Transport Emissions Modeling using Google Maps: An alternative approach for vehicle flow analysis

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Abstract. Continuous measurements of transport emissions are considered key issues for air pollution management in the transportation sector. In some instances, researchers may come across difficulties in doing transport emissions modeling such as overcomplexities and laborious methodologies. In this regard, the authors are introducing a novel method of doing a transport emissions modeling by utilizing Google Maps data. By getting the average travel time of a road segment and the corresponding length, the average speed can be obtained. This speed will be used to identify the flow of vehicles in terms of Passenger Car Unit (PCU) through a speed-flow curve on the basis of a Roadside Frictions Index (RSFI). PCU percentages are derived from the actual counting of vehicles using the street view features of Google Maps. Once the PCU count and the PCU percentages are established, the actual number of vehicle flow per type can now be determined. Consequently, emissions loads are calculated by multiplying the vehicle flow and road length to emissions factors derived from reliable sources.

1. Introduction

According to IEA[1], the global energy-related CO\textsubscript{2} emissions have hit a record high of 33.1 Gt CO\textsubscript{2} in 2018 or an increase of 1.7%. This is effectuated by the rising global energy consumption demand which increased by 2.3% in 2018 or almost twice the average growth rate since 2010. Such occurrence is quite alarming despite the implementation of the Paris Agreement which intends to limit the global warming below 2°C in the pursuing efforts of Greenhouse Gas (GHG) emissions reduction. The GHG emissions and the effects of global warming and climate change are some of the critical issues the global community is facing today [2]. The Paris Agreement is a treaty which requires all the 196 participating countries to develop and submit long-term plans of lowering GHG emissions. These plans are called nationally determined contributions, and each country will have to communicate each action they perform in reducing GHG emissions in order to achieve the goals of the agreement. The conference of the parties will be held every five years and all countries should find a way to evaluate their progress “based on the best available science” [3].

The transportation sector being one of the most fossil product-consuming sectors in the world accounts for around 21% share of the total global carbon emissions [4]. It should be noted that the transport sector alone covers approximately 24% share in the global CO\textsubscript{2} emissions by sector in 2018 [5]. In the report of Hall and Lutsey [6], road transport dominates the share of GHG emissions in the overall sectoral emissions by mode in 2018. In addition, all road vehicles when combined was estimated to be 77% of the distribution of GHG emissions by the transportation sector worldwide. However, the relevancy of these data is topical and there is a need to regularly quantify, monitor and evaluate whether emission reduction goals are properly monitored and met. From year to year, studies pertaining to quantification of emissions are done for the purpose of evaluating vehicular emissions and air quality.
assessment. As regards transportation, assessment of mobile emissions is important in air quality improvement programs [7].

In the interest of exploring the dynamics, scale and magnitude of emissions from the transport sector, transport emissions modeling provides useful emission data which may be essential for the theoretical and conceptual development of a particular area [8]. Moreover, continuous estimation and measurement of emissions by road traffic are considered significant issues for air pollution management in the transportation sector. However, it is not easy to do a road transportation emissions modeling and there are difficulties faced in this regard. Doing one may sometimes depend on the assessment of the researcher as well as the methodology that will better fit the situation. For instance, vehicle flow analysis is one part of transportation emissions modeling. The more disaggregated the data gathering is, the more time consuming the study will be [9]. Additionally, the process becomes labor-intensive.

In this study, the authors are introducing a novel method for transportation emissions modeling. The analysis is performed through available data generated from Google Maps with respect to Epifanio de los Santos Avenue (EDSA), a major road located in Metro Manila, Philippines. EDSA will be divided into a number of segments where each segment will undergo emissions load calculation. The objective of this study is to quantify GHG emission shares specifically the emission shares of air pollutants in the transport sector coming from the various types of vehicles plying along each defined road segments in EDSA. By acquiring the average travel time of vehicles from Google Maps in a certain segment and the corresponding road length, the average speed of vehicle flow is obtained. Furthermore, the traffic flow as passenger car unit (PCU) count per time unit is determined through speed-flow curves in reference to a roadside friction graph. In a general concept, emissions are calculated by multiplying emission factors of a pollutant and a rate of an activity [10]. With regards to transportation systems, the estimation of emission load is calculated by multiplying activity data on the basis of PCU count and emissions factors [11].

