadequate drainage infrastructure is the primary cause of the flooding incidents occurring within the urban area. During periods of precipitation, particularly in the rainy season, a significant segment of the road is consistently inundated by floodwaters. The occurrence of flooding on roadways presents numerous challenges that disrupt the smooth movement of cars. Following a rainfall event, the occurrence of traffic congestion becomes more noticeable on the main thoroughfares and secondary roads inside the urban area of Port Harcourt.

During precipitation events, drivers typically exhibit a tendency to refrain from accelerating at high rates, opting instead to maintain lower speeds and exercise greater caution while driving. The relationship between acceleration and speed plays a significant role in determining the capability of the highway system. The reduction in road capacity due to rainfall leads to the formation of extended queues. Furthermore, as a result of inadequate drainage infrastructure, there is a buildup of water that inundates significant sections of the road network. The inundation effectively obstructs the roadway, leading to a near-total reduction in the capacity of the affected road segment. This phenomenon leads to an increase in the duration of travel, accompanied by a reduction in the capacity of the road network.

The management of drainage and transportation are perennially significant concerns within metropolitan environments. Port Harcourt city is currently seeing significant challenges in effectively managing drainage systems and traffic flow. Although, a great job has been done by government in constructing flyovers which has helped a little in tackling traffic congestion, but a lot still need to be done to further alleviate the sufferings of the road users. The inadequate management of drains and traffic leads to the unfortunate consequences of rains. The observed outcome can be attributed to inadequate urban planning. The matter at hand necessitates appropriate attention, particularly within urban settings, as urbanized regions serve as the central focal point for planning, development, and administration of drainage system and traffic congestion for the wellbeing of the dwellers. In order to mitigate the aforementioned challenges, it would be beneficial to conduct a research study that employs a data-driven approach to examine the influence of rainfall on traffic congestion.

The objective of this study is to develop a regression model that examines the relationship between rainfall and traffic speed in Port Harcourt which are listed as;

1. To study the traffic and rainfall data, and evaluate their patterns.
2. To model vehicle speed and rainfall data using regression model
3. Simulate the system in MATLAB to see how rainfall affect traffic
4. Validate the model using R-Squared method.

However, there has been an increasing focus on examining the effects of inclement weather on vehicular mobility. Several research studies have been undertaken to examine the influence of adverse climate conditions on the traffic flow of two highways located in the territory of Florida [4]. The influence of meteorological conditions on the level of traffic, particularly the daily influx of cars at a certain site, is a subject of considerable importance for travel demand analysts. The research undertaken by [5] examined the effects of rain and snow on different traffic flow variables, such as free-flow speed, capability, and speed. The free-flow speed, capacities, and speed at capacity saw declines that varied from 6% to 9%, 10% to 11%, and 8% to 14%, respectively, across varying levels of precipitation severity. Moreover, the authors have introduced novel weather-adjustment criteria to incorporate unfavorable weather conditions. In their study, [6] devised a thorough evaluation approach to assess the impact of precipitation on traffic patterns across different scales, namely microscopic, mesoscopic, and macroscopic. The researchers noted a reduction in capacity from 21% to 18.5% and a drop in free-flow frequency from 12.6% to 8% across varying degrees of rainfall intensity, as indicated by their analysis of the macroscopic basic diagram. Nevertheless, it was observed that the density of traffic congestion remained unaltered, which is consistent with prior research. [7], carried out a study to investigate the impacts of meteorological conditions, surface characteristics, and the presence of heavy vehicles on the associations between speed, flow, and density on urban roadways. The researchers observed a decline in capacity of roughly 7-8% and a reduction in vehicle speed by approximately 8-12% under rainy weather conditions. The study done by [8] investigated the influence of precipitation on the capacity of a single-lane roadway under three separate wet and dry conditions. The objective of the study undertaken by [9], was to evaluate the relationship between snowfall and temperature on two separate classifications of vehicle traffic, afterwards analyzing their implications on highway traffic. [10] reports showed that inclement weather has the capacity to impede and modify travel arrangements. The primary behavioral adaptations that were commonly noticed encompassed changes in transportation mode, adjustments in departure schedules, and departures from the customary route. [11] introduced two methodologies, namely the product restriction and weighted mean harmonic techniques, for evaluating the urban highway's capacity as well as free-flow speed during adverse weather conditions, such as snow or rain. The researchers made a significant finding indicating that the presence of precipitation, in the form of rain and snow, had an adverse impact on the overall capacity of urban roadways and the ability of traffic to flow smoothly and without hindrance. The objective of the research undertaken by [12] was to evaluate the influence of precipitation on traffic conditions, with a particular focus on a specific expressway in Hainan. According to existing research, it has been found that severe weather conditions possess the capability to influence multiple facets of road operation, including capacity, volume, speed, and duration. However, it is important to acknowledge that a significant proportion of research examining the influence of weather conditions on urban capacity and flow of highways has been conducted by developed countries [13]. The study revealed that different levels of rainfall, namely trace, light, and heavy, were associated with a decrease in capacity ranging from around 1% to 3%, 5% to 10%, and 10% to 17% correspondingly. The results of this study align with the recommendations specified in the Highway Capacity Manual (HCM). In a distinct inquiry carried out by [14], it was found that the occurrence of precipitation led to a reduction in capacity by 25%. [15] conducted a study with the objective of evaluating the influence of several meteorological variables, such as visibility, temperature, precipitation, and wind speed, on the hourly traffic volumes recorded on the roadways in Buffalo, New York. The weather and traffic statistics were altered with the intention of producing scenarios that accurately depict both typical and unfavorable weather circumstances. Through the process of conducting a comparative analysis between the base case and a scenario characterized by severe weather conditions, the moment at which the most significant reduction in volume occurs was found. The study findings indicate a significant reduction in traffic volume during adverse weather conditions in comparison to dry weather, namely during the high-traffic periods of 7:00 am to 9:00 am and 3:00 pm to 5:00 pm. The findings of the analysis indicated a notable reduction in volume observed during the hours of highest demand, resulting in a decline of 34%. The study revealed that the influence of wind speed and temperature on hourly traffic volume was negligible, however visibility emerged as the predominant determinant. [16] incorporated lane features and temporal parameters, including traffic month, day, and hour, into his regression equation to examine their influence on both operating speed and road capacity. The presence of precipitation led to a decline in operating efficiency and a fall in the capacity of roads. The study revealed that precipitation emerged as the principal determinant in the mitigation of traffic congestion. [17] executed a study with the objective of investigating the impact of meteorological conditions on various traffic metrics. These metrics included traffic frequency, in both directions traffic, as well as traffic counts at four specific locations. The Flemish Traffic Control Center assessed the degree of traffic intensity by utilizing minute-level data acquired from inductive loop detectors. The weather-related incidents were gathered by the Belgian Royal Meteorological Institute. The study employed a linear regression model to ascertain and quantify the effects of climatic variables. The presence of precipitation, rainfall, and wind speed has been observed to reduce the intensity of traffic, whereas maximum temperature has been found to have a notable effect on increasing traffic intensity.

