

Assessment of Carbon Dioxide Emissions From Mobile Sources in the Local Area

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Abstract— The excessive amounts of carbon dioxide produced in particular by mobile sources is a relevant problem for densely populated urban areas. The study represents the estimation of CO₂ masses released by the motor vehicles in one of the Russian Federation regions – Nazran city and Nazran district of Ingush Republic. The main points of research are the identification of periods of maximum and minimum amounts of daily emissions of CO₂ and the charting of daily accumulation of CO₂ emitted into the atmosphere by automobiles in the investigated area. The study includes the comparative analysis of the negative environmental impact of vehicle groups classified by the main consumer feature and the type of used fuel. The article presents the algorithm of calculating the masses of polluting substances emitted by motor transport in the city agglomeration area. The obtained results can be used for the supply air volume calculation based on the accounting for hydrocarbon fuel consumption and finally for the identifying of the ecosystem's carrying capacity.

Keywords: *greenhouse gases, carbon dioxide, emissions, ecosystem, carrying capacity*

I. INTRODUCTION

Despite the beliefs of greenhouse effect theory supporters drawing the apocalyptic pictures of “heat stroke” [1 – 4], the increasing masses of man-made carbon dioxide (CO₂) are still being successfully absorbed by the world's oceans and restoring the original chemical balance of the atmosphere. However, CO₂, as well as other air polluting substances' emission, has to be limited and not to surpass some ultimate level for a particular ecosystem, i.e. environmental carrying capacity [5]. Otherwise, extreme pollution will result in the inevitable decrease in the ecosystem's productivity and the decline in economic development. The negative impacts of the increased carbon dioxide concentration in the air especially occur in the urban highly populated areas. The main sources of pollutants' emission are the motor vehicles that release over 90 percent of the total emission of air

contaminating substances in the large cities and over 50 percent – in the countryside [6].

The research aims to estimate the CO₂ emissions from the mobile sources in Nazran city and Nazran district of the Ingush Republic (IR), the Russian Federation (RF). The obtained results can be used for the supply air volume calculation based on the accounting for hydrocarbon fuel consumption and finally for the identifying of the ecosystem's carrying capacity [5].

II. METHODS

The inventory of automobiles registered in the administrative entity area on the basis of the main consumer feature and the type of used fuel is performed using the data provided by the State Road Safety Inspectorate of the Ministry of Internal Affairs of the RF in the IR (SRSI MIA RF, IR), AUTOSTAT Analytical Agency etc. [7, 8] to estimate carbon dioxide emissions from motor vehicles in Nazran city and Nazran dist.

The average traffic speed is identified for the investigated area during the 24 hours at 2 hours intervals on the basis of online resource “Yandex. Maps” [9]. Then, the weighted average harmonic velocity, m/s, is determined for each period

$$v = \frac{\sum_1^n L_n}{\frac{L_1}{v_1} + \frac{L_2}{v_2} + \dots + \frac{L_n}{v_n}}, \quad (1)$$

where L_1, L_2, \dots, L_n are the lengths of investigated road sections, m; v_1, v_2, \dots, v_n are the average traffic velocities on the investigated road sections in the 2 hours, m/s.

TABLE I. THE PARK OF MOTOR VEHICLES STRUCTURE FOR NAZRAN CITY AND NAZRAN DIST.

Main consumer feature of vehicle	Used fuel type			
	Petrol		diesel	gas
	carburetor	injector		
Passenger cars	0,4539	0,3185	0,0417	0,0203
LCV	0,0183	0,0299	0,0276	0,0035
CV and HCV	0,0222	0,0028	0,0515	0,00043
Buses	0,0036	0,00145	0,0043	0,00002

The average speed of vehicles according to their main consumer feature is identified considering the online resources' methods of collecting information on traffic. Indeed, due to the predominance of passenger cars in the traffic flow, the quantity obtained from the online application is taken as their speed. The light (LCV) and heavy commercial vehicles (CV and HCV) and buses velocities are calculated with sufficient accuracy for estimates using the empiric equation [10]

$$\begin{aligned}
 &\text{If } j = 1 \text{ than } v_j = v; \\
 &\text{if } j = 2 \text{ than } v_j = 0.575v; \\
 &\text{if } j = 3; j = 4 \text{ than } v_j = 0.4465v,
 \end{aligned} \quad (2)$$

where j is the type of vehicle according to the main consumer characteristic (1 – passenger cars, 2 – LCV, 3 – CV and HCV, 4 – buses); v_j is the j^{th} vehicle velocity, m/s.

