A Study on Local Air Pollution Due to Transport Emissions in Kandy City

Sachintha Yatigammana[1], Gayashika Fernando[2], Migara Liyanage[2]
[1]School of Civil and Mechanical Engineering, Faculty of Science and Engineering, Curtin University, Kent St, Bentley WA 6102, Australia
[2] Faculty of Engineering, Sri Lanka Institute of Information Technology
New Kandy Rd, Malabe, 10115, Sri Lanka
gayashika.f@sliit.lk, migara.l@sliit.lk
Corresponding author: s.yatigammana@student.curtin.edu.au

ABSTRACT

Air pollution has become one of the greatest challenges that the world is facing today. According to World Health Organization (WHO)there are 4.2 million annual deaths due to outdoor air pollution. Furthermore, about 90% of global population breathe polluted air. The most harmful cause of outdoor air pollution is recognized to be unorganized traffic management. In the instance of Sri Lanka, Kandy city has been recognized as crucial where necessary actions are required to be taken. This study presents harmful emission values produced by a daily count of vehicles entering the city alongside respiratory diseases and illnesses recorded. Detailed analysis provides pollutant emissions due to unorganized traffic management within Kandy city concentrating over locations from Getambe Junction to Kandy Clock tower and from the city centre towards Mahaiyawa Tunnel and Ampitiya Junction (locations are pinned on figure 1). Calculation of pollutant factors are intended to be done using three main methods namely, Tier 1, Tier 2 and V/C ratio method aided by vehicle fuel type, fuel efficiency, travelled distance and carriageway congestion values. Emission values for pollutants Carbon monoxide (CO), Nitrogen oxides (N_2O, NO_X) and Sulphur dioxide (SO_2) were identified in this study along with PM2.5 and PM10 values. It was to be seen that, over 100,000 vehicle cross Kandy city limits on both weekdays and surprisingly higher values in weekend with each carriageway within the city resulting over a 65% of congestion value. With 31% of daily trips being travel to work, the public transport system fails to deliver its purpose efficiently and effectively. With unorganized traffic management, stagnant and slow-moving vehicles tend to pollute 41% more SO_2 and 14% more NO_X gasses above global standards affecting the first five kilometers from the city center, which claimed to facilitate the zone of highest quality of life. Current records show PM2.5 values in Kandy to read above 50μg/m3 and PM10 values to be as high as 100μg/m3.

KEYWORDS: *Kandy, Air pollution, Traffic management, Emission, Respiratory, Sri Lanka*

1 INTRODUCTION & BACKGROUND

Breathing sustains life as we breathe to live for another day. Rapid development of technology has neglected the damages caused to mother nature including our atmosphere where we face the consequences today. The World Health Organization points out 4.2 million people die due to outdoor air pollution whereas 9 out of 10 people breathe air with pollutants. Scientists believes that association of air molecules with chemical and microbial pollutants happen to pollute air around us. *(Wei et al., 2010)* Air surrounds humanity providing breathable air to all lives therefore, upholding an environment with quality breathable air is a necessity. Particles originate from roadside soil due to wind turbulences are known to be natural, while anthropogenic particulates are generated by domestic emissions, industrial activities and mainly by automobile vehicle exhaust, tire wear, and road wear. *(Wei et al., 2010)*

The World Heritage City of Kandy regrettably suffers from a rising high air pollution threat over the past decade. Kandy is situated in a valley of mountain ranges, expects to have high air pollution owing to its geographical location and the increasing number of automobiles. The matter in hand is not

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foreign as numerous studies have been carried out in the past. Key highlights would be studies by Illeperuma (2010) since 2002 to 2020. Where he made the bold statement of vehicle emissions to be the main cause for Kandy air pollution threat.