2. Methodology

EDSA serves as a major thoroughfare connecting the northern and southern parts of Metro Manila while interlinking five large cities [12]. EDSA as the object of this study was divided into 12 segments. For simplification purposes, each segment was bounded by two points in reference to the successive Metro Rail Transit Line 3 (MRT-3) stations. Starting from the northernmost station of MRT-3 in EDSA, the first 5 stations which are located in Quezon City are the following: North Avenue Station, Quezon Avenue Station, GMA Kamuning Stations, Araneta Cubao Station and Santolan-Annapolis Station. Ortigas Avenue station is the sixth station situated in Pasig City. Mandaluyong City has Shaw Boulevard Station as the seventh station and Boni Avenue Station as the eighth station. Makati City has the ninth, tenth and eleventh stations which are Guadalupe Station, Buendia Station and Ayala Avenue Station, respectively. Lastly, Taft Avenue Station as the only station located in Pasay City is the twelfth station [13]. Both the southbound and northbound directions of the road are considered in the emission load calculation.

![Diagram](image)

**Figure 1.** The conceptual framework in the estimation of emission load.
To estimate the emission load for each segment, the conceptual framework for this study is presented in Figure 1. Initially, the average travel time data and the road length per road segment were collected from Google Maps. These factors were converted into the average speed of all the vehicles passing through a segment for each hour in a 24-hour time. Using a Speed-Flow Curve, the estimated hourly vehicle flow in terms of Passenger Car Unit (PCU) is determined by plotting the computed bulk speed into the curve. The hourly PCU counts were consolidated in one day followed by converting the rate of periodicity from daily to monthly PCU count on the basis of a classified PCU count. The PCU mix is derived from actual classified counting of vehicles using the street view of Google Maps. Finally, the emission load is estimated by multiplying the monthly vehicle count and the corresponding emission factor per vehicle type. Each concept will be further discussed in the succeeding subsections.

2.1 Average Travel Time per Road Segment

The average travel time data was collected from Google Maps. One of the considerations of the authors was to perform the study in the month of June when typically, most schools in the country begin their school years. The month of June is also considered the onset of the rainy season in the Philippines[14]; however, the impacts of weather conditions on vehicle flow characteristics were not considered in this study. As regards to the collection of hourly average travel time data, a 24-hour time frame was used by recording all the full hours travel time data starting from 0:00 to 23:00. For each day, the average travel time was calculated every hour in a 24-hour time frame by getting the mean value of the minimum and maximum travel time data generated in Google Maps. In the interest of saving time during data collection, all the days in June 2019 were grouped into five classifications depending on the traffic situation per day. The classifications were Monday, Weekday, Friday, Saturday and Sunday. The traffic situation during Tuesday, Wednesday and Thursday were assumed to be identical; therefore, these days comprise the Weekday classification. June 1 (Saturday), June 2 (Sunday), June 3 (Monday), June 4 (Weekday) and June 7 (Friday) were the specific dates of the data collection. One difficulty encountered during the actual data collection was that the travel time collected in Google Maps had slight variations from one collection day to another notwithstanding the fact that the reference date is the same. To deal with this constraint, the authors conducted five sets of data collection on five different days attributed to the specific dates of collection and calculated the average of these data as a standard data value for each day classification.

2.2 Bulk Speed

Bulk speed is the average speed of all vehicles in a segment. To calculate for the segment average speed, the segment length or the distance between two coordinate points of a segment was divided by the corresponding average travel time [15]. The formula for bulk speed is expressed in Eq 1. Vehicle bulk speed $V_B$ is in terms of kilometers per hour (km/hr), $L_S$ is in terms of kilometer (km), and $T_{Ave}$ is in terms of minutes (min).

$$V_B = \frac{L_S}{T_{Ave}} \times 60$$  \hspace{1cm} (1)

2.3 PCU Count

The calculated bulk speed for each segment was used in determining the PCU Count. PCU is the conversion of a traffic volume having a characteristic of vehicle-type heterogeneity by the use of a relative weightage factor to an equivalent homogeneous quantity [16]. The calculated average speed was plotted horizontally from the $y$-axis of a Speed-Flow Curve which in return gave the volume of vehicle flow. By plotting a line vertically from the intersection of the horizontal line and the Speed-Flow Curve to $x$-axis, the vehicle flow was determined in PCU/hr.