The primary objective of the study done by researchers was to analyze the influence of environmental conditions on the free flow speed. This research examines the effects of the interstate highway system on various dimensions, as outlined by [18]. The study investigated various parameters, including road conditions, wind speed, and visibility. In instances of inclement weather, such as reduced visibility, there was a decrease in the speed of cars. The phenomenon under consideration is attributed to reduced visibility caused by the presence of significant precipitation in the form of rain and/or snow. [19] conducted a study that provides empirical support for the notion that non-recurring congestion caused by rainfall leads to a substantial delay of approximately 1.8 million vehicle-hours per year on motorways in Korea. Upon further analysis, it was shown that there exists a positive association between the length and strength of precipitation and the amount of time delay encountered per unit of distance traveled. The study suggests that it is advisable to impose limitations on the reduction of vehicle speeds when precipitation is present. [20] discovered that the existence of wetness on pavement surfaces led to a decrease in vehicle speed. The present study suggests prioritizing the evaluation of weather-induced impacts on road infrastructure in areas that experience consistently unfavorable weather conditions for the majority of the year. Through empirical tests, it has been discovered that severe weather conditions, particularly precipitation in the form of rain, have a negative impact on the flow of vehicles. This leads to an increase in delays and the formation of lines, hence reducing the capacity of roadways. The research conducted by [21] examined the impact of winter weather conditions on traffic patterns in two urban areas over a period of two years. [22] reported a decrease in traffic flow during seasons characterized by intense snowfall and rainfall. [23] conducted a study to examine the performance of 15 motorway traffic counters situated in Milwaukee, Wisconsin, during inclement weather conditions. The aforementioned studies together investigate the influence of precipitation on traffic conditions. [24] have observed that Nigeria has a restricted corpus of research pertaining to weather and road traffic studies, which stands in stark contrast to the substantial research undertaken in industrialized nations, as emphasized by [25].

This investigation collected meteorological and traffic data from multiple intersections and constructed a theoretical framework to clarify the influence of weather conditions, particularly rainfall, on traffic congestion.

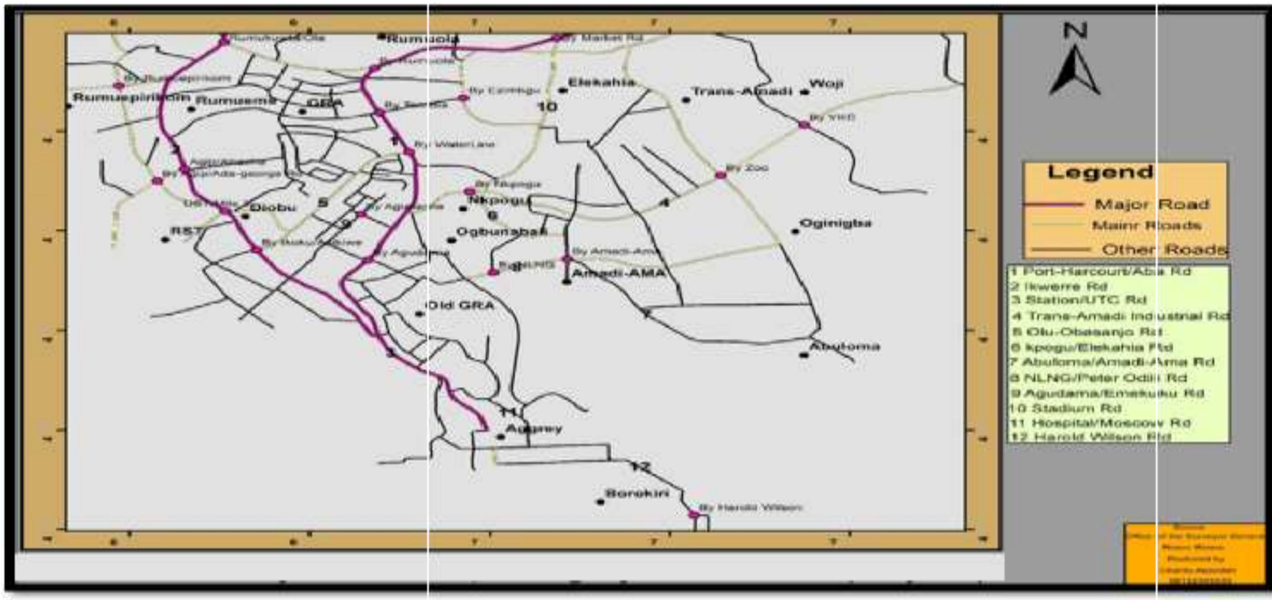

Figure 1 displays a street map of Port Harcourt, illustrating the various study routes. According to the National Research Development Agency (2016).

3. MATERIALS AND METHODS

3.1.1 MATERIALS

1. Radar Speed Gun
2. MATLAB Software
3. Excel Software

3.1.2 METHODS

A volumetric survey was conducted on the traffic at Location Junction, Port Harcourt. An annual traffic data was obtained from Federal Road Safety Corps, Rivers State Command after her traffic count conducted during the 2018 end of year Special Patrol. Also, manual count was applied from 7am to 7pm on a daily basis, it is necessary to determine the magnitude of traffic flow, as well as the fluctuations in vehicle density on an hourly basis from June, July and August, 2018.

Table 1 presents one-week manual traffic count as was done for three months period.

Table1; One-week hourly traffic count at Location Junction, Port Harcourt, 2018

TIME(HR)	MONDAY 18/06/2018	TUESDAY 19/06/2018	WEDNESDAY 20/06/2018	THURSDAY 21/06/2018	FRIDAY 22/06/2018	SATURDAY 23/06/2018	SUNDAY 24/06/2018	TOTAL VOLUME
7-8 am	3591	4566	4076	3620	2399	6792	2132	**27176**
8-9am	5742	6247	7217	6742	5760	5418	3321	**40447**
9-10am	7348	7831	9319	7349	7349	4088	4611	**47895**
10-11am	6462	5664	7292	5770	6663	3412	3120	**38383**
11-12noon	4889	4831	6242	6024	7812	2788	2100	**34686**
12-1pm	4282	3143	3441	4018	4182	2016	1120	**22202**
1-2pm	3124	1894	1500	2899	3688	1347	918	**15370**
2-3pm	1174	3440	1638	1204	1175	3557	126	**12314**
3-4pm	1626	2532	1847	1328	1626	3632	2704	**15295**
4-5pm	2814	3342	2378	2118	2641	2330	3256	**18879**
5-6pm	3629	4418	3199	3630	4623	4017	4698	**28214**
6-7pm	5247	5627	6231	5427	6318	5324	5496	**39670**
.UME FOR 12 DAY	**49928**	**53535**	**54380**	**50129**	**54236**	**44721**	**33602**	
RAGE	**4161**	**4461**	**4532**	**4177**	**4520**	**3727**	**2800**	