The relative power of an automobile, the excess air relative ratio, indicator and mechanic efficiency factors and other indicators which are used to calculate the volumetric flow rate of exhaust gases (EG) and CO₂ concentration in the EG are identified on the base of acquired information about speed quantities of automobiles in the traffic flow and time percentage of engine's operation mode. The CO₂ mass flow rate from the single automobile M_i , kg/s, can be determined as the product of the EG volumetric flow rate and the researched pollutant's concentration in it.

$$M_i = 10^{-3} Q_{EG} c_i, \quad (3)$$

where Q_{EG} is the volumetric flow rate of the exhaust gases, m³/s; c_i is the concentration of the i^{th} pollutant in the EG, g/m³.

In this case, the carbon dioxide concentration in the EG is determined using the equations:

for diesel engines

$$c_i = 6.2629\bar{N}^2 + 129.13\bar{N} + 37.739, \quad (4)$$

for petrol carburetor engines

$$c_i = -55.839\bar{\alpha} + 257.92, \quad (5)$$

for petrol injector engines and spark-ignition gas engines

$$c_i = 364.65\bar{\alpha}^3 + 96.8, \quad (6)$$

for gas diesel engines

$$c_i = 6\bar{N} + 96.8, \quad (7)$$

where \bar{N} is relative power of automobile; $\bar{\alpha}$ is excess air relative ratio.

These correlations can be used in the absence of certified data on the $\bar{\alpha}$ values for some types of vehicles

for petrol carburetor engines

$$\begin{aligned}
 \bar{\alpha} = &5.7177\bar{N}^5 - 19.129\bar{N}^4 + 24.345\bar{N}^3 - \\
 &-15.012\bar{N}^2 + 5.0774\bar{N} + 0.0018,
 \end{aligned} \quad (8)$$

for petrol injector engines and spark-ignition gas engines

$$\begin{aligned}
 \bar{\alpha} = &5.4938\bar{N}^5 - 17.571\bar{N}^4 + 21.748\bar{N}^3 - \\
 &-13.621\bar{N}^2 + 4.9501\bar{N}.
 \end{aligned} \quad (9)$$

The applying of (8) and (9) is particularly useful when identifying correlations between indicator efficiency factor and excess air relative ratio for carburetor and injector petrol engines and spark-ignition and pre-chamber flare gas engines [10]

for petrol carburetor engines

$$\eta_i = -0.2324\bar{\alpha}^3 + 0.0424\bar{\alpha}^2 + 0.2095\bar{\alpha} + 0.2915, \quad (10)$$

for petrol injector engines

$$\eta_i = -0.3754\bar{\alpha}^2 + 0.4272\bar{\alpha} + 0.2861, \quad (11)$$

for spark-ignition and pre-chamber flare gas engines

$$\eta_i = -0.2493\bar{\alpha}^2 + 0.3501\bar{\alpha} + 0.1852. \quad (12)$$

TABLE II. THE WEIGHTED AVERAGE HARMONIC VELOCITY OF THE CITY TRAFFIC FLOW DURING THE 24-HOUR PERIOD

Day time	Velocity, m/s	Day time	Velocity, m/s	Day time	Velocity, m/s
7 a.m.	9.1	3 p.m.	9.6	11 p.m.	11.5
9 a.m.	9.2	5 p.m.	9.8	1 a.m.	12.5
11 a.m.	9.9	7 p.m.	10.3	3 a.m.	14.4
1 p.m.	9.3	9 p.m.	10.9	5 a.m.	13.5

TABLE III. THE TIME PERCENTAGE OF VEHICLES ENGINES' OPERATION MODES

The operation mode of engine	acceleration	constant speed	idling	braking
Time percentage	0.185	0.292	0.128	0.395