Speed-Flow Curves are the variations of speed profiles of the operating vehicle volume. Various friction elements are used to develop these Speed-Flow curves. In actual scenarios, these friction elements known as side friction factors are activities that occur on the side of the roads or on the roads themselves which affect the normal traffic flow of vehicles [17]. These side friction factors are based on the static and dynamic characteristics and positions on a road. On the basis of quantifying side friction factors, an index called Roadside Friction Index (RSFI) is introduced. For this study, the authors adopted the graph of the Speed-Flow Curve in the study of Pal and Roy [18] which is presented in Figure 2. This study utilized the Speed-Flow Curve with an RSFI value of less than 40.
To accurately calculate the hourly vehicle flow, multiple points were fitted on a second-degree curve based on the referred Speed-Flow Curve with a less than 40 RSFI value as seen in Figure 2. Thus, a quadratic equation as a function of speed was developed.

The equation for computing the hourly vehicle flow is shown on Eq 2 where the variable $PCU_{\text{Count}}$ is the hourly vehicle flow in PCU/hr. The number of lanes is assumed to be 5 for both northbound and southbound carriageways, and this is multiplied in the $PCU_{\text{Count}}$ value in order to get the total vehicle volume.

$$PCU_{\text{Count}} = 2843 - 180.09 V_B + 3.26 V_B^2$$

However, the authors hypothesize that the derived parabolic equation only applies from 5:00 to 22:00 during the 24-hour time frame. This is due to the assumption that there is a significant drop in vehicle flow along EDSA starting from 23:00 to 5:00. Correction factors were introduced in the computation of vehicle flow as constants of proportionality in reference to an actual counting of vehicles for all the hours of the day. These correction factors were multiplied to the summation of the PCU count values from 5:00 to 22:00 hours on the same reference day. The hours of the day with significant drops in vehicle volume and the respective constant of proportionality are presented in Table 1.

| Hours with Significant Vehicle Volume Drop | Correction Factor |
|-------------------------------------------|-------------------|
| 0:00                                      | 0.02              |
| 1:00                                      | 0.01              |
| 2:00                                      | 0.01              |
| 3:00                                      | 0.01              |
| 4:00                                      | 0.02              |
| 23:00                                     | 0.03              |

### 2.4 Monthly Vehicle Count

To determine the share of each vehicle type in a segment, Google Maps is capable of showing street view on a selected point coordinate. Actual counting of vehicles was done to break down the vehicle volume by vehicle type. This was accomplished by selecting point coordinates within a segment. The number of point coordinates per 1 km of EDSA is 4. Additionally, the points were selected with approximately equidistant spacing one point after another. After counting all the vehicles per type for all the selected point coordinates, the PCU percentage per vehicle type was established by integrating the array of the total number of vehicles per type and recommended passenger car equivalence factors (PCEF). Table 2 shows the summary of different PCEF for each vehicle type [19]. According to the reference, tricycle, car, jeepney, bus, light-duty truck and heavy-duty truck have the following...
respective PCEF: 1.0, 1.0, 1.5, 2.0, 2.0 and 2.2. The authors of this paper assumed that a motorcycle has a 0.05 PCEF while a taxi and a sport utility vehicle (SUV) both have the same PCEF as a car.

Table 2. Summary of the Recommended PCEF for each vehicle type

| Type of Vehicle | PCEF |
|-----------------|------|
| Tricycle        | 1    |
| Motorcycle      | 0.5  |
| Jeepney         | 1.5  |
| Taxi            | 1    |
| Car             | 1    |
| SUV             | 1    |
| Light duty      | 2    |
| Bus             | 2    |
| Heavy duty      | 2.2  |

The PCU percentage for each vehicle type was used to calculate the monthly vehicle count. In sub-section 2.3, the calculation of the hourly PCU count was explained. The hourly PCU counts were consolidated into total daily PCU count by integrating all the calculated hourly PCU counts in reference to the 24 full hours starting from 0:00 and ending at 23:00. The rate of periodicity is then converted from daily to monthly per type of vehicle by getting the product sum of the daily PCU count to a factor pertaining to the specific number of days according to the day classification.

