Evaluating the Impact of a New Ring Road on Urban Traffic in a Mountainous City: Amasya, Turkey

Dağlık Bir Kentte Yeni Yapılan Bir çevre Yolunun Kentsel Trafik Üzerindeki Etkisinin Değerlendirilmesi: Amasya, Türkiye

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Öz

Şehir merkezindeki yol ağı, yalnızca konforlu ve sağlıklı bir yaşam tarzı sağlamak için değil, aynı zamanda ekonomik kalkınmayı teşvik etmek için de kritik bir unsurdur. Bu nedenle yol ağlarının etkinlik, hız, konfor ve güvenlik standartlarını karşılaması gerekir. Ancak bu standartlara ulaşmak Amasya gibi bazı şehirler için zor olabilir. Türkiye'de tarihsel olarak küçük bir şehir olan Amasya, coğrafi koşulları nedeniyle yol kapasitesini genişletme veya yeni yollar inşa etme konusunda sınırlamalarla karşı karşıyadır. Bunun yerine, trafik sıkışıklığını azaltmak için Amasya'nın şehir merkezi etrafında bir çevre yolu inşa edilmiştir. Bu çalışma, yeni açılan çevre yolunun Amasya'daki şehir içi trafiği üzerindeki etkisini araştırmaktadır. Amasya şehir merkezindeki 26 yol için manuel trafik verileri, çevre yolu açılmadan önce ve açıldıktan sonra 11 saat boyunca (sabah 7'den akşam 6'ya kadar) toplanmıştır. Üç farklı varsayım altında, bu bağlantılar için 1 saatlik trafik hacimleri tahmin edilmiş ve ardından iki farklı zamanda elde edilen trafik verileri arasında karşılaştırmalar yapılmıştır. Bulgular, çevre yolunun açılmasından sonra yolların %92'sinde trafikte bir azalma olduğunu ve yolların %35'inde %20'den fazla bir azalma gözlemlendiğini göstermektedir. Bu düşüş için istatistiksel destek, %95 güven düzeyinde eşleştirilmiş t-testi ile sağlanmıştır. Ayrıca, Karbon Monoksit (CO), Hidrokarbonlar (HC), Nitrik Oksit (NOx), Partikül Madde (PM) ve Sülfür Oksit (SOx) dâhil olmak üzere yedi kirletici dikkate alındığında, çevre yolunun açılmasının ardından trafik kaynaklı hava kirliliğinde %6,6'lık bir azalma tespit edilmiştir.

Anahtar Kelimeler: Çevre yolu, Trafik politikası, Trafik yönetimi, Altyapi tasarimi, Trafik etki değerlendirmesi

ABSTRACT

The road network in the city center is a critical element, not only for ensuring a comfortable and healthy lifestyle but also for fostering economic development. Therefore, road networks must meet standards of effectiveness, speed, comfort, and safety. However, achieving these standards can be challenging for some cities, such as Amasya. Amasya, a historically small city in Turkey, faces limitations in expanding road capacity or constructing new roads due to its geographical conditions. Instead, a ring road has been constructed around Amasya's city

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center to reduce traffic congestion. This study investigates the impact of the newly opened ring road on urban traffic in Amasya. Manual traffic data for 26 links in Amasya's city center were collected over 11 hours (from 7 AM to 6 PM) before and after the ring road was opened. Under three different assumptions, 1-hour traffic volumes for these links were estimated, and subsequent comparisons were made between traffic data obtained at two different times. The findings indicate a decrease in traffic for 92% of the links after the ring road's opening, with more than a 20% reduction observed in 35% of the roads. Statistical support for this decrease is provided by the paired t-test at a 95% confidence level. Additionally, taking into account seven pollutants, including Carbon Monoxide (CO), Hydrocarbons (HC), Nitric Oxide (NOx), Particulate Matter (PM), and Sulfur Oxide (SOx), a 6.6% reduction in traffic-related air pollution was found following the opening of the ring road.

Keywords: Ring road, Traffic policy, Transportation management, Infrastructure design, Traffic impact assessment

INTRODUCTION

Roads are one of the most fundamental elements in transporting people, goods, and services from one place to another (Abdollahi, Pradhan, and Shukla, 2019; Biçici and Zeybek, 2021; Zeybek and Biçici, 2023). That is, they connect great distances and lead to significant economic development (Biçici and Zeybek, 2021). A safe, comfortable, and efficient road network is particularly crucial for developing countries like Turkey. For this reason, existing roads in the road network are expanded, or new roads are built on the road network in order to reach the required standards. However, these changes in the road network must show the expected impact.

