DEVELOPING SPATIAL DECISION SUPPORT SYSTEM TO ASSESS TRAFFIC CONGESTION IN THE CITY OF JOHANNESBURG

A. K. Adeleke [1] *, R. M. Gebashe [1]

[1] Department of Geography, Geoinformatics and Meteorology, Faculty of Natural and Agricultural Sciences, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa – adedayo.adeleke@up.ac.za, u17348987@tuks.co.za

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ABSTRACT:

African cities are rapidly experiencing an increase in population, thereby making it difficult to attain self-sustainability. Traffic congestion is a major contributing factor to this issue. Johannesburg's inner-city fits this profile, with an increasing decline in economic and social activities, and quality of life due to traffic congestion. Furthermore, the lack of a road transport infrastructure geodatabase and traffic data in these cities makes it more difficult for stakeholders to make an informed decision on how to effectively manage roads prone to traffic congestion or due for infrastructure upgrade. This paper focuses on developing a geodatabase using factors that cause traffic congestion such as bus stops, traffic lights, speed humps, t-joints, cross joints, street parking, and others. These factors were investigated on some selected roads within the Johannesburg inner-city by enumerating the number of such factors existing on each road with the aid of high-resolution aerial imagery. The developed geodatabase becomes a tool that can support the decision-making process in solving traffic congestion by querying the geodatabase to select roads that are prone to traffic congestions depending on the number of factors occurring along a road.

1. INTRODUCTION

Traffic congestion is regarded as one of the most challenging issues in cities globally, it also poses a major challenge to improving sustainability in cities around the world. Traffic congestion is characterised by slower speeds, longer trip times and increased vehicular queuing (Rao et al., 2014). Traffic congestion occurs when a road network surpasses its design capacity. Most cities' economic activities occur within the inner city or Central Business District (CBD), thus attracting a lot of vehicular movements to this zone.

Traffic congestion can negatively impact the economy of a city in diverse ways including, missed or late deliveries, late arrival of employees to the workplace, reduced and restricted productivity amongst others (Choi et al., 2013). A sustainable road network is non-negotiable in achieving sustainability in urban areas. It includes the free flow of traffic or sub minimal traffic, where there is a clear provision of access for all users on the road such as bus lanes, cycle lanes, pedestrian markings, safe road dividers, clear lane markings, and other factors.

One of the ways that traffic congestion can be assessed and monitored is through the use of a Geographic Information System (GIS). This can be done by creating an updated road transport infrastructure geodatabase containing attributes, factors that can help assess traffic congestion. The geodatabase can be then queried to identify the roads or sections of road that are prone to traffic congestion and requires infrastructure upgrade.

From research and findings, it is noticed that the city of Johannesburg does not have such a geodatabase that could help in assessing traffic congestions in its inner city. As such, it becomes difficult for the city to monitor traffic congestion and make an informed decision on which sections or portions of the roads require infrastructure upgrades. Consequently, the lack of means to assess traffic congestion in the city has led to a decrease in Johannesburg's economic and social activities. This has also led to a significant increase in the inner-city's crime rate, several road accidents, thus leading to a decrease in the quality of life and lack of sustainability generally.

Therefore, this paper aims to assess possible traffic congestion in the City of Johannesburg CBD by developing a comprehensive road transport spatial data infrastructure, which can be queried to identify roads or portions of it that are highly or less susceptible to traffic congestion. This would in turn help to facilitate an informed decision-making process by the municipality concerning road transport infrastructure and towards achieving the Sustainable Development Goal (SDG) 11.

2. RELATED WORKS

From the literature, it is noticed that various factors are responsible for traffic congestion in various countries. According to a study conducted by Rao and Rao (2012) in India, the cause of traffic congestion was due to factors such as poor road conditions, improper bus stop location and design, uncontrolled on-street parking amongst others. In addition, a study done by Zhang (2011), revealed that the causes of traffic congestion in China are due to ineffective use of public transport service as the main source of transportation and the opposite relationship that exist between the number of vehicles and road capacity.