The traffic count commenced at 7 a.m. on June 18th, 2018. Hourly tallies were conducted over a span of twelve hours per day till the date of June 24, 2018. In addition, weather data were collected in order to monitor the impact of varying levels of rainfall on traffic patterns. The city of Port Harcourt experiences the highest amount of precipitation throughout the months of July, August, and September every year. The measurement of dry, light, medium, and heavy rain can be expressed in either inches or millimeters. The present study gathered precipitation data spanning the months of June through August in the year 2018. In order to ascertain the impact of precipitation on traffic congestion, the study employed a radar speed gun and human count to track the average speed of vehicles. A measurement of zero inches per hour signifies the absence of precipitation. On June 21, 2018, a total of 4177 vehicles were observed, under weather conditions devoid of precipitation. On June 9, 2018, a total of 5464 vehicles were observed to have seen a precipitation level of 0.1 inches. On June 2, 2018, a total of 1830 cars traversed a road surface that had a precipitation level of 0.3 inches, characterized as moderate rain. On June 20, 2018, a total of 195 vehicles were observed, coinciding with a precipitation level of 2.8 inches. The precipitation intensity of heavy rain exceeds 0.5 inches per hour. The low traffic volume is obviously as a result of heavy rainfall. In this research, it should be noted that hazardous rainfall intensities are not considered and can be assumed to be unsafe for traveling vehicles, and therefore should be avoided. Tables 3, 4 and 5 show the traffic volume, average speed and rain data respectively obtained from field data observations for a period of 3 months June, July and August 2018.

Table 2: Rainfall intensity in Port Harcourt for the month of June, July and August, 2018. Source; https://www.visualcrossing.com/weather-history

DAYS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
JUNE (inches)	0	0.3	0.2	0	0	0.4	0	0.2	0.1	0.2	0	0.3	0	0.1	0
JULY (inches)	0.3	0.6	2.4	0	0	2.8	0	1.6	0.3	0	0	0.5	0	0.6	3.2
AUG. (inches)	0	0.6	0.4	0	0	0.4	0	0.8	0.5	0.26	0	0.4	0	1.2	0.66
DAYS	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
JUNE (inches)	0.1	0	0.2	0.2	2.8	0	1.8	0	0	0	0	0	0	0.2	0
JULY (inches)	2.8	0	0.2	1.6	2	0	3.8	0	2.0	0	0	0	0	0.1	0
AUG. (inches)	0.1	0	0.2	0	3.6	0	0	0	0.4	0	0	0	0	0.3	0
DATE	**31**														
JUNE (inches)	-														
JULY (inches)	0														
AUG. (inches)	0														

Table 3: Effect of rainfall on average speed for the month of June, 2018

S/N	Rain Intensity (Inches)	Traffic Volume	Average Speed (km/hr) No Rain	Average Speed (km/hr) Rain	% Speed Reduction due to Rain	Maximum Allowable Speed (km/hr)
1	0.3	1830	58	13.3	77.8	60
2	0.2	2412	49	19.2	68	60
3	0.4	1366	38.7	36	40	60
4	0.2	2374	32	17.1	70.5	60
5	0.1	5462	54	44.7	25.5	60
6	0.2	2371	55	32.1	46.5	60
7	0.3	1821	57	26.3	56.2	60
8	0.1	5460	60	9.6	84	60
9	0.1	5464	48	16	73	60
10	0.2	2370	54	25.6	57.3	60
11	0.2	2372	59	9.6	84	60
12	2.8	195	49	24.4	59.3	60
13	1.8	303	52	17.3	71.2	60
14	0.2	2374	54	14.8	75.3	60

Assuming that all vehicles obey maximum allowable speed, then,
Percentage Speed reduction due to rainfall =

$$\frac{Max.\ allowable\ speed - Speed\ at\ rainfall}{Max.allowable\ speed} x\ 100 \quad (1)$$

$\frac{60-13.1}{60} x\ 100 = 77.8\%$, and son on.

Where maximum allowable speed is the vehicle speed recommended for road users in the city.

From table 3, Average Traffic Volume under rainfall condition for the month of June

$$= \frac{\mathbf{1830+2412+1366+2374+5462+2371+1821+5460+5464+2370+2372+195+303+2374+303+2374}}{\mathbf{14}} = \mathbf{2584}$$

Table 4; Rainfall, traffic volume and average speed data for the month of July, 2018.
(Source: Field Survey)

S/N	Rainfall Intensity (Inches)	Traffic Volume	Speed (km/hr) No Rain	Speed (km/hr) due to Rain	% Speed Reduction due to Rain	Max. allowable Speed(km/hr)
1	0.7	2117	57	19.8	67	60
2	0.4	2390	48	22.4	62.7	60
3	0.3	2380	42.5	22.8	62	60
4	0.1	3120	31	29.9	50.2	60
5	2.2	1170	59	11.2	81.3	60
6	0.7	1800	53	17.2	71.3	60
7	0.1	3600	44	34.4	42.7	60
8	0.8	2900	55	18.2	69.7	60
9	0.5	2180	46	20.9	65.2	60
10	4.6	1180	58	11.3	81.2	60
11	1.4	2112	50	20.2	66.3	60

From table 4, Average Traffic Volume under rainfall condition for month of July, 2018 is

$$= \frac{\mathbf{2117 + 2390 + 2380 + \ldots\ldots + 1180 + 2112}}{\mathbf{11}}$$

$$= \mathbf{2177}$$

Table 5; Rainfall and average speed data for the month of August, 2018 (Source: field data)

S/N	Rain Intensity (Inches)	Traffic Volume	Average Speed(km/hr) (No Rain)	Average Speed(km/hr) (Rainfall)	% Speed Reduction (Rainfall)	Max. allowable Speed
1	0.6	923	60	38	36.6	60
2	0.4	1402	57	21.5	64.1	60
3	0.4	1390	52	19	68.3	60
4	0.8	692	54	25	58.3	60
5	0.5	1107	56	34	43.3	60
6	0.26	2129	59	42	30	60
7	0.4	1380	60	35	41.7	60
8	1.2	461	55	40	33.3	60
9	0.66	839	52	32.5	45.8	60
10	0.1	5536	59	27	55	60
11	0.2	2768	58	26	56.6	60
12	3.6	154	57	17	71.6	60
13	0.4	1384	54	29	51.6	60
14	0.3	923	56	35	41.7	60

From table 5, Average Traffic Volume due to rainfall for month of August 2018 =

$$\frac{\mathbf{923+1402+1390+\cdots\ldots\ldots+1384+923}}{\mathbf{14}} = \mathbf{1446}$$

In order to comprehensively analyze the influence of rainfall on traffic speed, it is imperative to construct a theoretical framework that can effectively establish the relationship between the intensity of rainfall and the incidence of traffic congestion, as manifested by changes in speed. This model aims to enhance the understanding of the correlation between traffic congestion and speed in the context of wet weather conditions.