2.5 Emission Factors

Various factors were considered by the way the emission factors had been derived. First, identification of different variants for cars and SUVs were considered in the study. Mini-compact sedan, subcompact sedan, compact sedan and full-size sedan were identified as the variants of car as a vehicle type. The supposition of the authors with regards to SUVs was that vans and pickups were included in the variant share of SUVs. As a result, the specific elements included in the SUV variant were multi-purpose vehicle (MPV), sports pick-up, crossover/compact SUV, mid-size SUV, full-size SUV and van. Alternatively, motorcycle and tricycle variations were distinguished according to the engine type, in particular, two-stroke and four-stroke engines. It is worth noting that other types of vehicle such as taxis, jeepsneys, buses, light-duty trucks and heavy-duty trucks remain without variations. The authors had also assumed values for emissions standards share such as the share of Pre-Euro, Euro 1, Euro 2 and Euro 4 as well as the fuel type share in each vehicle type and corresponding variants. In order to arrive from the final emission factor values for vehicle type per GHG and other air pollutant emission as referred in Table 3, interplay between factors such as variant share, emission standard share, fuel share, fuel economy in g/km and specific fuel consumption in g/gfuel transpire. For the data utilized in the variant share, emission standard share and fuel share, own estimates of the authors were used although alternative data concerning the transport sector in a country could be available from the websites of government institutions or agencies. For example, the Land Transportation Office (LTO) is the one responsible for all land transportation matters in the Philippines. On the other hand, the data utilized in fuel economy and fuel consumptions were taken in databases of Argonne National Laboratory which are the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) Model [20] and the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool [21].

3. Results and Discussion

As discussed previously in this paper, the emission loads are calculated through emission factors and the activity data of vehicles. As response to the research objectives of this study, emissions of air pollutants were quantified in accordance with the different types of road transport vehicles. The processes in computing or quantifying transport emission were applied for both southbound and northbound roads in EDSA. The analysis of this study involved disintegrating EDSA to a number of segments in reference to the MRT-3 stations. For each segment, emission loads were calculated, and
the results are presented in succeeding the sub-chapters. The relative amount for each transport air pollutants emission particularly with regards to carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), nitrogen oxide (NOx), Sulfur oxide (Sox) and particulate matter (PM) are presented in charts.

Table 3. Summary of the computed air emissions per vehicle type

| Types of Emission | Emission Factors | Tricycle | Motorcycle | Jeepney | Taxi | Car | SUV | Light duty | Bus | Heavy duty |
|-------------------|------------------|----------|------------|---------|------|-----|-----|------------|-----|------------|
|                   |                  |          |            |         |      |     |     |            |     |            |
| NMVOC             |                  | 4.090558 | 2.302180   | 0.235721 | 0.300046 | 0.740802 | 0.353766 | 0.364807 | 1.287302 | 1.023751 |
| CO                |                  | 25.664082| 13.167092  | 3.120396 | 3.726704 | 9.062073 | 3.110799 | 4.127887 | 4.419186 | 3.884681 |
| NOx               |                  | 0.257945 | 0.252788   | 0.243801 | 0.245913 | 0.699392 | 0.961852 | 2.696264 | 15.797963 | 26.101508 |
| PM10              |                  | 0.056193 | 0.033614   | 0.846569 | 0.001137 | 0.022993 | 0.143038 | 0.751884 | 0.753899 | 0.673095 |
| PM2.5             |                  | 0.056193 | 0.033614   | 0.846569 | 0.001137 | 0.022993 | 0.143038 | 0.751884 | 0.753899 | 0.673095 |
| SOx               |                  | 0.003073 | 0.002390   | 0.021766 | 0.003425 | 0.061980 | 0.006930 | 0.027374 | 0.045460 | 0.054021 |
| CH4               |                  | 4.090558 | 2.302180   | 0.235721 | 0.300046 | 0.740802 | 0.353766 | 0.364807 | 1.287302 | 1.023751 |
| N2O               |                  | 0.002080 | 0.001499   | 0.031586 | 0.003893 | 0.009883 | 0.006310 | 0.022603 | 0.022228 | 0.024668 |
| CO2               |                  | 66.974662| 60.098277  | 668.741525 | 41.920420 | 109.895772 | 92.403869 | 842.085172 | 1406.230130 | 1672.436324 |