The amount of traffic is also increasing rapidly day by day due to factors such as population growth, urbanization, and increased economic activities (Afrin and Yodo, 2020). Therefore, the road network needs to grow fast enough to accommodate the increasing level of traffic. Particularly in city centers, population growth contributes to a rise in urban traffic, which causes both environmental (air) and noise pollution (World Health Organization, 2016). These traffic-related pollutions need to be considered much more nowadays, particularly in densely populated city centers (Bhalla, et al., 2014; Burnett et al., 2018). In a study conducted by the World Health Organization (WHO) in 2016, it was found that 92% of the world's population lives in cities where it exceeds WHO quality guidelines (World Health Organization, 2016). Several studies highlight the adverse effects of traffic-related air pollution on public health and the environment in city centers. These studies are carried out in cities in Turkey such as Gaziantep (Cuci and Ergün Polat, 2015), Balıkesir (Mutlu, 2019), Van (Yakın and Behçet, 2019), and Malatya (Behçet and Yakın, 2020) as well as in other cities around the world such as Paris (Leroutier and Quirion, 2022), London (Zhai and Wolff, 2021), and Toronto (Shamsi et al., 2021). In addition, Burnett et al. (2018) estimated that deaths due to air pollution reached 8.9 million in 2015 using the Global Exposure Mortality Model. Another study by Bhalla et al. (2014) revealed that traffic-related air pollution contributes to 184,000 deaths annually.

Turkey is a developing country located on the border of Asia and Europe. It has recently progressed significantly in terms of transportation infrastructure. Several studies indicated that the length of the highway has increased by more than 50% since 2000 (Coşar and Demir, 2016; Turkish General Directorate of Highways, 2023). In addition, large-scale transportation projects have been carried out recently to improve the quality of the transportation system in Turkey. Some of these large-scale transportation projects are the Marmaray Tunnel, the Osmangazi Bridge, the Yavuz Sultan Selim Bridge, and some ring roads around city centers. Large-scale projects on the road network infrastructure are expected to bring about significant changes in environmental, economic, and transportation aspects. For instance, traffic-related air pollution analysis was carried out on three bridges (i.e., the 15 July Martyrs Bridge, the Fatih Sultan Mehmet Bridge, and Yavuz Sultan Selim Bridge) over the Bosphorus and the noteworthy decrease in both the amount of traffic and air pollution on the 15 July Martyrs Bridge and the Fatih Sultan Mehmet Bridge in 2016 was observed (Kilic and Sen, 2017). The primary factor contributing to the decrease in traffic volume and air pollution is the opening of the Yavuz Sultan Selim Bridge in 2016. In another study, it was found that after the Marmaray tunnel was opened, the number of people traveling by Rail System increased from 3% to 27.7% (Efe and Curebal, 2010). It is also predicted that traffic on the bridges over the Bosphorus will decrease in the coming years (Efe and Curebal, 2010). Study conducted by Akyürek et al. (2018) investigated the changing environmental impact and land use with the opening of Istanbul new airport. Similar studies have also been conducted in other parts of the world (Mangones et al., 2019; Pu et al., 2019; Tennøy et al., 2019; Rad and Naghipour, 2022).

In this study, Amasya`s urban traffic and air pollution was investigated after the newly opened ring road. Given the geographical constraints of Amasya, the road network cannot adequately meet the increasing population and traffic, which has led to higher levels of traffic-related air pollution and noise pollution, as evidenced in previous studies (Güremen, 2014; Cansaran, 2019; Aylar and Zeybek, 2021). The daily noise level on the main and alternative roads in the city center, where the traffic level is intense, was 10 dBA above the average level determined by the standards (Güremen, 2014). Therefore, the newly opened ring road is anticipated to not only impact urban traffic of Amasya but also influence the quality of air pollution.

The remainder of this paper is organized as follows. The study area is presented in the next section. Then, the overall materials and methods are introduced. Specifically, the data collection method and the estimation method are discussed in this section. Finally, after presenting the results, the manuscript ends with a conclusion.

STUDY AREA

The study area is located in the city of Amasya. Amasya is a small city in the Middle Black Sea region of Turkey (see Figure 1(a)). It has a surface area of 1,730 km2 at an altitude of 411 meters with a population of approximately 335,300. There are seven districts in the city of Amasya, namely Hamamözü, Gümüşhaciköy, Merzifon, Suluova, Taşova, Göynücek, and Amasya City Centre (see Figure 1(b)). In this study, only Amasya City Center traffic was interested. Amasya city center is located around the Yeşilırmak River. It is also sandwiched between Kırklar Mountain in the north and Sakarat Mountain in the south. Therefore, the city does not expand equally in all directions. In general, the growth takes place in the northeast and southeast directions.