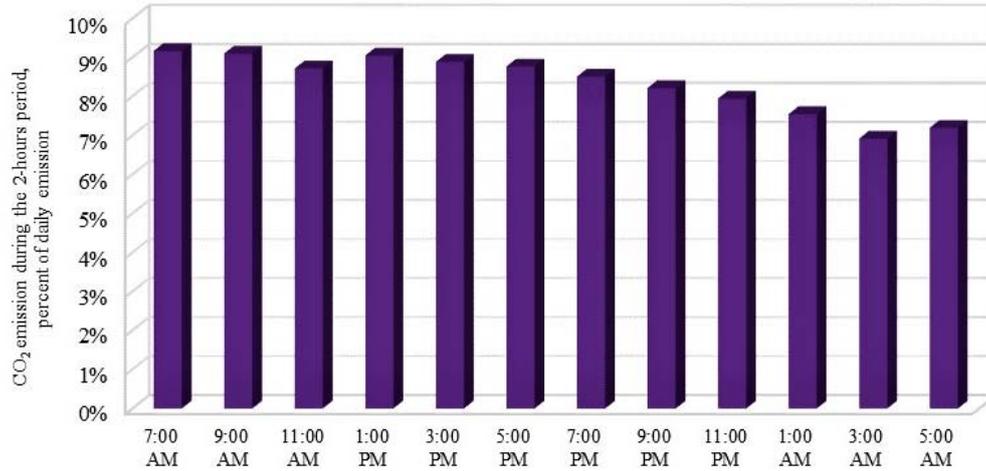


Fig. 1. The change in carbon dioxide daily emission

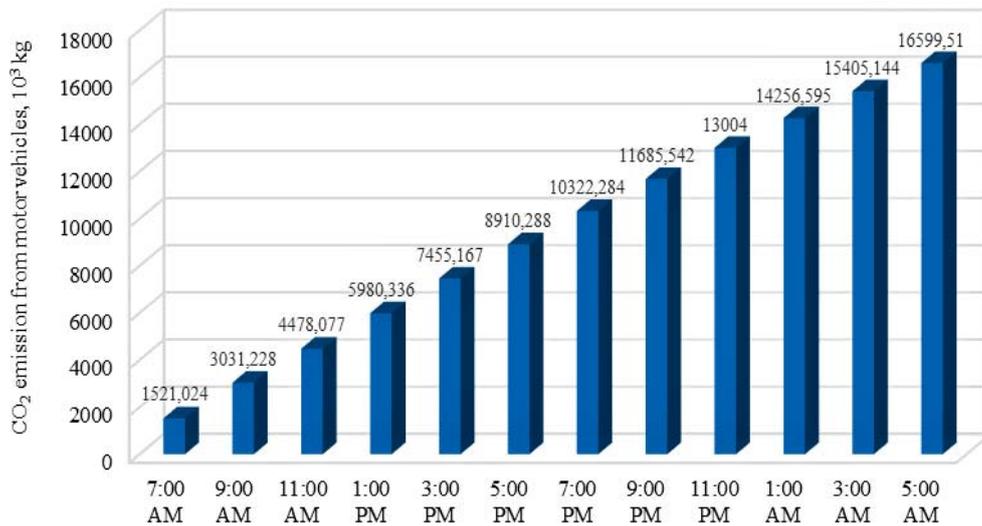


Fig. 2. The CO₂ daily accumulation in Nazran city and Nazran dist., t

Then CO₂ mass flow rate from the motor vehicle in the investigated area is calculated considering the traffic structure data [7, 8, 10, 11]

$$\sum M_{ijd} = \sum_{j=1}^4 \sum_{d=1}^4 \sum_{b=1}^4 M_{ijdb} \lambda_{jd} R, \quad (13)$$

where M_{ijdb} is the mass flow rate of i^{th} polluting substance from the single j^{th} d^{th} b^{th} automobile, kg per 24 hours; d is the used fuel type (1 – petrol, carburetor engines; 2 – petrol, injector engines; 3 – diesel; 4 – gas fuel); b is the engine’s operation mode (1 – acceleration; 2 – constant speed; 3 – braking; 4 – idle mode); R – is the number of vehicles moving in the traffic at the same time.

The calculation of CO₂ emission masses from mobile sources in Nazran dist. area is performed according to the following algorithm. The length of every street and average traffic velocity are identified using online services every 2 hours during the 24 hours. Then the weighted average

harmonic velocity is calculated for every period with the use of (1); the average speeds of vehicles categorized by the main consumer feature are determined using (2). The number of vehicles moving in the traffic at the same time is identified as follows

$$R = \left(\frac{\sum_{n=1}^n L_n - d_a}{h} + 1 \right) z, \quad (14)$$

where d_a is the average length of vehicle, m; h is the spatial interval between the automobiles (which is calculated as in the study [11]); z is the number of traffic lanes.

The mass of CO₂ emission is calculated with the use of (8).