4.0 MODELLING RAIN-VEHICULAR SPEED LINEAR REGRESSION MODEL

The utilization of the Linear Regression equation serves the purpose of establishing a relationship between variables that are dependent and those that are independent. The objective of this study is to examine the correlation between rainfall intensity and traffic congestion by analyzing the average vehicle speed during rainy period in the city of Port Harcourt, Nigeria. Assuming a linear equation given as;

$$\mathbf{Y = QX + Z} \qquad (1)$$

such that Y is speed, and X denote the rainfall intensity. Using linear regression method, coefficients Q and Z can be solved as,

$$\mathbf{Z = Y - QX} \qquad (2)$$

$$\boldsymbol{Q} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \qquad (3)$$

where x and y are the samples, n is the number of samples, and $\bar{x}$ and $\bar{y}$ are the mean values of x and y respectively.

Let $y = vehicle\ speed$

$x = rainfall\ intensity$,

both were obtained from field survey. Table 6 shows the average values of vehicle speed and rainfall intensity obtained at Location Junction, Port Harcourt city for a period of three months. This data was used to develop regression model that shows the relationship between vehicle speed and rainfall intensity in that city.

Table 6; Correlational analysis of average speed and rainfall intensity for months June, July and August, 2018.

S/N	x	y	$(x - \bar{x})$	$(y - \bar{y})$	$(x - \bar{x})(y - \bar{y})$	$(x - \bar{x})^2$
1	0.3	58.33	-0.5513	5.79	-3.192	0.3039
2	0.5	51.33	-0.3213	-1.21	0.3888	0.1032
3	1.0	44.4	0.1487	-8.14	-1.21	0.0221
4	1.2	39	0.3487	-13.54	-4.7214	0.1216
5	0.8	56.33	-0.0513	3.79	-0.1944	0.0026
6	0.3	55.67	-0.5513	3.13	-1.7256	0.3039
7	0.23	53.67	-0.6213	1.12	-0.6959	0.3860
8	0.4	56.67	-0.4513	4.13	-1.8639	0.2037
9	0.63	48.67	-0.2213	-3.87	0.8564	0.0490
10	1.93	57	1.0787	4.46	4.8110	1.1636
11	1.0	55.67	0.1487	3.13	0.4654	0.0221
12	0.2	51.5	-0.6513	-1.04	0.6774	0.4242
13	0.9	52.5	0.0487	-0.04	-0.0019	0.0024
14	2.8	55	1.9487	2.46	4.7938	3.7974
15	1.2	53	0.3487	0.46	0.1604	0.1216
16	0.2	52	-0.6513	-0.54	0.3517	0.4242
$\sum$	**13.62**	**840.73**			**-1.1002**	**7.4515**

Solving for the mean values of x and y,

$$\overline{x} = \frac{13.62}{16} = 0.8513$$

$$\overline{y} = \frac{840.73}{16} = 52.54$$

Therefore, from equation (2) and (3),

$$Q = \frac{-1.1002}{7.4515} = -0.15 \quad \approx -0.2$$

But, $Z = \overline{y} - Q\overline{x} = 52.54 - (-0.2x0.8513)$

$$Z = 52.7 \approx 53$$

Therefore, substituting $Q \approx -0.2$ and $Z \approx 53$ into equation (1)

then, Linear Regression Model for vehicle speed and rainfall intensity is developed as;

$$\boldsymbol{Y = -0.2X + 53} \qquad \textbf{(4)}$$

Where Y represents average speed of vehicle and, X represents rainfall intensity.

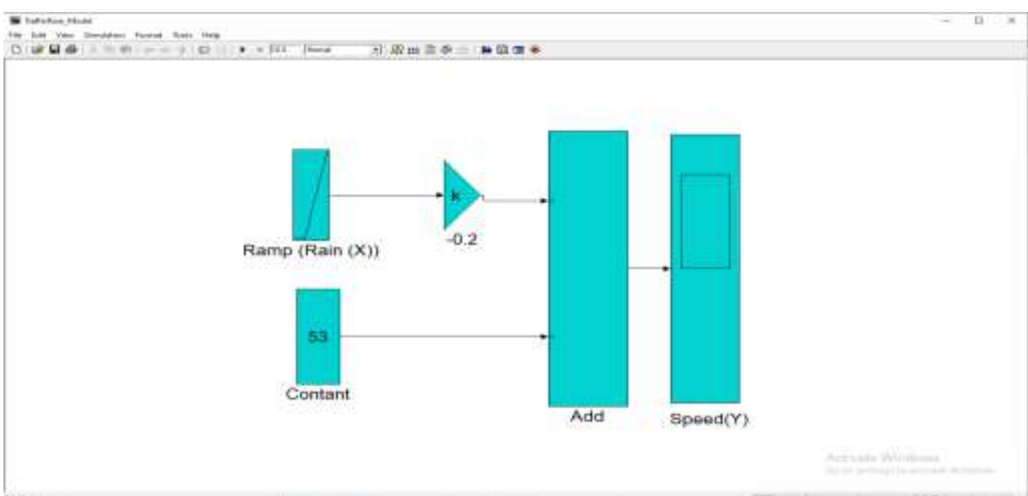

Fig. 11, Speed-Rain Model from MATLAB.

Figure 11 illustrates a system that utilizes equation (4) to showcase the impact of rainfall intensities on road traffic speed. The estimation of traffic congestion is influenced by various factors related to rainfall.
The system is designed using MATLAB. The model blocks are utilized to represent individual system variables in order to facilitate the completion of the cycle run time. The gain block performs a multiplication operation on the input data of rainfall, using the ramp block and the variable 'X' as factors. The vehicle speed output signal is determined by this factor.
The Constant block in Simulink serves as a representation of a fixed value within the model. In this particular case, it represents the constant value of 53. This constant value is then added to the product of the rainfall data and another Constant (-2) block, resulting in the determination of the vehicle speed. The data in Figure 11 demonstrates a negative correlation between rainfall and vehicle speed, indicating that as rainfall levels rise, vehicle speed tends to decrease. Figure 12 presents the simulated analysis results.

5. PRESENTATION OF RESULTS

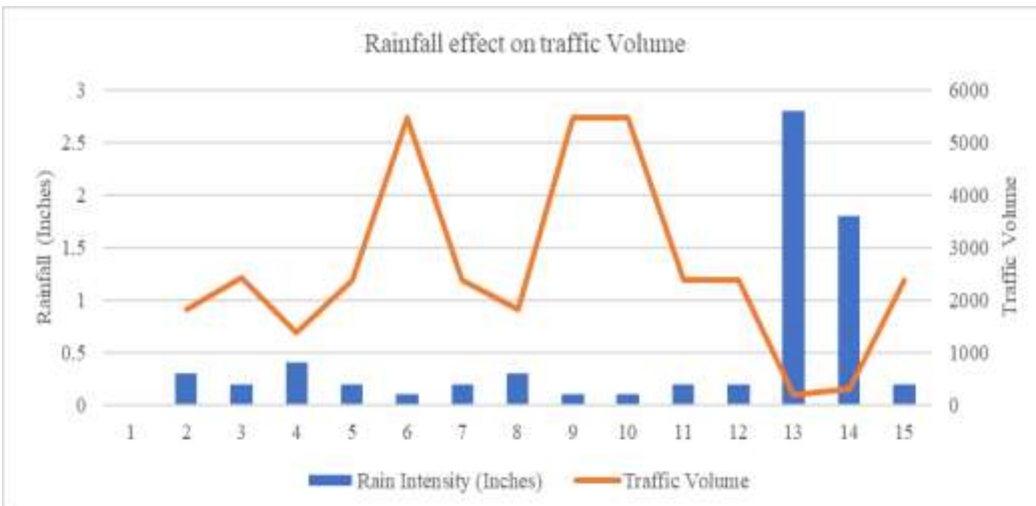

Fig.2; Traffic Volume reduces as Rain fall intensity increases, and vice versa in June, 2018

Fig.3; Vehicle Speed during dry weather is higher compared to wet weather for June, 2018.