Furthermore, Bashit et al. (2018) posited that unbalanced transportation growth compared to road construction gave rise to traffic congestion in the city of Semarang, Indonesia. Studies

* Corresponding author

conducted by Selvasofia et al. (2017) and Anjana et al. (2018) both have some similarities in their studies where the former concluded that traffic congestion is caused by poor driving habits, inadequate road capacity, roadside parking, work zones, etc. The latter identified road width, road structure and various land-use as some factors responsible for traffic congestion. Additionally, Mahona et al. (2019) observed that the causes of traffic congestion are related to road design factors such as bus stops, T-junction, cross junction, traffic lights and humps.

Selvasofia et al. (2017) used the vector analysis method to illustrate where traffic congestion occurs. The study was carried out in the Coimbatore district of the state of Tamil Nadu in India. An overlay analysis was performed using factors highlighted earlier, which were converted to raster layers to perform the overlay analysis. The study conducted by Anjana et al. (2018) used manual counts by collecting data to map out friction points using QGIS software. They used tally sheets, mechanical count boards and electronic count boards systems. In addition, the location and speed of vehicles used were collected using a Global Positioning System (GPS) device.

Another study done by Jaro (2015) developed a GIS-based road transport information management intending to map the road infrastructures of the study area by building a geodatabase for the road infrastructures. Using the created geodatabase, queries are designed to analyse road characteristics. In a study carried out by Droj et al. (2022) real-time traffic data, network analysis, simulation and mathematical models were integrated to assess traffic congestion in Oradea, Romania. Also utilizing real-time traffic data, Ye et al. (2020) integrated other multi-source data such as bus stop data, building data, land-use data, road data digital elevation data amongst others using geographically weighted regression and kernel density estimation to analyse traffic congestion in the inner city of Chongqing, China.

From the literature reviewed, it is noticed that many factors that can be modelled spatially can be utilized to assess traffic congestion using various geospatial analyses. It was also observed that none of the studies reviewed considered the analysis of the cumulative numbers of the factors identified to cause traffic congestion along a road segment nor attempted to classify the rate of congestion based on the cumulative number of factors causing traffic congestion. Furthermore, when traffic data (historic or real-time) such as travel time and travel speed are not available, it becomes more difficult to assess traffic congestion. Consequently, this study aims to demonstrate the use of a spatial decision support system to aid the assessment of traffic congestion by considering the cumulative number of factors identified to cause traffic congestion and in the absence of traffic data, using the inner city of Johannesburg in South Africa as a case study.

3. METHODS AND MATERIAL

To achieve the aim of this paper, factors considered being responsible for traffic congestion are extracted from the aerial imagery, whereas, other data are sourced from the data custodian. A mix of methods was subsequently employed to analyse the data and develop the geodatabase.

3.1 Conceptual Framework

The framework adopted to assess traffic congestion in this paper involves creating a geodatabase containing as attributes some factor highlighted from literature, which causes traffic congestion. As illustrated in Figure 1, the road feature class was clipped to the study area boundary as shown in Figure 2. Whereas, other feature classes representing the identified factors were digitized from the high-resolution aerial imagery, as well as the necessary attributes. The factors were extracted for each road segment within the study area as well as the cumulative numbers of the factors captured as attributes for the merged road layer. The geodatabase created forms the backdrop for the SQL and symbology based on the attribute to determine congested roads and levels of congestions.