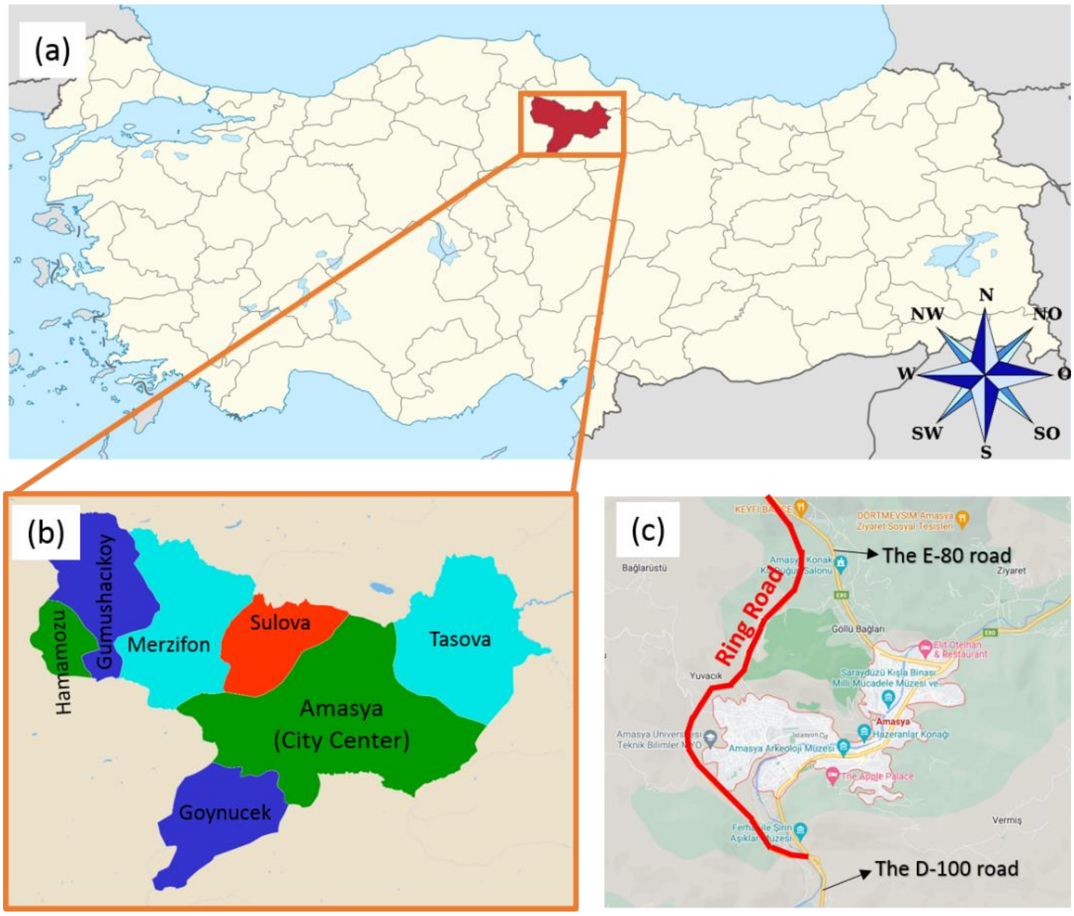

Figure 1. a) The location of the study area within the borders of Turkey, b) The locations of Amasya's districts, and c) Amasya city center boundary and newly-opened ring road.

Due to its geographical location, Amasya city center has become an important junction point where both highway and railway transportation routes pass (Aylar and Zeybek, 2021). Therefore, a significant number of vehicles traveling between cities pass directly through the city center since there has been no ring road until recently. In addition, Amasya has hosted many great empires, such as the Hittites, Lydians, Romans, Seljuks, and Ottomans (Aylar and Zeybek, 2021). Due to the cultural and historical significance of Amasya, the road network faces limitations in constructing wide roads.

In August 2020, the ring road connecting the D-100 road (the Amasya-Erzincan road) and the E-80 road (the Amasya-Samsun road) directly without entering the Amasya city center was opened (see Figure 1(c)). In other words, the ring road directly connects the southwestern entrance of Amasya with the northwestern entrance of Amasya. After the construction of the ring road, the urban traffic speed is expected to increase, and the urban traffic density and the number of vehicles, such as trucks and big buses, is expected to decrease. Additionally, a decrease in traffic-related air pollution is anticipated. Therefore, in this study, the impact of the newly-opened ring road on Amasya's urban traffic and traffic-related air pollution was investigated.