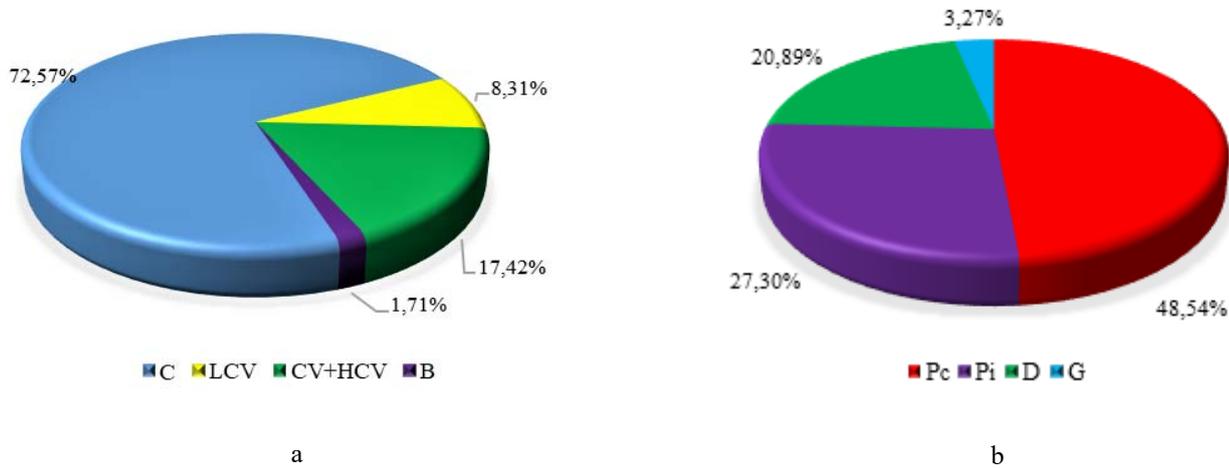


Fig. 3. The carbon dioxide daily emission in the Nazran city and Nazran dist., percent of total, from automobiles: a) by the main consumer criteria (C – passenger cars, LCV – light commercial vehicles, CV+HCV – commercial and heavy commercial vehicles, B – buses); b) by the type of used fuel (Pc – petrol, carburetor engines, Pi – petrol, injector engines, D – diesel, G – gas

III. RESULTS AND DISCUSSION

Table 1 represents the structure of the park of motor vehicles for Nazran city and Nazran dist. according to the data provided by SRSI MIA RF in the IR, AUTOSTAT and so on.

The streets of Nazran city with the most intensive traffic were chosen as representative objects to research the average traffic speed in the investigated area (1 – Suvorov St., 2 – Asiyat Tutaeva St., 3 – Mutaliev St., 4 – Archakov St., 5 – Cartoev St., 6 – Shaymiev St., 7 – Gairbec-Khajy St.). Table 2 shows the weighted average harmonic velocity values on the city streets during the 24 hours. Table 3 adduces the vehicles engines' operation modes time percentage of total exploitation period [12].

The calculations of carbon dioxide emissions from motor vehicles in the investigated area during the 24 hours showed that the maximum emission mass (9.16 percent of daily emission) corresponds with the minimum traffic velocity value that was observed at 7 a.m. and the minimum emission mass (6.92 percent of daily emission) matches with the maximum traffic velocity value that was observed at 3 a.m. (see table 2, fig. 1).

It should be noted that the minimum CO₂ emission mass is observed in the evening and night hours. This fact is primarily related to the increase in traffic velocity (see table 1).

The fig. 2 shows that the mass of CO₂ daily emissions from the motor vehicles in Nazran city and Nazran dist. is 16599.51 tons. According to this information, it is possible to evaluate the environmental impact caused by the anthropogenic activity and, for example, to limit the near-the-motorways outdoors stay of the population at risk of the disease according to the permissible rate of exposure for the researched substance [13].

Fig. 3 (a, b) represents the distribution of carbon dioxide emissions by groups classified by the main consumer criteria and the type of used fuel.

It is becoming apparent that passenger cars make the largest contribution to the total average daily emission (72.57 percent, see fig. 3, a). This fact can be explained by their predominance in the regional automobile park (over 80 percent, see table 1). The petrol vehicles with carburetor engines which are about 50 percent of total traffic flow (45 percent within this number consists of passenger cars) have the most negative environmental impacts (about 50 percent of total average daily CO₂ emission, see fig. 3, b). The reducing of carbon dioxide emission reserve is hidden within the attitude change toward passenger cars [14]. The implementation of automobiles with injector and gas engines can positively affect the environmental situation both in the city and in the Republic as a whole.

IV. CONCLUSIONS

The result of the research consists of the carbon dioxide emission masses calculation, which is performed for the motor vehicles in Nazran city and Nazran dist. of the IR, the RF.

It should be emphasized that the changes in CO₂ daily emissions are correlating with traffic velocity at any given time (see fig. 1). The chart on fig. 2 shows the daily accumulation of CO₂ emitted into the atmosphere by automobiles in the investigated area.

The comparative analysis of territorial traffic structure and negative environmental impact of vehicle groups classified by the main consumer feature and the type of used fuel allows concluding that such measures as modernization of regional park of passenger cars and transition to alternative fuels show the great potential as the means to reduce the negative environmental impacts. Besides, it seems advisable to restrict the traffic of some categories of vehicles in the evening and night time due to vegetations' lack of natural CO₂ absorption capacity in these periods.

Therefore the suggested approach to the air pollution assessment in the agglomeration area can serve as a basis for the weighted reasonable administrative decision making on the reduction of technogenic influence on the environment.

In addition, it provides the scientifically sound opportunity to organize the city traffic and to estimate the necessary number of trees in the specific area.

The represented method can be applied for the accounting of other pollutants emissions from the motor vehicles in the urban areas.

The obtained results can be used to calculate the supply air volumes in the investigated area, to identify the carrying capacity of ecosystem and, finally, to estimate the negative environmental impacts of automobiles.

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