Early testing of pollutants results 55-60% of air pollution to be documented by automobiles with SO_2, NO_2 and O_3 percentages are above expected levels by 41%, 14% and 28% with motorcycles, passenger cars and three-wheelers to have increased by 290%, 300% and 380% respectively for the last decade. Elangasinge & Shanthini (2008) including Illeperuma evaluated PM10 values in Sri Lanka to rise 55% within half a decade. Extensive results from past show around 112,000 vehicles cross the district weekdays which can be roughly translated into around 56,000 entering Kandy city limits daily. Furthermore, 25 sampling sites around Kandy reported Nitrogen oxides, Sulphur dioxide and Ozone (O_3) concentrations had already exceeded standards by 38%, 53% and 40% respectively. A highest PM10 value of 340 µg/m3 was recorded towards Katugastota area with Gatambe roundabout emitting 230 µg/m3 daily. The study on "Kandy city Transport Study" was done by University of Moratuwa with associating University of Peradeniya in the year 2011 points out around 112,000 vehicles cross the study area and 56,000 vehicles entering Kandy city limits daily.

The Sri Lankan situation is no different to other developing countries. As *Abeyratne et al., (2010)* states 60% of total ambient air pollution in Sri Lanka is to be due to vehicular emissions and over the past few years high levels of air pollutants were recorded during the Northeast monsoon period from mid-November to January. Sri Lanka does not have a perfect record in air quality as parts of the island suffers from severe air pollution issues. A key highlight would be cities within the central highlands such as Kandy where pollution records tend to point high. *(Ileperuma, 2010)*. A study done by Illeperuma in 2020 states "Air quality in Kandy is worse than that of Colombo owing to its geographical location." Apart from mother nature, many researchers and environmentalists believe, unorganized and uncontrollable flow of traffic within Kandy city causes bad air pollution the most. As Vilani (2006) points out, "the city of Kandy is situated in a valley between two mountain ranges, expects to have high degrees of air pollution owing to its geographical location and the increasing number of automobiles" which has led to a congested traffic flow within city limits. As latest studies show that, Kandy to be the highest most air polluted city in Sri Lanka revealing its true danger. As a study *(Abeyratne et al., 2011)* points out Kandy holds a daily traffic volume of 106,000 vehicles within 4km^2 of limited land and resting a population above 250,000 people. It was Illeperuma who made the first steps on proving automobile emissions to cause the most air pollution regardless natural effects. As his study extends, air pollutant percentages collected within different types of monsoons result higher SO_2, NO_2 and O_3 percentages during the north-east monsoon period recording 46%, 43% and 39% respectively. As previously assumed sea winds to gather pollutants around central highlands was proved wrong since south-west monsoon recorded 31% SO_2, 28% NO_2 and 28% O_3. With comparatively lower pollutant values recorded by inter-monsoons, Illeperuma states "the only possible explanation to this observation is transboundary pollution." Traffic congestion in Kandy produces SO_2, NO_2 and O_3 above expected levels by 41%, 14% and 28% during the years 2001-2005. With data acquired from Ministry of Environment (2012) he points out 55-60% percent of air pollution to be documented by automobiles where 20-25% was due to industries and 20% by domestic sources, highlighting the fact that automobiles play the huge roll in air pollution.

2 METHODOLOGY

To answer the emission issue using traffic data would be the sole objective and quest of this paper where current vehicle data and emission factors are proposed to calculate harmful pollutants in the city of Kandy. This was referred to the "Katmandu Model" where vehicle and traffic data were considered to calculate emission values at various locations. Subsequently, a study area was created covering the city of Kandy and all its main corridors that would lead to and from the city centre. The study area was then broken down into six (6) pinpoints to analyze and calculate traffic data and emission data more accurately. Emission factors were referred with respect to fuel type used by each vehicle type in Sri Lanka to proceed with calculations. Thus, the main objective of this paper to study and quantify the emissions put out in Kandy city by vehicular transportation. It would also relate to vehicle data and health risks due to air pollution.

The methodology laid by using vehicle and traffic data to calculate emission values at various locations. Subsequently, a study area was created covering the city of Kandy and all its main corridors that would lead into and from the city centre. The study area was then broken down into six (6) pinpoints to analyze and calculate traffic data and emission data more accurately. Emission factors were referred with respect to fuel type used by each vehicle type in Sri Lanka to proceed with calculations where globally accepted calculation methodologies were used. These data were obtained for the set pinpoints and thereafter analyzed to obtain rich information to graphically interpolate on an open-source GIS software and discuss. Many obstacles did lay at each step such as the acquisition of vehicle and traffic data for the current year (2019) where extrapolation methods were followed using previous research records. Hence the very narrow topic, media such as research papers, journals and other publications were hard to find or refer. Additionally, due to the global pandemic and lockdowns, reaching out to institutions were out of possible as well. This matter also led to lack of updated government reports for the years 2019 and 2020 hence extrapolations methods were to be the only method to drive through.