MATERIAL AND METHODS

Traffic Data Collection

There are three essential questions to investigate the impact of the ring road on Amasya's urban traffic. The first question is when data will be collected. Traffic counts were conducted before and after the opening of the ring road. Data collection at two different times (i.e., before and after) should be done under the same conditions as possible. Data for the first period was collected from 07 to 09 August 2020, and for the second period from 27 to 29 August 2021. In this study, only the weekday traffic was investigated, specifically on Tuesday, Wednesday, and Thursday for both data collection times. No special days, holidays, or festivals occurred during these times, and universities and schools were closed. Additionally, the air temperatures for the two periods were similar, varying between 30 and 34 degrees. Both data collection times coincided with the COVID-19 pandemic period, and certain practices, such as restrictions on going out at specific hours, directly affected traffic conditions. COVID-19 practices were also consistent during both data collection periods.

In this study, data were collected only between 7 AM and 6 PM. This time period contains the morning peak period (from 7 AM to 9 AM), midday period (from 11 AM to 1 PM), and evening peak period (from 4 PM to 6 PM). Therefore, 11-hour of traffic data were used. The remaining periods were not considered since most city traffic was off the road.

The second question is from which links will data be collected. There are many links in Amasya city center. However, it is impossible to count all the links since there are not enough facilities. Therefore, a specific set of 26 links were selected and counted in this study. To determine these links, the following idea was taken into account. There are three commonly used paths connecting Amasya's southwest and northwest entrances. These three paths are shown in Figure 2. The links near the southwest and northwest entrances of these three paths are identical. However, as they approach the city center, the roads along these paths begin to differ in their characteristics. Path 1, commonly used before the construction of the ring road, is a local road consisting of two lanes per direction with a central median. Path 2 consists of the links along the Yeşilırmak, which is a local two-way roads with a central median. Path 3 is a newly established path created by incorporating the Ferhat Tunnel, opened in 2018. The effect of the ring road can be observed directly on these paths. Therefore, the links on these paths were selected. There are 12, 15 and 11 links in Path 1, Path 2 and Path 3, respectively. However, as mentioned before, some of the links in the three paths are common. Therefore, a total of 26 links were selected to be collected.

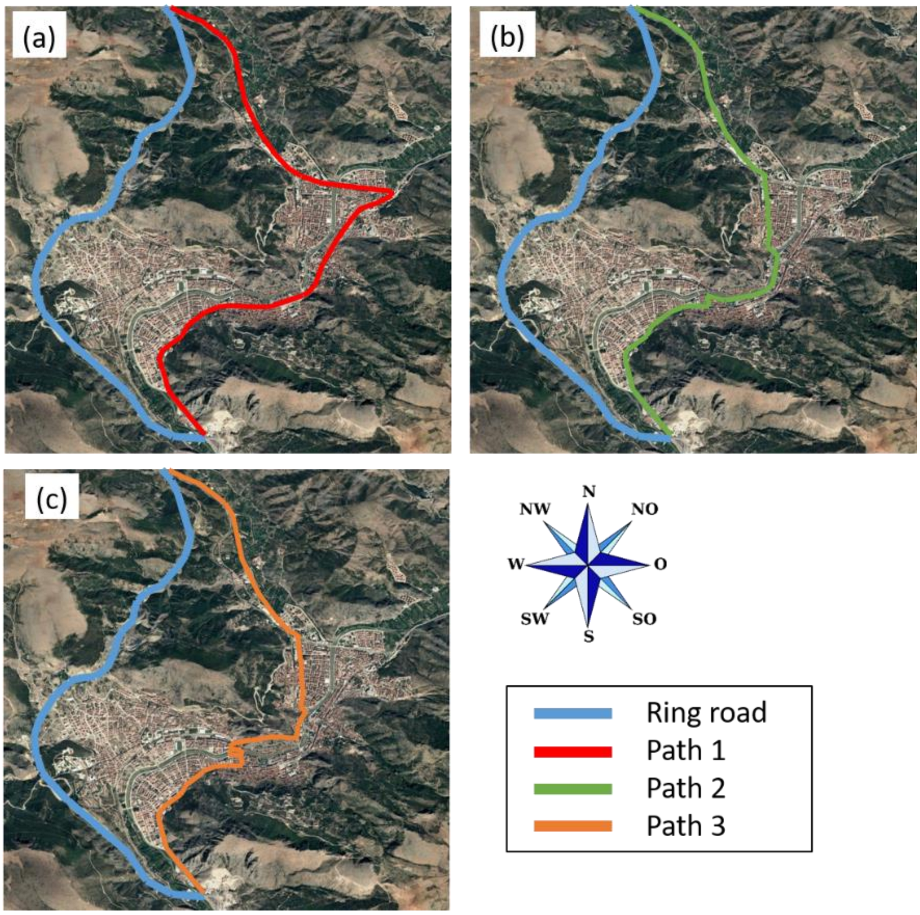

Figure 2. Three paths connecting the southwest and northwest entrances in Amasya: a) path 1, b) path 2, and c) path 3.