3.1 Transport emissions of air pollutants per road segment

Table 4 summarizes the results that emerged from computing the amount of air pollutant emissions by road segment for both southbound and northbound EDSA. The figures for the southbound EDSA emissions show that CO has the biggest share in the transportation emissions. The 39.38 tons of CO corresponds to approximately 64% of the total emissions. Furthermore, 14.76%, which is considered the largest proportion, of the CO share came from GMA Kamuning-Araneta Cubao Station segment. Although GMA Kamuning-Araneta Cubao segment does not have the largest road stretch in all the southbound segments, the large share in CO is justifiable since this particular road segment has a lot of commercial establishments nearby. It is also worth mentioning that this road segment contains several bus terminals which some of these terminals operate 24 hours a day and 7 days a week.

In relation to the emissions on northbound EDSA, CO still has the largest share in the computed emissions. A 68.7% share is attributed solely to CO. The most notable road segment of all segments in northbound EDSA is the Santolan Avenue-Ortigas Avenue segment. Referring to Table 4, it has the largest Shares in CO, NMVOC and SOx, second largest in NOx and third largest in PM. Aside from having the highest road length among all with 2.3 km stretch, there are a lot of occurrences taking place in this area. One of the largest shopping malls in the Philippines namely, SM Mega Mall, is located at the start of this road segment, and several interchanges exist particularly along the EDSA-Ortigas avenue intersection. All these features affect the side friction of the road and therefore affect the flow of vehicles through vehicle deceleration. If the flow of the vehicles or the average speed is affected due to deceleration, then the average speed is reduced and the PCU count is increased based on Figure 2.

3.2 Transport emission share per type of vehicle

The total shares in emissions per vehicle type in EDSA are summarized in Figure 3 and Figure 4 for southbound and northbound EDSA, respectively. For southbound, motorcycles which use petrol as fuel provided the largest share in CO and NMVOC emissions, respectively, 35.67% and 45.1% of the total. Buses, on the other hand, which operate through diesel fuel contributed the largest share of NOx, SOx and PM emission, respectively, at 75.23%, 44.11% and 51.85%. The same is the case for northbound wherein shares in CO and NMVOC emissions were highest in motorcycles relative to 38.87% and 43.55%, while shares in NOx, SOx and PM emissions were highest in buses relative to 68.17%, 34.96% and 43.58%. Second to motorcycles in CO and NMVOC emissions shares were the cars whereas SUVs are second largest NOx, SOx and PM emissions contributor. In reference to the charts in Figure 3 and Figure 4, it may be regarded as certain that the type of emissions is dependent on the fuel type used by the vehicle. Vehicles utilizing petrol are expected to release more CO and NMVOC emissions in contrast to vehicles utilizing diesel which are expected to release more NOx, SOx and PM after fuel combustion.
Table 4: Transport emissions of air pollutants in tons per road segment