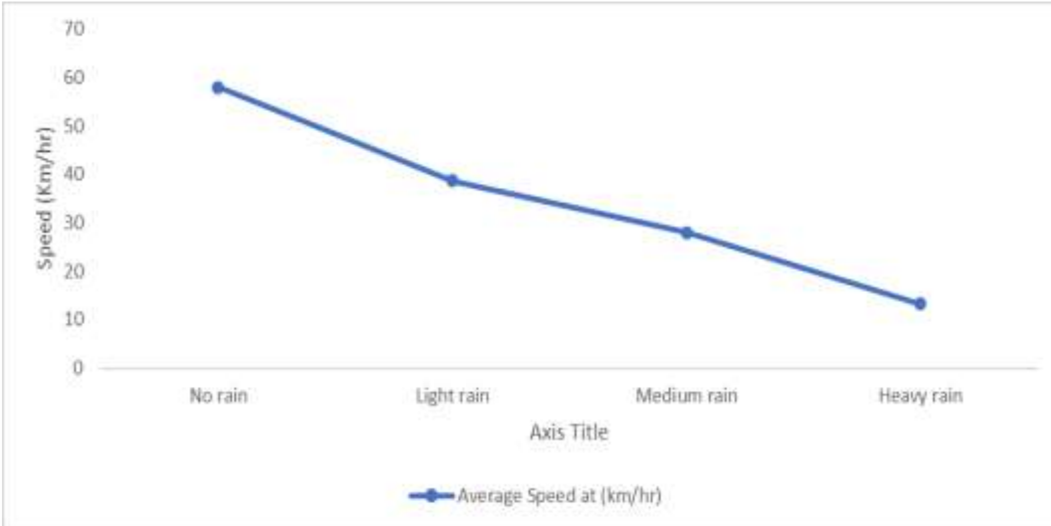

Fig4; Single plot representation of rainfall effect on average vehicle speed in the month of June 2018.