The third question is how we collect the data. A traditional method to collect traffic data is manual collection. In this case, data collectors manually collect traffic data by the roadside using equipment such as tally sheets, mechanical count boards, and electronic count board systems (Paľo et al., 2019). However, manual methods are time-consuming and labor-intensive (Zheng and Mike, 2012). On the other hand, modern methods and technologies have been emerged to collect traffic-related data quickly and effectively. These are road tubes (Larue and Wullems, 2019), loop detectors (Grote et al., 2018), and piezoelectric sensors (Wang et al., 2020). These methods and technologies collect different types of traffic data and can obtain different road information. In this study, manual data collection was used due to the lack of necessary technologies. Additionally, manual traffic data can usually be collected when traffic counts at a specific location and when the time frame is less than 24 hours (Roess, Prassas and McShane, 2011). Please note that the data was collected from a safe place on the side of the road, and there was no adverse effect on the flowing traffic.

Traffic Volume Estimation

The most crucial challenge with manual traffic counts is collecting and recording the traffic counts at periodic intervals and resetting the count for the next period, as it is impossible to count while the data collector is recording the information. For this reason, regular and systematic short breaks should be taken while doing manual traffic counting in the field. Counting can be done in different periods, such as 5-minutes, 15-minutes, and 60-minutes. In this study, a 5-minutes counting period was used, consisting of a 4-minutes count and a 1-minute break for recording the count. During short breaks, the expected traffic counts must be expanded to ensure a continuous count. To expand this, it is assumed that the flow rate in the counting period is the same as in the short breaks period. Then:

$$V_{5min} = V_{4min} \times \frac{5}{4} \quad (1)$$

where V_{4min} is the actual traffic count during the 4 minutes and V_{5min} is the expanded traffic count for the 5 minutes.

In this study, two-way traffic counts were counted. That is, the 4 minutes count was collected in one direction, and a short break of 1 minute was taken. Then, a similar count was repeated in the other direction. This process was continued alternately. To calculate the missing period, the average of the previous and the next periods, which were collected, were taken. This process is called straight line interpolation (Roess, Prassas and McShane, 2011).

$$V_{5min}^{j} = \frac{V_{5min}^{j-1} - V_{5min}^{j+1}}{2} \quad (2)$$

where V_{5min}^{j-1} and V_{5min}^{j+1} are the expanded 5 minutes traffic count during period *j-1* and period *j+1*, respectively. V_{5min}^{j} is the estimated 5 minutes traffic count during period *j*. Finally, the 1-hour traffic volume is calculated by summing all 5-minute traffic counts in that hour.

In this study, 26 links were selected to investigate the impact of the newly-opened ring road on Amasya's urban traffic and air pollution. However, due to limited resources, manual collecting 11-hours of traffic count for all 26 links were impractical, requiring a total of 286-hours. To address this limitation, the following procedures are usually applied (Roess, Prassas and McShane, 2011). 11-hours traffic counts were collected for some links. These links are called control links. Simultaneously, only 1-hour traffic count was collected for the remaining links. These links are called coverage links. The missing 10-hours missing traffic counts for coverage links were then estimated using the data collected from the control links.

There are several guidelines for selecting the location of the control links. First, control links should be distributed throughout the network. Second, different control links should be established for each type of link (e.g., freeway, local road, etc.). Similarly, different control links should be established for different land uses. Taking into account these information, three links were selected as control links in this network (see Figure 3). Specifically, one control link was chosen at the city's southwest entrance, another at the city's northwest entrance, and a third in the city center.