| Road Segment                        | Southbound Emissions (ton) | Northbound Emissions (ton) |
|-------------------------------------|-----------------------------|----------------------------|
|                                     | CO  | NMVOC | NOx  | SOx  | PM | CO  | NMVOC | NOx  | SOx  | PM |
| North A - Quezon A                  | 2.471001 | 0.357895 | 1.054745 | 0.004045 | 0.066745 | 4.073651 | 0.517722 | 1.079694 | 0.06723 | 0.092190 |
| Quezon A - G Kamuning               | 2.031109 | 0.274553 | 0.214561 | 0.002228 | 0.026995 | 2.519460 | 0.311280 | 0.583175 | 0.03445 | 0.038591 |
| G Kamuning - A C Cubao              | 5.913515 | 0.921262 | 1.950281 | 0.008155 | 0.133137 | 5.194019 | 0.789036 | 1.618692 | 0.00767 | 0.005377 |
| A C Cubao - Santolan A              | 4.481821 | 0.611804 | 2.674337 | 0.014104 | 0.163559 | 5.489553 | 0.740800 | 2.454482 | 0.01346 | 0.153220 |
| Santolan A - Ortigas A              | 5.459905 | 0.719022 | 1.979905 | 0.013098 | 0.137982 | 7.282521 | 0.890840 | 2.034889 | 0.01249 | 0.155190 |
| Ortigas A - Shaw B                  | 2.475599 | 0.299337 | 0.656823 | 0.004446 | 0.057265 | 3.958517 | 0.517703 | 1.397273 | 0.00709 | 0.087752 |
| Shaw B - Boni                       | 2.475599 | 0.299337 | 0.656823 | 0.004446 | 0.057265 | 3.958517 | 0.517703 | 1.397273 | 0.00709 | 0.087752 |
| Boni- Guadalupe                     | 1.576624 | 0.218005 | 0.558684 | 0.002887 | 0.038647 | 3.588510 | 0.439801 | 0.883447 | 0.00537 | 0.060093 |
| Guadalupe - Buendia                 | 4.037532 | 0.500287 | 1.741180 | 0.008922 | 0.116692 | 6.530134 | 0.852339 | 1.691332 | 0.01000 | 0.312176 |
| Buendia - Ayala                    | 1.971459 | 0.276435 | 0.564844 | 0.002959 | 0.042790 | 1.829786 | 0.234669 | 0.654341 | 0.00340 | 0.045096 |
| Ayala - Maguilinnes                 | 2.893416 | 0.497639 | 2.484726 | 0.008514 | 0.129282 | 3.116394 | 0.418325 | 0.761915 | 0.004940 | 0.067528 |
| Maguilinnes - Taft A               | 3.706428 | 0.499241 | 0.938450 | 0.008609 | 0.123897 | 4.077608 | 0.547273 | 1.214540 | 0.009330 | 0.172308 |
| **Total**                           | 39.380538 | 5.445817 | 15.518434 | 0.076173 | 1.074445 | 52.273832 | 6.775574 | 15.771053 | 0.088500 | 1.177369 |

Figure 3. Shares in transport emissions of air pollutants per vehicle type in southbound EDSA

Figure 4. Shares in transport emissions of air pollutants per vehicle type in northbound EDSA

4. Conclusions and Recommendations

A novel method for quantifying transport emissions is introduced in this study. Through the use of Google Maps data, an alternative method for transport modeling was created. EDSA, a major thoroughfare connecting several roads in Metro Manila, Philippines, was chosen to be the interest of the study. The study was done by dividing EDSA into 12 successive segments bounded by the sequential MRT-3 stations which are North Avenue Station, Quezon Avenue Station, GMA Kamuning Stations, Araneta Center-Cubao Station, Santolan-Annapolis Station, Ortigas Avenue, Shaw Boulevard Station, Boni Station Avenue, Guadalupe Station, Buendia Station, Ayala Station and Taft Avenue Station. The end goal for this study was to calculate the monthly transport emission load for both southbound and northbound EDSA in reference to the whole month of June 2019. This month was specifically chosen by the authors in order to analyze transport emission load during a normal school month.

In the results with regards to emissions per road segment, approximately 64% of the total transport emissions were carbon monoxide for southbound EDSA. Furthermore, GMA Kamuning-Araneta Cubao Station was the segment with the highest share of CO having 14.76% of the total. Concurrently, the highest share in the total emissions for northbound EDSA is CO with 68.7% share. Based on Table 4, the Santolan Avenue-Ortigas Avenue segment had the largest Shares in CO, NMVOC and SOx among all other road segments, second largest in NOx and third largest in PM. In relation to the transport emission share per vehicle type, motorcycle which uses a petrol had the highest share in CO (35.67%) and NMVOC (45.1%) emissions for southbound EDSA, while buses which utilize diesel fuel had the...
highest share in NOx (75.23%), SOx (44.11%) and PM (51.85%) emissions. In the same case, motorcycles had the highest emission share in CO (38.87%) and NMVOC (43.55%) for northbound, while buses had the highest emission share in NOx (68.17%), SOx (34.96%) and PM (43.58%). This led to the conclusion that vehicles with petrol engines are expected to release more CO and NMVOC emissions; meanwhile, vehicles with diesel engines are expected to release more NOx, SOx and PM emissions.

In order to further establish the verified findings of this paper, the next step for this research would be the validation of the modeling results utilizing actual on-road data. Another recommendation from the authors is to take into account the effects of weather conditions on vehicle flow characteristics such as the bulk speed and the PCU count for the future progress of this research. In the Philippines, the month of June is considered the onset of the rainy season.

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