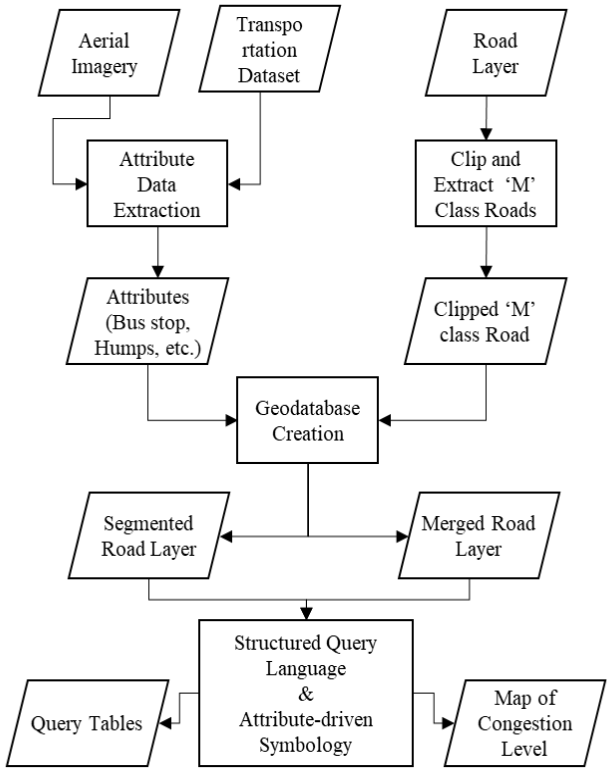

Figure 1. Conceptual framework.

3.2 Study Area

The Johannesburg CBD was chosen for this study as traffic congestion is a common occurrence in this area. Johannesburg CBD lies in the centre of South Africa in the Gauteng Province as shown in Figure 2. It is located on longitude 26˚12' S and 28˚2'E, it spans about 1.09 km2 in area. Incessant traffic congestion in this area has brought about a decrease in the area's economic and social activities. It has also led to a significant increase in the inner-city's crime rate.

3.3 Resources

The aerial imagery, transportation dataset and the road feature class were all obtained from the municipality. These form the major input layers required to develop the geodatabase. The aerial imagery was acquired in 2019 and has a spatial resolution of 8cm, which covers the entire City of Johannesburg Municipality. Some of the road feature class and transportation covers the entire country, whereas, others are provincial. Some factors, such as traffic lights and bus stops, required to be captured into the geodatabase are already available as a feature class in the transportation dataset. Other factors were captured using high-resolution aerial imagery.