Kandy district is a vast area of study hence it combines a few major cities consisting dense population. Due to this matter, this study considers a planned boundary around Kandy City central connecting all major entrances and exits towards and out of Kandy City. Geographically, the study area was as shown below. A total of six (6) pinpoints were chosen coveting main traffic corridors in Kandy city namely, Getambe Junction (1), Mulgampola Junction (2), Kandy Girls' High School Junction (3), Kandy Clock tower roundabout (4), Mahaiyawa Tunnel (5) and Ampitiya Junction (6) as illustrated on figure 1 below.

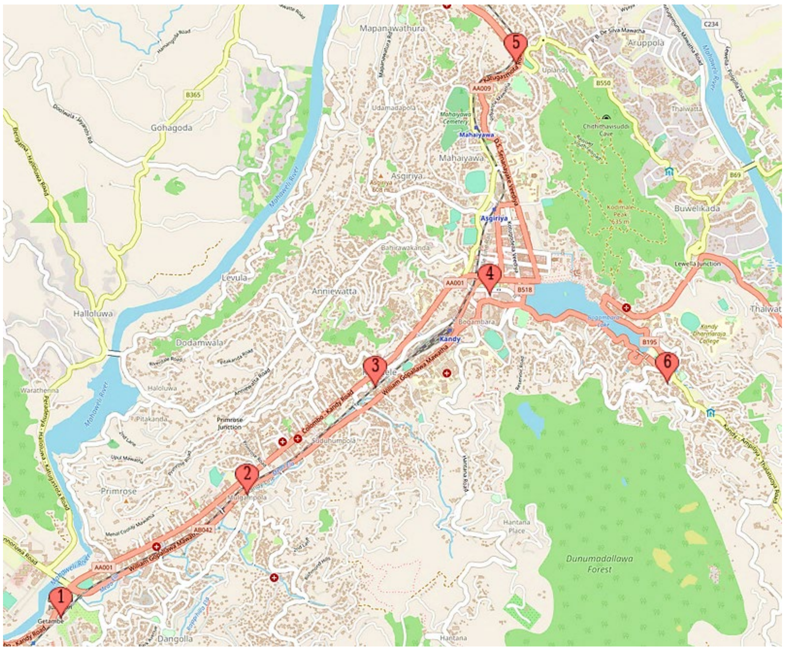


Figure 1. Study Area map consisting of the 6 pinpoints for this research

National Transport Authority have conducted annual statistics for provincial vehicle registrations up to year 2017. With obtained values per annum, linear extrapolation was used to calculate vehicle data for the years 2017 and above. Due to the incomplete data and resources on vehicle and traffic data, extrapolation of data for the years 2018 and 2019 were decided to be feasible and applicable.

With considerable deviations, it was decided to adopt Central Provincial data for continuation as the boundary was more authentic and realistic compared to nation-wide values. After settling on the obtained values from National Transport Authority above, the extrapolation method was used to find current traffic values for Kandy city. The linear projection of all vehicle types was obtained by a continuation from past years. Thereafter, vehicle values for years 2018 and 2019 were obtained using the generated equation of the graph and were tabled as shown by table 1 below.

Table 1. Extrapolated Vehicle data for years 2018 and 2019

Vehicle Type	2012	2014	2015	2016	2017	2018	2019
Bikes	86,887	103,494	127,184	146,131	161,523	**176,915**	**192,307**
Light Vehicles	82,752	102,748	119,609	127,504	130,655	**133,806**	**136,957**
Passenger Vehicles	32,767	38,188	47,107	50,378	53,109	**55,840**	**58,571**
Light Commercial	25,129	29,161	30,650	30,992	32,135	**33,278**	**34,421**
Heavy	23,472	24,019	24,716	25,340	26,279	**27,218**	**28,157**