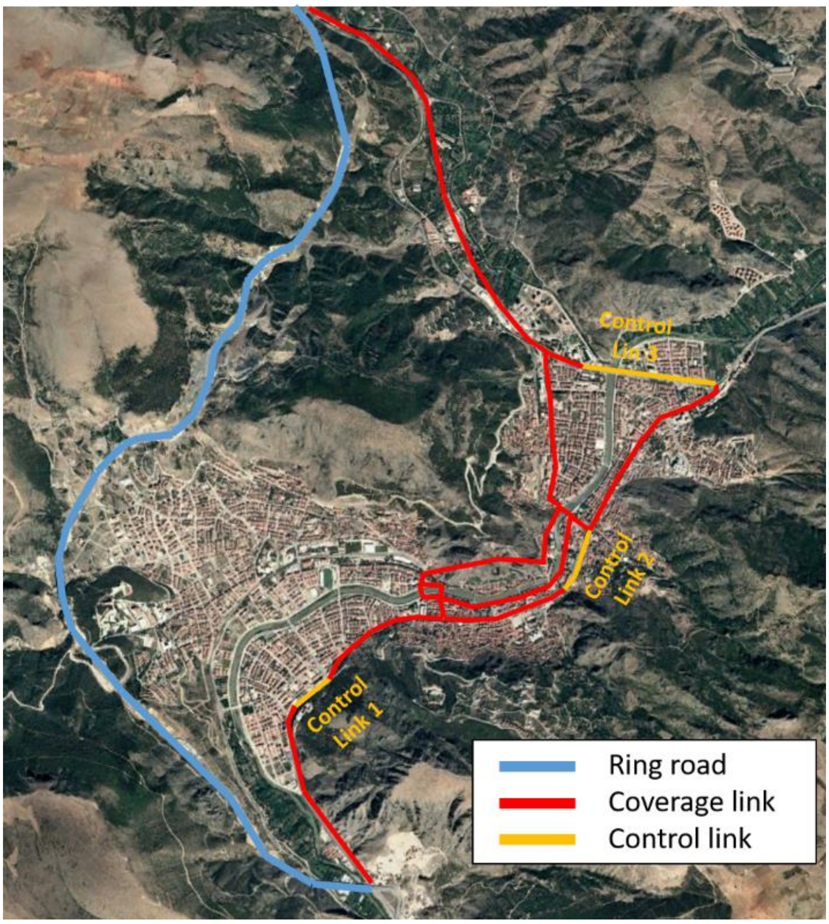

Figure 3. The location of three control links.

In this study, there are three assumptions to use control links to estimate missing hours for coverage links. In the first assumption, only the control link closest to the coverage link was used to complete the missing hour. Therefore, the following equation was used for assumption 1;

$$V_i^j = \frac{V_{Control}^k \times V_i^k}{V_{Control}^j} \text{ for i=1...I, for j=1…H, for k=1…H} \quad (3)$$

where V_i^j and V_i^k are the 1-hour traffic volume for coverage link *i* during period *j* and *k*, respectively. Similarly, $V_{Control}^j$ and $V_{Control}^k$ are the 1-hour traffic volume for control link that is closest to coverage link *i* during period *j* and *k*. I is the number of coverage links, and H is the total period in this study. The number of coverage links and the total period are 23 and 11, respectively.

In the second assumption, the missing hours for coverage links were estimated using all the control stations. Then, the arithmetic mean of the traffic volume for the same period and the link was calculated. Therefore, the following equation was used for assumption 2;

$$V_i^j = \frac{1}{C} \sum_{c=1}^{C} \frac{V_{Control,c}^k \times V_i^k}{V_{Control,c}^j} \text{ for i=1...I, for j=1…H, for k=1…H} \quad (4)$$

where V_i^j, V_i^k, I and H are defined as above. $V_{Control,c}^j$ and $V_{Control,c}^k$ are the 1-hour traffic volume for control link *c* during period *j* and *k*. C is the total number of control links, which is 3 in this study.

In the third assumption, similar to the second assumption, all control stations were used. Then, the weighted mean was taken rather than arithmetic mean. The weighted mean was calculated, with weights determined based on the distance between each control station and the coverage link. Therefore, control stations closer to the coverage link carried more weight, while those farther away had less weight. The following equation was used for assumption 3;

$$V_i^j = \sum_{c=1}^{C} \frac{V_{Control,c}^k \times V_i^k}{V_{Control,c}^j} \times \frac{\grave{L}_{i,c}}{\sum_{c=1}^{C} \grave{L}_{i,c}} \text{ for i=1...I, for j=1...H, for k=1...H} \quad (5)$$

V_i^j, V_i^k, $V_{Control,c}^j$, $V_{Control,c}^k$, I, H and C are defined as above. $\grave{L}_{i,c} = \frac{1}{L_{i,c}}$ where $L_{i,c}$ is the distance between coverage link *i* and control link *c*.

26 links for 11 hour traffic data were estimated before and after the ring road opened using three assumptions described above. Then, the effect of the newly-opened ring road on Amasya urban traffic was investigated by comparing the data at two different time points.