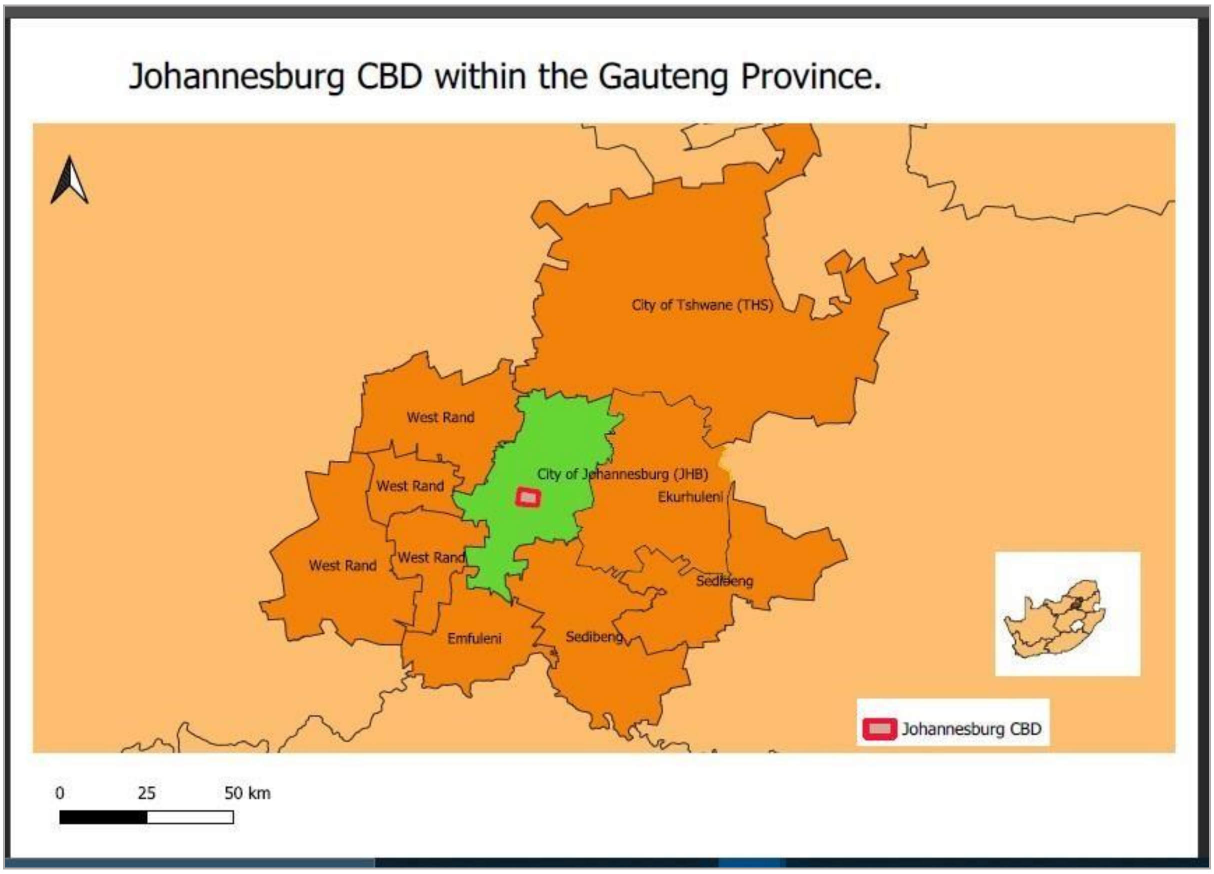

Figure 2. Johannesburg CBD.

3.4 Method Used

A mix of methods was employed to achieve the aim of this study. Methods used include:

3.4.1 Kernel Density: It calculates the density of a feature within a specified radius or neighbourhood of another feature. This method can be applied to either a point or linear feature. It is a smoothing function adapted after the quartic kernel function presented by Silverman (2018).

3.4.2 Geodatabase Creation: A file geodatabase is adopted for this study. The geodatabase is to contain two linear features. One of the road feature classes represents the segmented road portions, whereas, the other represents a merged road within the study area. The geodatabase creation forms the framework for the attribute query and map symbolization based on the attributes.

3.4.3 Attribute Query: This process involves using Structured Query Language (SQL) to search and retrieve records of features from a feature class's attribute table. Criteria (attributes) can be combined to produce the desired results using various operators including Boolean, comparators and functions.

3.4.4 Attribute-driven Symbology: It involves symbolizing the geometric features of a map based on the unique or range of values captured in the attribute table. This makes map symbolization dynamic and unique to the study at hand, thus making the map readable to the intended audience. This method is employed in this study to map levels of congestion of the roads analysed.

4. RESULTS AND DISCUSSION

To demonstrate the concept, the major roads within Johannesburg inner-city designated as "M" class were selected, then using the data sourced and methods discussed previously, the following steps were followed in the open-source QGIS environment to achieve the aim of the study:

4.1 Geodatabase Creation

A boundary around the inner-city is determined by creating a new polygon feature class to determine the study area as. Areas within the CBD includes Bellevue, Berea, and Hillbrow lying north of the city, Braamfontein, Vrededorp and Fordsburg on the western side. On the southern side lies Newton and on the eastern side lies Jupith's Pearl and Jeppestown. The study area boundary feature class becomes useful in clipping the road feature class to the study area.

The next step is to clip the road feature class to the study area using the CBD boundary. This was achieved using the clip tool, subsequently, the other road classes were filtered out with the "M" class remaining as shown in Figure 3.

Figure 3. Clipped and filtered road feature class.

Subsequently, factors contributing to traffic congestion were captured into the clipped road feature class. New fields were created in the feature class to capture the factors namely: bus stop, t-joints, cross-joints, traffic light, speed humps, parking and bus lanes. Some of these factors already existing as a feature class in the transport dataset were overlaid on the clipped road feature class. Each segment of the road was physically inspected and wherever these factors occur along a road, a Boolean variable "Yes" is entered into the appropriate field.