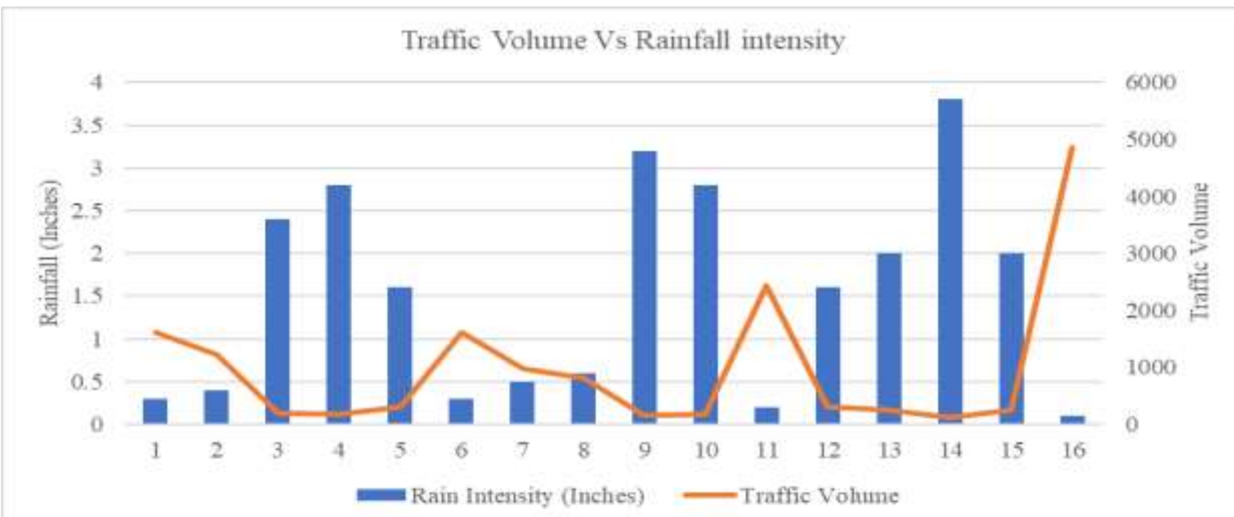

Fig. 5; Rainfall influence on traffic volume for the month of July 2018

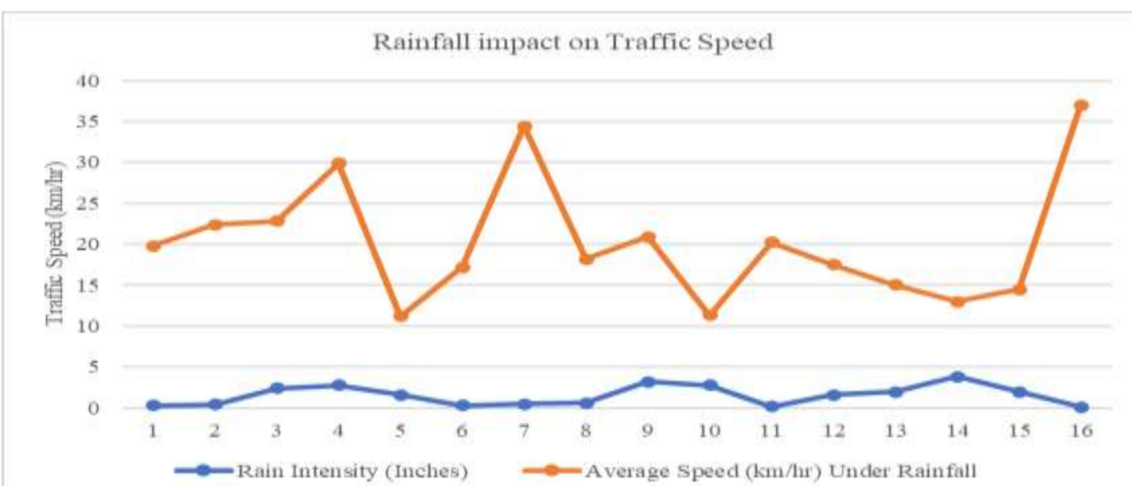

Fig 6; Traffic Speed reduces at high Rainfall for the month of July 2018

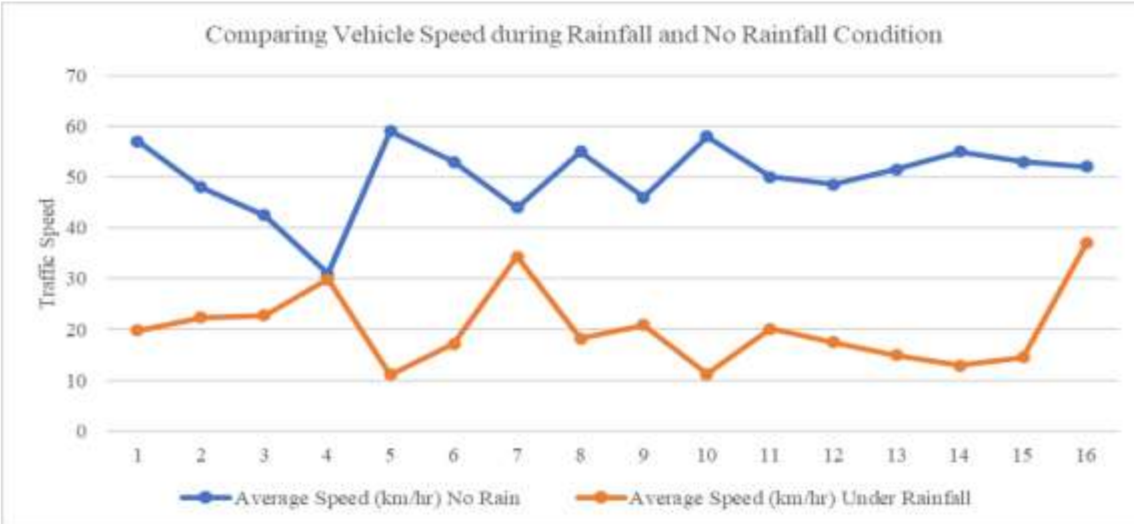

Fig. 7; Vehicle speed decreases under rainfall while vehicle speed increases under no rain

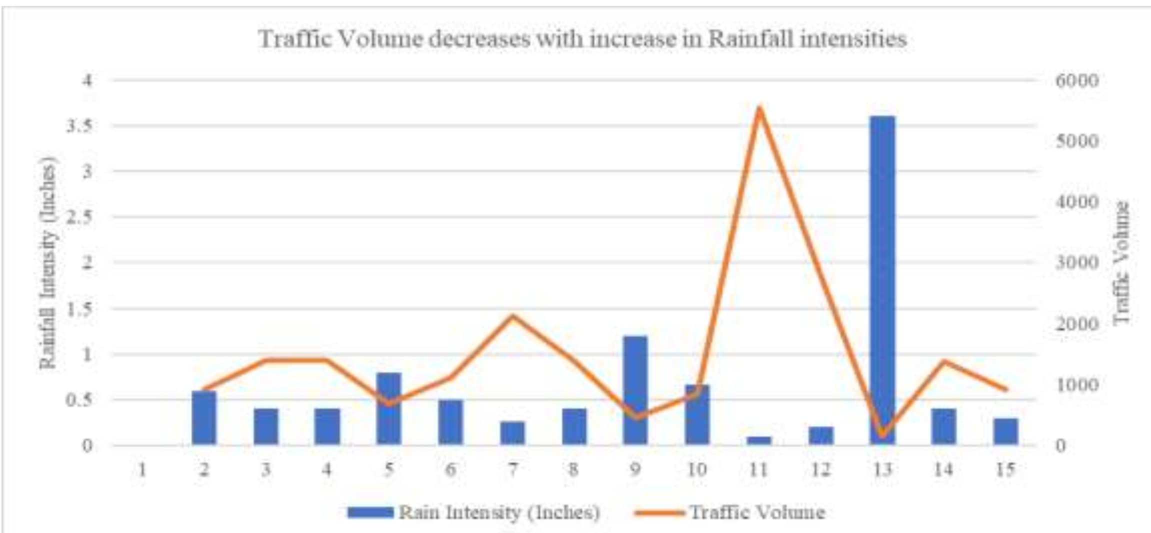

Fig. 8 illustrates a significant reduction in traffic volume throughout the month of August 2018, due to heavy precipitation.

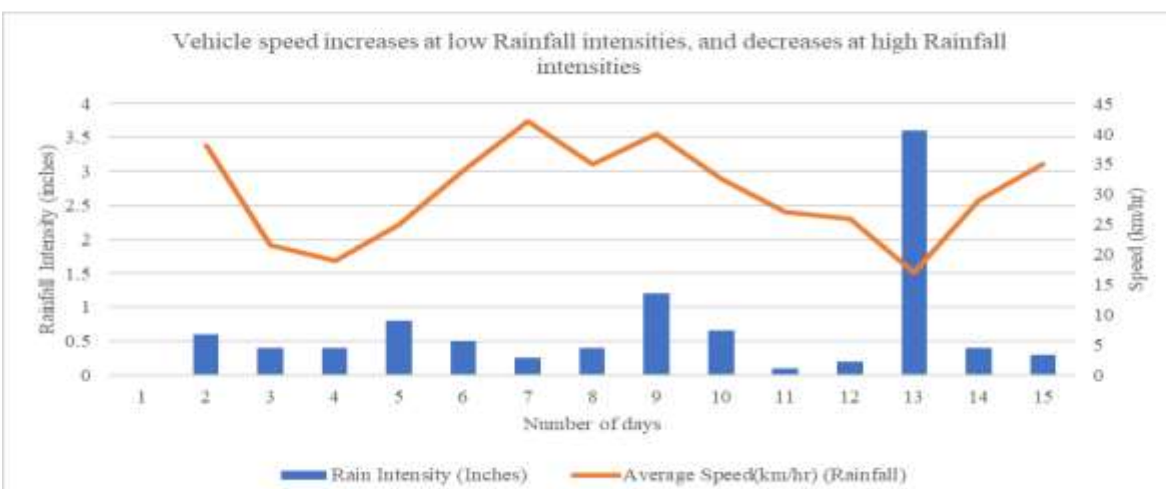

Fig.9: Rainfall Intensity increases while vehicle speed decreases for month of August, 2018.