Traffic Related Air Pollution Estimation

Many studies investigate the amount of traffic-related air pollution (Kilic and Sen, 2017: Mangones et al., 2019; Rad and Naghipour, 2022). A considerable number of these studies estimate air pollution using simulation-based commercial software such as COPERT (Coşar and Demir 2016; Mangones et al., 2019), SUMO (Lemos and Pasin 2016). However, some studies make certain assumptions and calculate traffic-related air pollution directly from traffic volumes (Kilic and Sen, 2017).

The impact of a vehicle on traffic-related air pollution depends on various parameters; including the type of vehicle (e.g., car, bus, truck, etc.), the type of fuel used (e.g., gasoline, diesel, hybrid, LPG etc.), engine maintenance and driving behavior such as acceleration, deceleration or maintaining a constant speed. Additionally, environmental and weather conditions also contribute to air pollution. While simulation-based software can account for some of these parameters, this study specifically focuses on calculating the impact by considering only the fuel consumption of the engine.

In this study, the emission model for link *i* and pollutant *p* depends on the number of vehicles driven through the link (of length l) and the emission factors.

$$E_{i,p}^f = V_i \times B^f \times l_i \times EF_p^f \text{ for } i\text{=1...I} \quad (6)$$

where $E_{i,p}^f$ is the emission of link *i* for vehicle fuel type *f* and pollutant *p*. V_i is the estimated 11-hours traffic volume for link *i*. B^f is the coefficient showing what percentage of vehicles use fuel type *f*. In this study, only two-vehicle fuel type were considered which are gasoline and diesel. According to Turkish Statistical Institute, 25% of the vehicles were recorded as gasoline, 38% as diesel in 2020 (TUIK 2020). Please note that LPG and hybrid fuel type were not include in this study. l_i is the length of link *i*. EF_p^f is the emission factors for vehicle fuel type *f* and pollutant *p*. Different emission factors for different pollutant were used in different studies (Mangones et al., 2019). The factors used in the study was obtained from the study conducted by Kilic and Sen (2017). Table 1 shows the emission factors for two fuel types and seven pollutants, namely, Carbon Monoksit (CO), Hydrocarbon (HC), Nitric Oxide (NOx), Particular Matter (PM), and Sulfur Oxide (Sox).

Table 1. The emission factors for two fuel types and seven pollutants (Kilic and Sen 2017).

Fuel Type	CO	HC	NO_x	PM	SO_x
Gasoline	16.1	1.8	3	0.05	0.05
Diesel	0.72	2.2	16.5	1.5	2

RESULTS AND DISCUSSION

Figure 4 compares the 11-hours traffic volumes before and after the opening of the ring road for 26 links under three assumptions. 11-hours volumes were calculated by summing up 11 consecutive 1-hour volumes. Please note that before and after represent the traffic volumes before and after the ring road opened, respectively. As expected, compared to the before case, the 11-hours traffic volume on many links in the after case decreased. Only two links, namely link 11 and link 12, showed an increase. Additionally, similar results and conclusions were obtained under three assumptions. Therefore, further analyses in this study are presented and discussed under assumption 3.