When there is no factor along the segment, a Boolean variable "No" is captured into the attribute table. An extract of the new attribute is shown in Figure 4. This method was used to capture the bus stops and the traffic lights. To capture the t-joints, cross joints, parking and speed humps, aerial imagery was used to check for the presence of such factors. This was done by selecting a particular road segment and zooming in and scrolling from its point of origin till its end. If there was any presence of the cross joint, parking or speed hump a "Yes" would be entered into the desired field of the factor, otherwise, a "No" is captured.

	ID	NAME	CLASS	LENGTH	Bus_stops	T_Joints	CrossJoint	TrafficLig
1	14348	[illegible]	M	402,94468332800	No	No	No	No
2	14349	[illegible]	M	499,63078972000	No	No	No	No
3	15812	Vickers Rd	M	54,16907599400	No	No	No	No
4	15809	Village Rd	M	697,44600805400	No	No	No	No
5	15811	Vickers Rd	M	54,80945499000	No	No	No	No
6	15608	De Villiers Graaf...	M	675,52029640900	No	No	No	No
7	15607	De Villiers Graaf...	M	362,89828890100	No	No	No	No
8	15585	De Villiers Graaf...	M	777,97957020300	No	No	No	No
9	15605	De Villiers Graaf...	M	1276,40477947000	No	No	No	No
10	15693	Heidelberg Rd	M	263,96537674000	No	No	No	No
11	15761	Siemert Rd	M	327,14141773000	No	No	No	No
12	15612	De Villiers Graaf...	M	858,91652465900	No	No	No	No
13	15692	Heidelberg Rd	M	373,49876502400	No	No	No	No
14	15784	Joubert St Ext	M	65,29523015300	No	Yes	No	No
15	15785	Joubert St Ext	M	63,04279166400	No	No	No	No
16	15762	Siemert Rd	M	445,74892642700	No	No	No	No
17	15763	Siemert Rd	M	679,14473769300	No	No	No	No
18	15803	Harrow Rd	M	307,75659779300	No	No	No	No
19	15804	Harrow Rd	M	327,22350387900	No	No	No	No
20	15798	Hoofd St	M	58,31719728300	No	No	No	No
21	15799	Hoofd St	M	64,74831150500	No	No	No	No

Figure 4. The attribute table of the segmented road feature class.

The next step under geodatabase creation involves merging the road segments for each major road and enumerating the factors occurring along each major road. The "join multiple lines" plugin was used in QGIS to merge the road segments. For factors with existing feature classes, the heat map (kernel density) tool was used to estimate the number of factors occurring along the road. Other factors were manually enumerated from the aerial imagery. Subsequently, a new field is added in the attribute table of the merged named "Sumof_Fact" to capture the sum of all factors for each major road using the field calculator. An extract of the merged road attribute table is shown in Figure 5.

	ID	NAME	Sumof Fact	Bus_stops	T_Joints	CrossJoint
1	9988	M11	68	1	13	19
2	121...	M10	60	6	5	16
3	100...	M71	35	0	1	14
4	2712	M31	17	0	0	8
5	512	M1	7	0	0	0
6	120...	M14	3	0	0	1
7	2714	M2	0	0	0	0

Figure 5. The attribute table of the merged road feature class.

With the assumption that the greater the number of factors occurring along a stretch of road, then the greater the chance that the road will be prone to traffic congestion. Results from the geodatabase show that M2 and M14 are least prone to traffic congestion, whereas, M1, M13 and M17 are mildly prone to traffic. In contrast, M10 and M11 are highly susceptible to traffic congestion due to high numbers of factors occurring along these routes. The result is visualized using the symbology tool as shown in Figure 6.

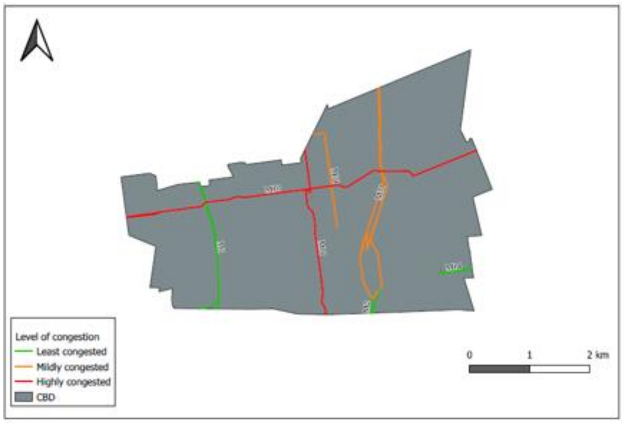

Figure 6. Roads in Johannesburg CBD susceptible to traffic congestion.