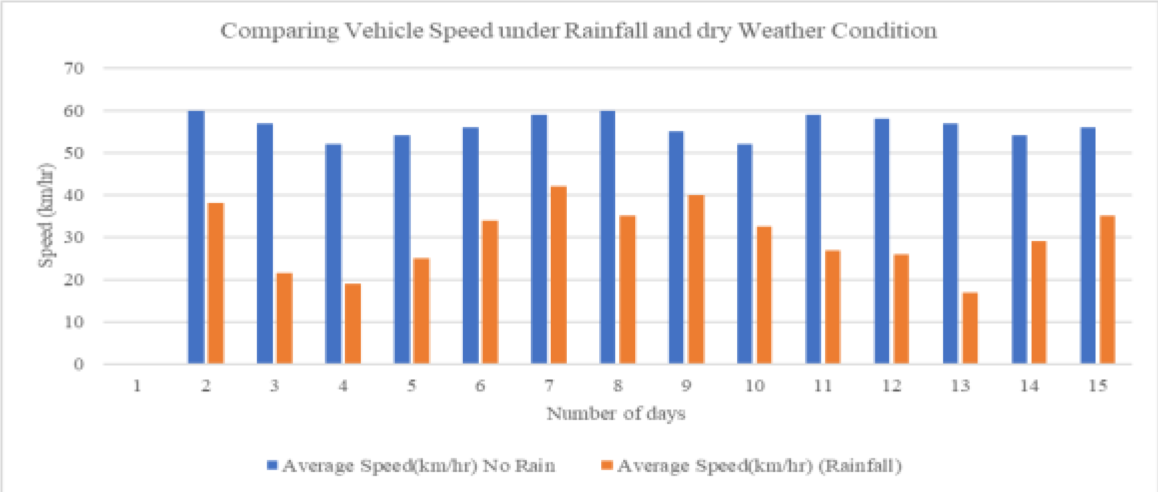

Fig. 10: Comparing vehicle speed under rainfall and dry weather for month of August, 2018.

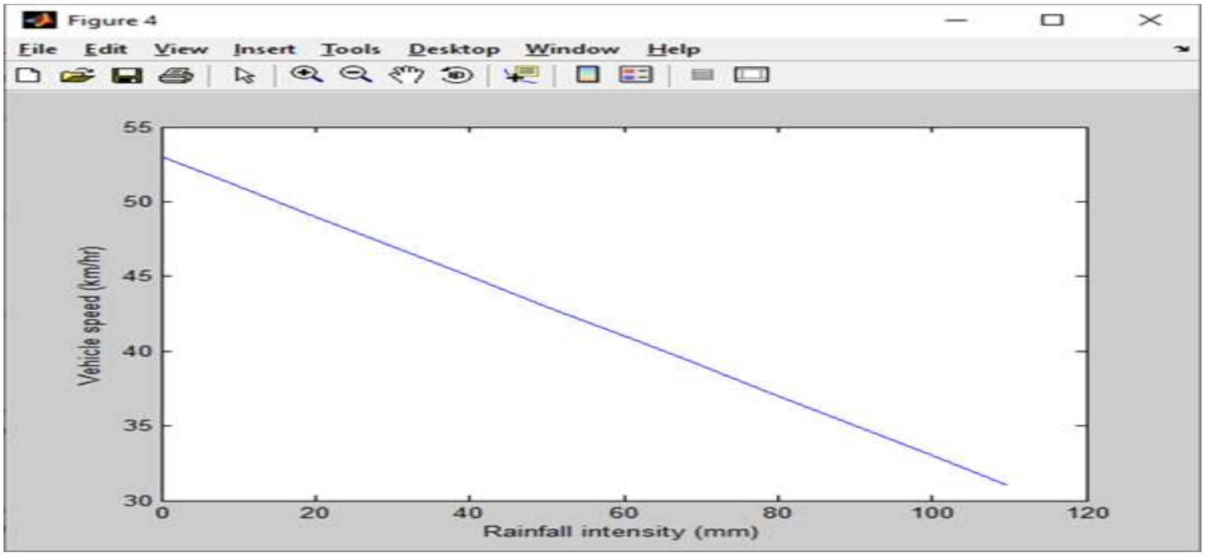

Fig.12; MATLAB simulation of Vehicular Speed versus Rainfall intensity from regression model

Table 7 displays the predicted average vehicle speed for various rainfall intensities using equation (4).

Table.7; Predicted traffic speed at different Rainfall Intensities

S/N	Rainfall intensity (mm)	Speed (km/hr)
1	0	53
2	10	51
3	20	49
4	30	47
5	40	45
6	50	43
7	60	41
8	70	39
9	80	37
10	90	35
11	100	33
12	110	31

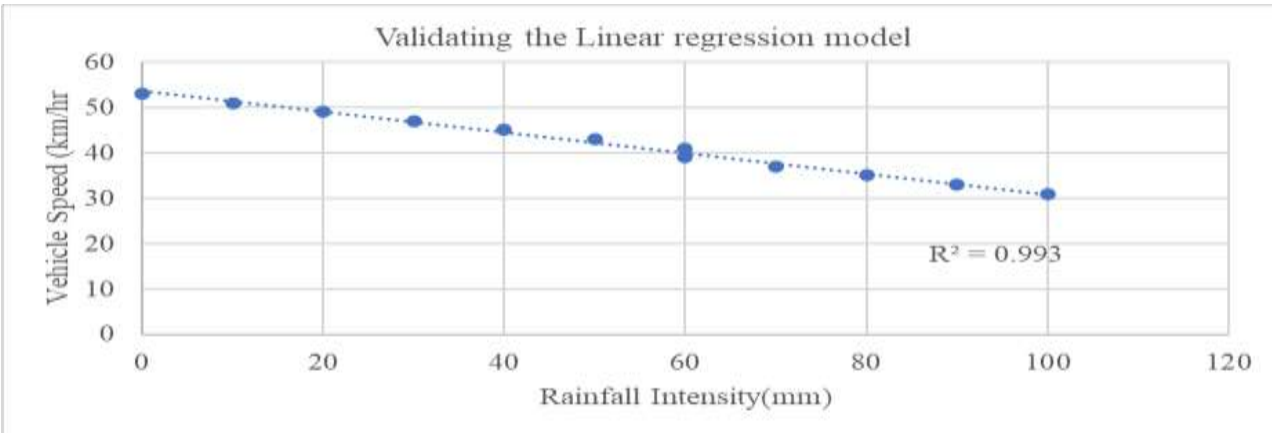

Fig. 13; Validating the regression model using R-Squared method.

6 DISCUSSIONS

The study's findings revealed significant associations between traffic patterns and weather conditions, specifically rainfall, which were limited in applicability to the study's specific geographical context. The present study aimed to assess the relationship between vehicle speed and rainfall intensity in Port Harcourt, Nigeria. The impact of rainfall on traffic is demonstrated in figures 2, 5, and 8. As the intensity of rainfall increases, there is a corresponding decrease in traffic volume. The data presented in figures 3, 6, 7, 9, and 10 illustrate the relationship between rain intensity and traffic speed.

A MATLAB simulation depicted in Figure 12 shows the relationship between vehicle speed and the intensity of the rainfall. The simulation demonstrates that the maximum vehicle speed is 53 km/h when there is no rain, and as the severity of the rain grows, the speed keeps dropping until there are no vehicles to be visible on the road, which may be the result of heavy rain.

Figure 13 illustrates the inverse relationship between vehicle speed and rainfall intensity, indicating a decrease in speed as the intensity of rainfall increases. Notably, in the absence of precipitation, the vehicle maintains a constant speed of 53 km/h. Additionally, this model establishes a correlation between the speed of vehicles and the intensity of rainfall. The coefficient of determination, shown as R-Square, indicates a robust correlation of 0.993 (99.3%) between precipitation and vehicle speed.