Further extrapolation results show over 187,000 vehicles cross Kandy city limits daily and there is no reduction for weekend values as weekend data shown an increase of over 700 vehicles. This proves the reduction factor is not as large as expected by the majority and does not exist in real-world calculations. Due to the constant traffic flow with smaller numbers on weekends, the number has managed to overcome weekday figures where vehicle flow shows periodic traffic hikes unlike constant moving flow on weekends. It was noticed that a high number of light vehicles and passenger vehicles to use by-pass roads as well as to share the greatest number of vehicle entries towards the city center. Around 30,000 vehicle units were reduced towards the city through by-pass roads. This scenario was tested back in the year 2011 by University of Moratuwa and University of Peradeniya.

The V/C ratio method would simply calculate the volume over congestion of a particular carriageway. To obtain this ratio, the designed maximum volume of a carriageway must be known and the present vehicle flow on the carriageway must be known as well. these calculations were carried out by the previous study in 2011 which resulted in heavy congestion factors for many roads in Kandy city. Data extracted from the study can be used in reference to this as the flow has increased slightly compared to 2011 values.

3 RESULTS

Table 2. Location based emission values with vehicle-wise (shown in- g/km.per day)

Corridor	Vehicle Type	Weekday				Weekend			
		Emission Values (g/km.per day)							
		CO	NO_X	N_2O	SO_2	CO	NO_X	N_2O	SO_2
Sirimavo Bandaranayake Mawatha	Motorbikes	140218	8978	93	9	122516	7844	81	7
	Light vehicles	29192	2440	87	16	33769	2822	101	19
	Passenger vehicles	20087	18056	339	35	17509	15739	295	30
	Light Commercial	7552	16736	181	10	8881	19679	213	12
	Heavy vehicles	771	26896	98	16	898	31334	115	19
	Total	272kg				262kg			
Katugastota Road	Motorbikes	68826	4407	45	4	60141	3851	40	4
	Light vehicles	14330	1198	43	8	16575	1385	49	9
	Passenger vehicles	9860	8863	166	17	8595	7726	145	15
	Light Commercial	3707	8215	89	5	4359	9660	105	6
	Heavy vehicles	378	13201	48	8	441	15382	56	9
	Total	296kg				284kg			

Sangaraja Mawatha	Motorbikes	100543	6437	66	6	87858	5625	58	5
	Light vehicles	20934	1750	62	12	24213	2024	72	13
	Passenger vehicles	14404	12947	243	25	12555	11286	212	22
	Light Commercial	5415	12000	130	7	6368	14112	153	8
	Heavy vehicles	154109	9867	102	9	644	22471	82	14
	Total	133kg				129kg			

City Centre	Motorbikes	29572	2472	88	16	131129	8396	87	8
	Light vehicles	21375	19213	360	37	35857	2997	107	20
	Passenger vehicles	7355	16300	177	10	18027	16204	304	31
	Light Commercial	969	33803	124	21	9176	20334	220	12
	Heavy vehicles	154109	9867	102	9	1143	39896	146	24
	Total	195kg				188kg			

When comparing weekday and weekend emissions, a rise in CO values can be seen throughout all locations due to its emission factor. The heart of the city still shows high pollution values overall. Weekday results show over 213kg of CO, 81 kg of NO_x and 8kg of N_2O with SO_2 values to be around 1 kg within Kandy city. Second most polluted location was to be pinpoint 1,2,3 of Sirimavo Bandaranayake Mw. Showing almost 200kg of CO, 73 kg of NO_x and 8kg of N2O. Ampitiya junction was to be the third highest polluted location showing 140kg of CO, 52 kg of NOx and 5 kg of N_2O. The pinpoint of Mahaiyawa was to show the least pollution with 97 kg of CO, 35 kg of NOx, 4 kg of N_2O and 0.5 kg of SO_2. Weekend values show a similar pattern with city centre values emerging on top over other locations. City centre values show a weekend reduction of 8.6% CO emissions whereas other pollutants were all increased. Due to the decrease of motorcycles and light vehicles towards the weekend, harmful pollutants from unrefined, small engines have reduced compared to weekday values. Even though CO values increase, NO_x, N_2O and SO_2 emission values show 7.5%, 1.65% and 3.2% reductions respectively.