4.2 Attribute Query

The "Select feature using an expression" tool was used to run various queries that could aid decision-making processes. To carry out a selection, the first function used is the "Fields and values" which contains the list of fields available from the geodatabase. The list of available fields after the creation of the geodatabase are ID, Name, Class, Length, Bus stops, T-Joints, Cross Joints, Traffic lights, Humps, Parking, Bus lane and Shape length as shown in Figure 7 by the red rectangle. Another function that is used in the select by expression tool is the one that falls under “Operations” “OR” and “AND”, then the “Select Features” function is used to specify the criteria.

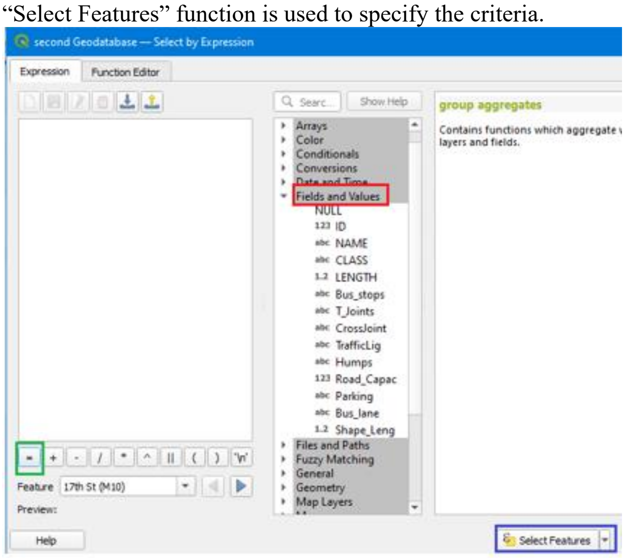

Figure 7. Select by expression view.

With this tool, a user can be able to select segments of the road with all, some or none of the factors established from literature to cause traffic congestion. For example, the result of a query to select road segments with all factors present is shown in Figure 8. This could indicate roads are highly susceptible to traffic congestions. Whereas, the result of a query to select road segments with no factors present is shown in Figure 9. This could indicate road segments are less susceptible to traffic congestion.

4.3 Discussion

With the successful creation of the geodatabase, it becomes easier to make informed decisions on which roads would have a greater chance of being congested with traffic or less chance, as well as portions or sections of a road requiring infrastructure upgrade. In this regard, necessary tools can be utilized across any GIS platform to help with such a decision-making process. With regards to the geodatabase created, a decision-maker can ask themselves one or more of the following questions or other possible combinations that could help to facilitate the decision-making process:

- Which roads contain all of the factors?
- Which roads does not contain any of the factors?
- Which roads have bus stops only?
- Which roads have T-joints and no traffic light?
- Which roads have cross joints and no traffic light?
- Which roads have T-joints and traffic lights?
- Which roads have cross joints and traffic light
- Which roads have speed humps only?
- Which roads have parking space only?

The geodatabase also offers the potential to interface between the two feature classes by forming a one-to-many relation between the two feature classes using the table join tool. The geodatabase could also be updated from time to time to reflect new additions, alterations or completed removal of road infrastructures.