7. CONCLUSIONS

This study examines the influence of the quantity of rain on the per hour traffic volume in the municipality of Port Harcourt, Nigeria. The research is data-driven, and involves an analysis of the relationship between rainfall and traffic volume, as well as the development of the regression method to forecast traffic volume during rainfall events. The findings, based on a field survey, indicate a substantial decrease in traffic volume at various time periods throughout the day. At high rainfall intensity, both traffic speed and traffic volume reduce gradually even at rush hours of the day. This research analyzed also traffic speed under rainfall intensity and under no rainfall (figures 3 and 10). It is obviously seen that the speed under no rain is higher than that under rainfall. The findings of this study have the potential to provide valuable insights for road safety officials, stakeholders, and planners on the assessment of the daily influence of weather conditions, specifically rainfall, on the traffic flow in Port Harcourt metropolis, Nigeria.

Declaration by Authors

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REFERENCES

1. Ogbonna, D.N., Amangabara, G.T. and Ekere, T.O.; Urban solid waste generation in Port Harcourt metropolis and its implications for waste management", Management of Environmental Quality, Vol. 18 No. 1, pp. 71-88. https://doi.org/10.1108/14777830710717730, 2007.
2. Wikipedia, Rivers State, Nigeria. Available online: https://en.wikipedia.org/wiki/Rivers State, Nigeria. (Retrieved 5th may, 2018).
3. Chinago B. A; Analysis of rainfall trend, fluctuation and pattern over Port Harcourt, Niger Delta coastal environment of Nigeria, Biodiversity International Journal, Volume 4, Issue, 1, DOI:10.15406/bij.2020.04.00158, 2020.
4. Angel, M. L., Sando, T., Chimba, D., and Kwigizile, V; Effects of rain on traffic operations on Florida freeways. Transportation Research Record, 2440, 51–59. http://dx.doi.org/10.3141/2440-07, (2014).
5. Rakha, H., Farzaneh, M., Arafeh, M., Sterzin, E.: Inclement weather impacts on freeway traffic stream behavior. Transp. Res. Rec. J. Transp. Res. Board. 2071(1), 8–18 (2008). https://doi.org/10.3141/2071-02
6. Billot, R., El Faouzi, N., De Vuyst, F.: Multilevel assessment of the impact of rain on Drivers' behavior. Transp. Res. Rec. J. Transp. Res. Board. 2107(1),134–142, https://doi.org/10.3141/2107-14, 2009
7. Akin, D., Sisiopiku, V.P., Skabardonis, A.: Impacts of weather on traffic flow characteristics of urban freeways in Istanbul. Procedia. Soc.Behav.Sci.16,89–99(2011). https://doi.org/10.1016/j.sbspro. 2011.04.432
8. Alhassan, H. M: Reliability of single lane road capacity subjected to rainfall disturbances. International Journal of Emerging Technology and Advanced Engineering. Volume 3, Issue 2, 587–594, February 2013.
9. Roh, H., Sharma, S., Sahu, P.K.: Modeling snow and cold effects for classified highway traffic volumes. KSCE J. Civ. Eng. 20(4), 1514–1525(2016). https://doi.org/10.1007/s12205-015-0236-0
10. Khattak, A. J., and A. De Palma; The impact of adverse weather conditions on propensity to change travel decisions. A survey of Brussels commuters Transp. Res. Part A Policy Pract, 31, 181-203, https://doi.org/10.1016/S0965-8564(96)00025-0, (1997).
11. Asamer, J. and Reinthaler, M.: Estimation of road capacity and free flow speed for urban roads under adverse weather conditions. 13th International IEEE Annual Conference on Intelligent Transportation Systems Madeira Island,Funchal, DOI:10.1109/ITSC.2010.5625152 (2010).
12. Yuan-Qing, W., and Jing, L: Study of rainfall impacts on freeway traffic flow characteristics. Transportation Research Procedia, http://refhub.elsevier.com/S0198-9715(18) 30062-0/rf0120, 25, 1533– 1543, (2017).
13. Agarwal M, Maze T H, Souleyrette R; Impacts of weather on urban freeway traffic flow characteristics and facility capacity. In: Mid-continent transportation research symposium, Iowa Google Scholar (https://scholar.google.com), 2005.
14. Smith B. L; An Investigation into the impact of rainfall of freeway traffic flow. In: 83rd Annual meeting of the Transportation Research Board, Washington, DC Google Scholar, 2004.
15. Bartlett. A, Lan W, Zhao. Y, and Zadek A. W; Impact of inclement weather on hourly traffic volume in buffalo, New York. Transportation Research Board 92nd annual meeting, 500 Fifth Street, NW Washington, DC United States,20001, https://trid.trb.org/view/1241923,2013.
16. Feng Hang, Changcheng Li, Nale Zhao and Han Hu: Modeling the impacts of related factors on traffic operation. Procedia Eng 12:99–104CrossRef https://doi.org/ 10.1016/j.proeng.2011.05.017), 2011.
17. Cools M, Moons. E and Weta G.; Accessing the impact of weather on traffic intensity. Weather climate and society, DOI:10.1175/2009WCAS1014.1, 2010.

18. Kyte M; Moscow and Ida; Effect of weather on free-flow speed. Transportation Research Board, pp 60–68 Google Scholar (https://scholar.google.com, 2002.
19. Chung Y: Assessment of non-recurrent congestion caused by precipitation using archived weather and traffic flow data. Transport Policy (19):167–173 Cross Ref (https://doi.org/10.1016), 2012.
20. Sterzin E. D; Modelling influencing factorsing a microscopic traffic simulator. In: Department of Civil and Environmental Engineering Massachusetts Institute of Technology, Massachusetts, P 95 Google Scholar (https://scholar.google.com), 2004.
21. Kwon, T. J., Fu, L., & Jiang, C; Effect of winter weather and road surface conditions on macroscopic traffic parameters. Transportation Research Record, 2329,54–62. http://dx.doi.org/10.3141/2329-07, 2013.
22. Samba, D., & Park, B. B.; Probabilistic modeling of inclement weather impacts on traffic volume. Transportation Research Board 89th annual meeting, no. 10-0646, 500 Fifth Street, NW Washington, DC United States 20001,http://refhub.elsevier.com/S0198-9715(18)30062-0/rf0095, 2010.
23. Dehman, A., and Drakopoulos, A: How weather events affect freeway demand patterns. Transportation Research Record, 2615,113–122. http://dx.doi.org/10.3141/2615-13, 2017.
24. Enete I.C. and Igu I.N: Analysis of Weather and Wet Road Crashes in Enugu Urban, Pakistan Journal of Social Sciences, 8: 289-293. DOI: 10.3923/pjssci. 2011.289.293, 2011.
25. Brijs T., Karlis D., Wets G: Studying the effect of weather conditions on daily crash counts using a discrete time series model, Accident Analysis and Prevention 40 (3), 1180–1190, 2008.https://doi.org/10.1016/j.aap.2008.01.001

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