Considering independent vehicle emissions, motorcycles have led at all locations with the highest numbers recorded. Motorcycles emit around 100kg a day at any given location stretch with peak values to be 154kg at city centre. The second highest harmful vehicle type was the three-wheeler (light vehicles) producing around 25 kg a day with peak values up to 30kg. A common issue for both vehicle types would be the use of poor-quality engines with small cylinder capacities that revs up to high rpm values to produce power in order to make a move on. This causes extreme high pollutant and emissions to travel a small stretch of road which would be the case identified in Kandy city. Passenger vehicles remain comparatively low as for their refined engine technologies as mentioned earlier that keeps daily emission values around 15kg. Considering weekday and weekends total pollution, weekday values tend to be overall high with weekend values to show certain hikes on certain locations due to the constant traffic flow over a weekend day compared to weekday partial hikes. Therefore, when observed, weekday values tend to produce higher values overall in many traffic hotspots. The highest concentration was recorded at the heart of the city which was at the clocktower where 284kg was noted on weekends and 296kg on weekdays. The main corridor of Sirimavo Bandaranayake Mawatha was second in concentration with 262-272kg values. The end of the lake round in Kandy where the road leads to Ampitiya is to have the third highest with 188-198kg of pollutants gathering daily. finally, the road leading to Katugastota, the Mahaiyawa road recorded the lowest pollutant value with 129-133kkg pollutants value on a daily basis.

Weekday and weekend traffic values show minor deviations that affects the overall pollutant composition. As for weekend values, there can be seen a reduction of motorbikes and light vehicles as travelling requirements towards the city centre is reduced on weekends due to work holidays. On contrast, private vehicles such as passenger vehicle ratio has increased. Total motorcycle population has only decreased by 3% where passenger vehicles have increased by 4%. Goods vehicles, and ither heavy vehicle types including route busses have increased over the weekend due to special projects, goods transport etc. The weekend traffic variation is not clear as the compounds remain largely unchanged. This can be clearly identified and discussed by identifying the number of vehicles at each location tested. This reduction has affected local pollutant percentages as CO emissions have reduced by 4% yet increased NOx gases by 4% as well. As mentioned earlier, the impact of NOx gases would affect the environment directly compared to CO gases. A key highlight would be the huge partition of pollutants owed by motorcycles on both weekends and weekdays where weekdays percentage to take up almost 3 quarters of total pollutants by all vehicles. the refined engines of passenger cars show account for only 10-15%. Due to the low number of heavy vehicles, they emit low percentages of pollutants corresponding to almost 1% on weekdays. However, the weekend scenario changes its course due to the variation in traffic and vehicle type. Goods and construction vehicles, lorries and busses have increased on weekends thereafter showing a 11% increase in pollutant percentages. However, motorcycles tend to be the highest environmental pollutant vehicle due to small, cheap, basic engines that are not ecofriendly to use.

However, the main focus of this study would be the determination of emission values. Cumulative sum of all pollutants with respect to the location were taken beforehand plotting to the Graphical Interpolation Software (GIS) (maptive.com).

Figure 2. Measured volume of vehicle for each corridor.

Data plotting began with vehicle count tracking study locations. Figure 2 plots out vehicle volumes measured at each corridor entering/leaving Kandy city. It was observed that Sirimavo Bandaranayake Road and William Gopallawa Road shares around 44,000-45,000 vehicles a day which adds up to a portion of city centre traffic which records a missive 150,000 vehicles a day. Though these values are two-way traffic data, for a small city as Kandy, the congestion is above global standards. Both Sangaraja Mawatha and Mahaiyawa roads show intermediate traffic values of around 60,000-70,000 a day. Figure 3 below illustrates, the derived emission values with radii in proportion to the severity of pollutants emitted. Naturally, the city centre was to emit the highest pollutants a day with Getambe junctions surprisingly showing high values as well. Sirimavo Bandaranayake Mw. Was second highest in emission values since the long stretch of road. As a result, both locations show above 250kg/km values within the day. Ampitiya road comes third with slightly less emission values. Mahaiyawa road shows the lowest emission values of around 100-150kg/km a day hence the loss of motorcycles and light vehicles observed within that stretch. As City centre and Getambe junction to be in the red zone while the rest of Sirimavo Bandaranayake Mw. To be in the orange zone. A relatively calm yet not safe blue zone is to be Mahaiyawa road with intermediate yellow zone to be the Ampitiya junction road.