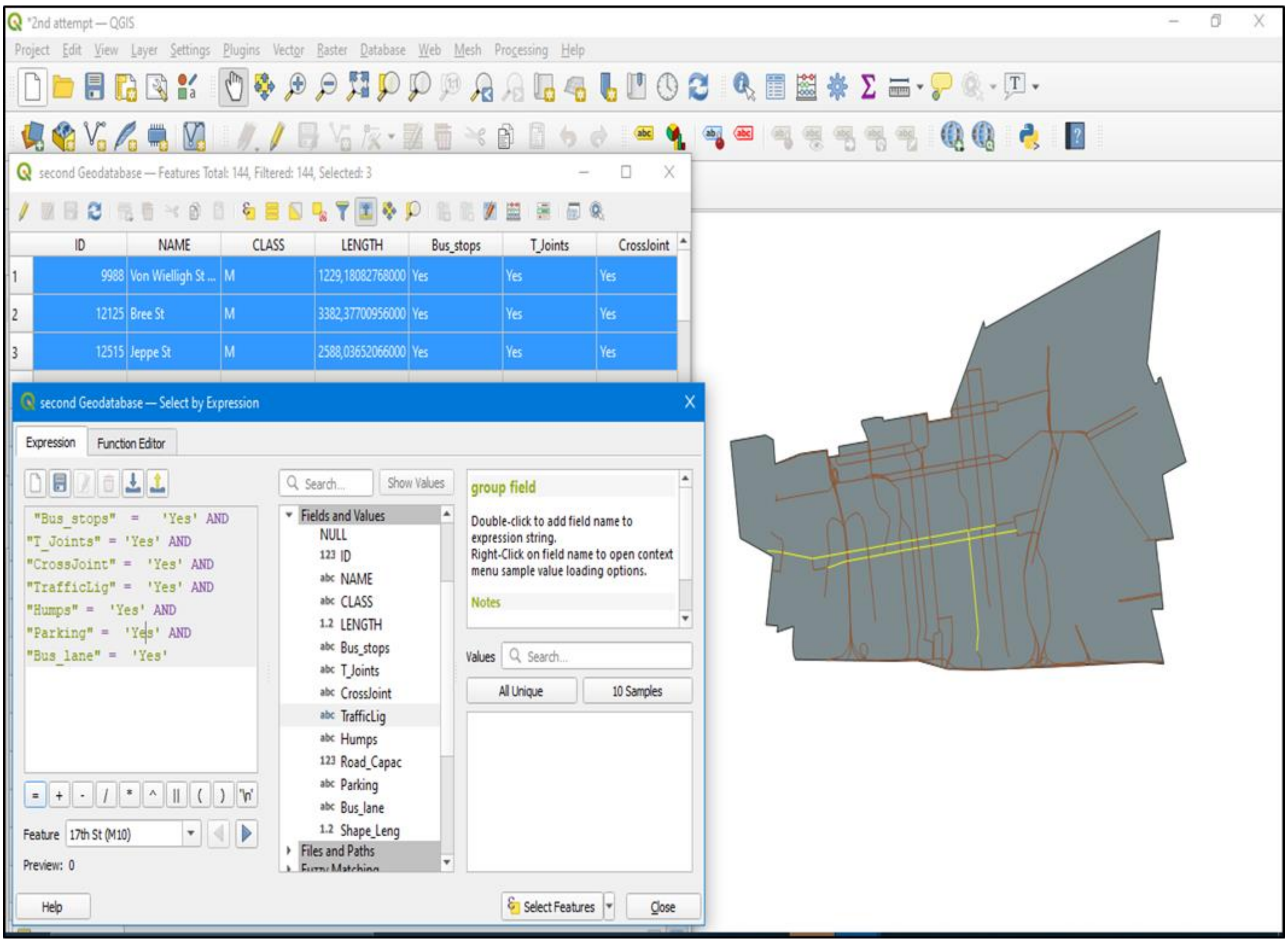

Figure 8. Road segments with all factors present.