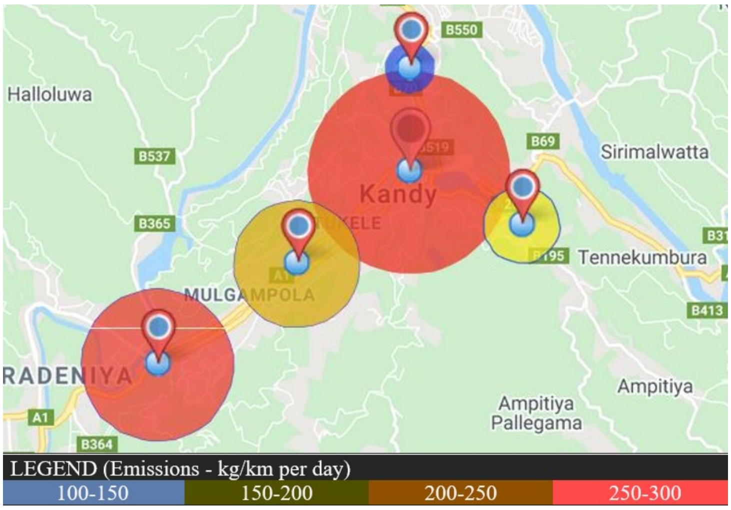


Figure 3. Severity of emission values between pinpoints

Emission calculations were also done using the V/C ratio method as well. the results show the congestion factor and the amounts of Carbon emissions emitted correspondingly. Both conditions have been plotted on figure 4 below. The flow condition is illustrated by the smaller radii with the color corresponding to its congestion factor. The larger radii would symbolize the emission values in proportion to the pollutants emitted as well.

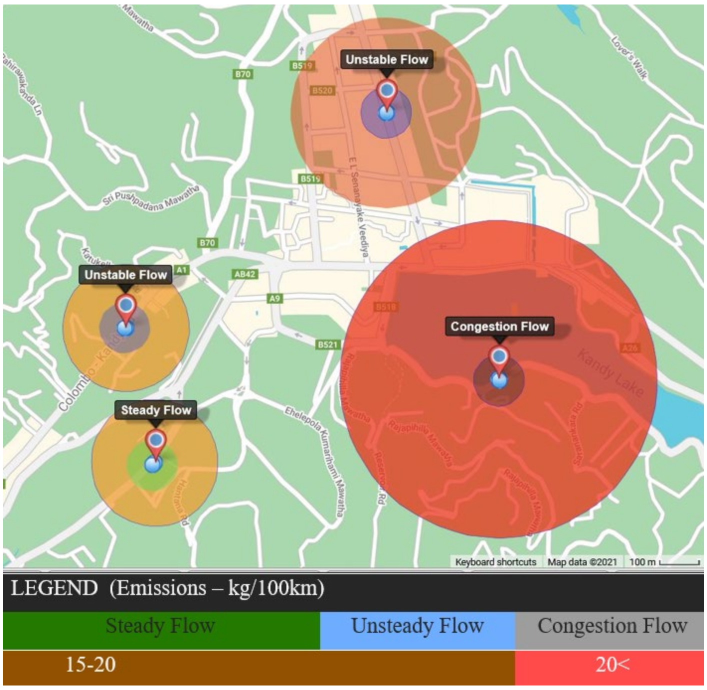
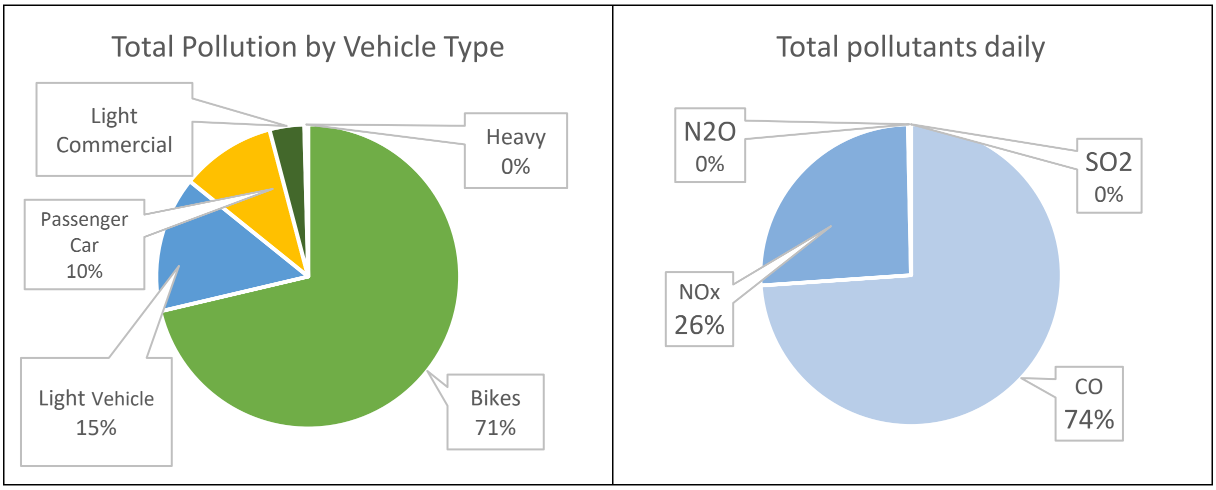