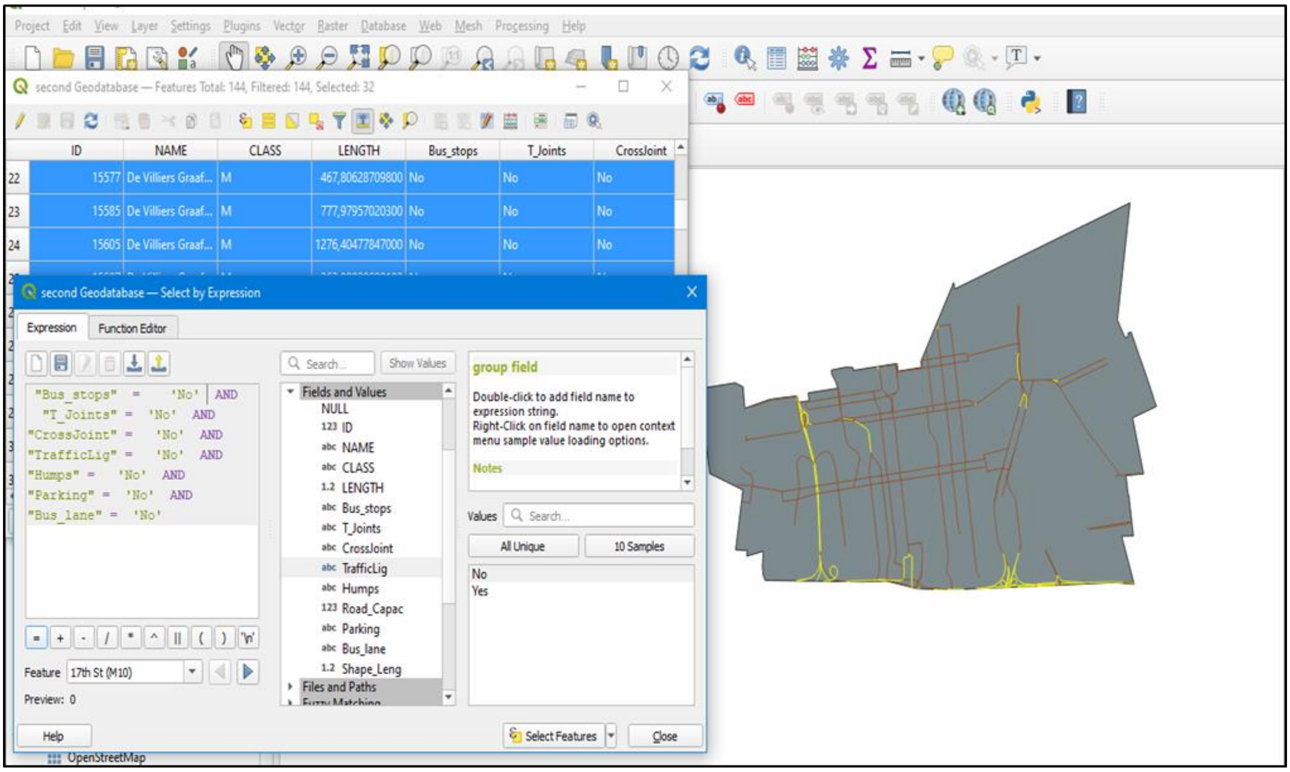

Figure 9. Road segments with no factor present.

5. CONCLUSION

The City of Johannesburg is striving to achieve sustainability in its inner-city, whereas, traffic congestion remains a major hindrance. By extension, this has led to a decrease in the inner city's economic and social activities. Having a road transport infrastructure geodatabase in the City would help facilitate informed decision making in tackling road congestions in the inner city. This prompted the aim of this paper, which is to assess traffic congestion occurring in the City of Johannesburg CBD by developing a road transport infrastructure geodatabase, this geodatabase is to be queried to be able to determine roads or portions of the roads that are highly or less susceptible to traffic congestion.

Processes involved include creating a geodatabase by capturing into the attribute tables, factors that cause traffic congestion. Some other factors, such as work zones could not be captured as these are temporary features. The successful development of the geodatabase forms the backdrop for the subsequent analysis and results, as it becomes fast and easy to run SQL queries to retrieve segments or stretches of road that are highly or less prone to traffic congestion. Mapping and visualization are also possible by symbolizing the attributes. Without a doubt, the application of GIS in the assessment of traffic congestion in Johannesburg's inner city would help facilitate quicker and informed decision-making concerning traffic congestions or road transport infrastructure upgrades. This would in turn aid the City in attaining road transport sustainability, thus achieving the SDG goal 11.2.

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