Figure 4. Carbon emission adapting V/C ratio method

William Gopallawa road was the only location with a steady traffic flow while the rest of Kandy carriageways were above designed values. Sangaraja Mawatha was showing congestion flows which was the worst-case scenario to be expected while Sirimavo Bandaranawake road and Adhahana maluwa road (Mahaiyawa Road) were to be unstable flows which was slightly better than a congestion flow. The results were not impressive as all main carriageways in Kandy were to be out of control showing high traffic flow values. The resulting Carbon emission values were also not within acceptable margins as well. As every location showed over 15kg/100km values with Mahaiyawa Road and Sangaraja Mawatha showing over 25kg/100km a day which include those locations to be in the red zone in figure 4.

Table 3. Emission results based in graphical form



Charts in table 3 would analyze the potential threat to Kandy with respect to the vehicle type which is crucial in this results stage. A key highlight would be the huge partition of pollutants owed by motorcycles on both weekends and weekdays where weekdays percentage to take up almost 3 quarters of total pollutants by all vehicles. the refined engines of passenger cars show account for only 10-15%. Due to the low number of heavy vehicles, they emit low percentages of pollutants corresponding to almost 1% on weekdays. However, motorcycles tend to be the highest environmental pollutant vehicle due to small, cheap, basic engines that are not ecofriendly to use. Daily values show CO emissions to be 74% with NOx gases by 26% with negligible SO_2 and N_2O gasses. The impact of NOx gases would affect the environment directly compared to CO gases.

4 CONLUSIONS

Many developing cities face the threat of air pollution whereas the historical city of Kandy was proven to be another victim. The results concluded showing the huge negative impact of air pollution faced by the city and the aftermath from it. Due to a very high volume of vehicles crossing city limits on both weekdays and weekends, many locations were to be over polluted in contrast to global standards with carriageways to over assist vehicles beyond the designed flow and to emit high values of emissions due to the vehicle types used. Derivations were calculated for the year 2019 extrapolating data from 2011 to 2017. IPCC emission calculation methods were followed aided by fuel type, fuel efficiency and travelled distance. Weekday and weekend traffic, pollutant values with percentages were key results obtained. A health risk analysis was carried also carried out to strengthen the argument. Over the period from 2011, almost over 50% of vehicles have increased producing 60% more CO and 50% more SO_2 and N_2O pollutants. The city was to emit over 900kg of pollutants daily with the heart of the city to be the most polluted. Respiratory diseases were to be filed as the 3rd leading cause of hospitalization and 4th leading cause of death in Kandy district establishing the degree of threat.

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