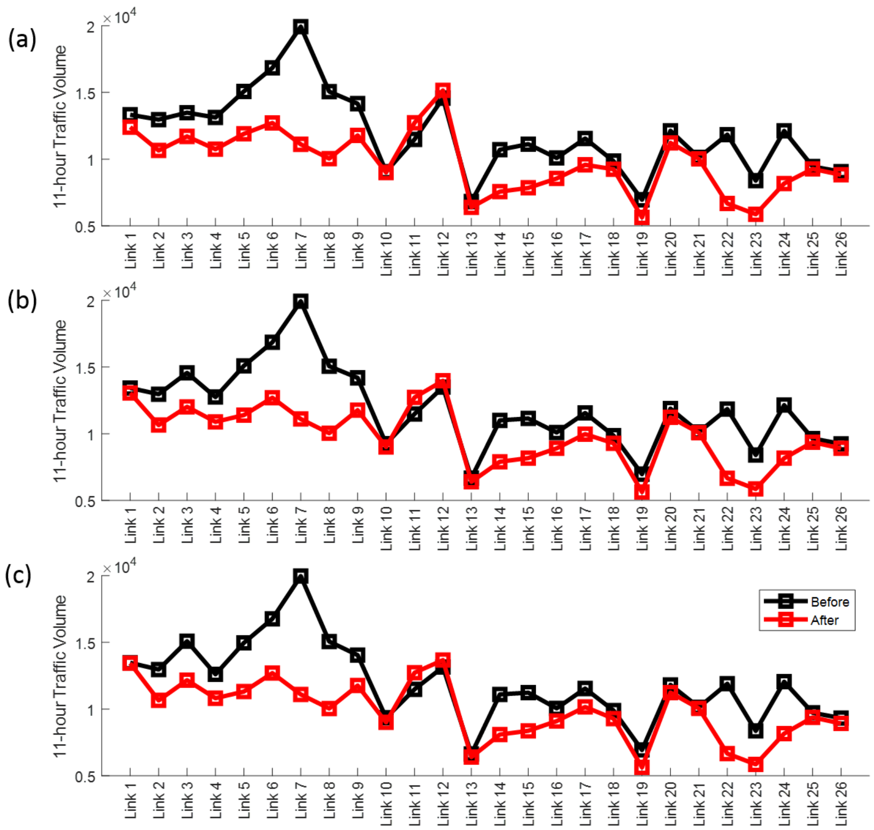

Figure 4. Comparing 11-hour traffic volume before and after under three assumptions: a) assumption 1, b) assumption 2, and c) assumption 3.

Two measures are used to quantify the change between before and after cases. They are called relative error (RE) and additive error (AE), and they are defined as follows.

$$RE = \frac{V_i^{Before} - V_i^{After}}{V_i^{After}} \tag{7}$$

$$AE = V_i^{Before} - V_i^{After} \tag{8}$$

where V_i^{Before} and V_i^{After} are the 11-hour traffic volume for before and after cases. Please note that a negative measure means that the 11-hour traffic volume for the before case is higher than the 11-hour traffic volume for the after case. Figure 5 shows the relative and additive errors, which are classified under four groups.

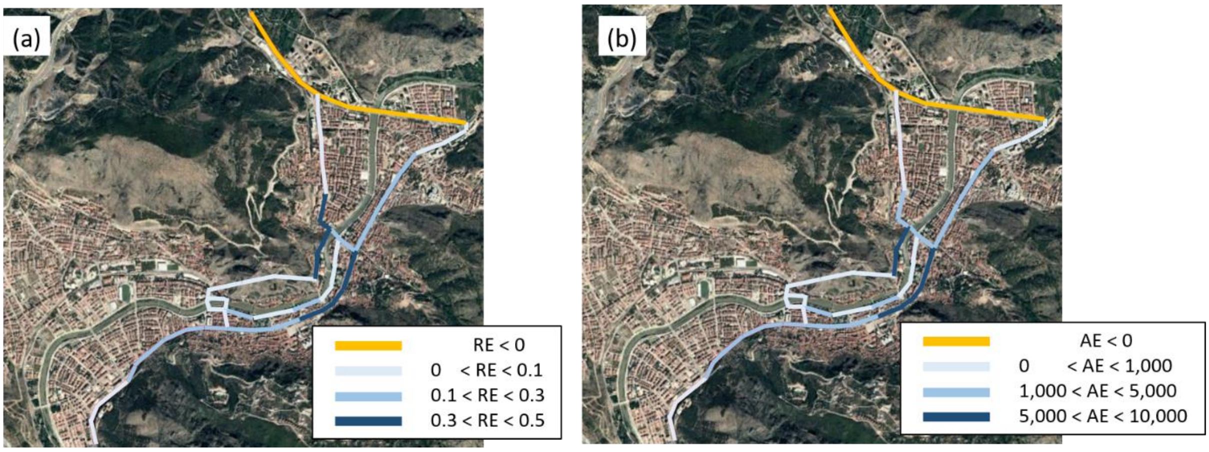

Figure 5. The error classes under assumption 3: a) relative error (RE), and b) additive error (AE).

Links, where no decrease is observed, are located in the northern part of the city center (indicated by yellow links in Figure 5). Two main reasons contribute to this observation. First, newly opened residential areas are around these roads, particularly on the north side, indicating a change in land use. Secondly, vehicles entering or coming from the northeast entrance of the city use these links directly, bypassing the city center and accessing the ring road. In contrast, before the ring road was opened, they passed directly through the city center. Thus, considering these two factors, a traffic volume increase in these links was reasonable. On the other hand, it has been observed that the decrease in the links close to southwest and northwest entrances is smaller, and the decrease increases as one moves towards the inner parts of the city center.

Figure 6 compares the 11-hour traffic volumes before and after the ring road opened for direction 1 and direction 2 under assumption 3. Direction 1 represents the direction from south to north while direction 2 represents the direction from north to south. Notably, only link 12 experiences an increase in traffic volumes for both directions after the ring road opens. On the other hand, some links show an interesting pattern where traffic volumes increase in one direction but decrease in the other. For example, a decrease in traffic volume was observed in direction 2, as well as an increase in direction 1 for links 1, and 11. Similarly, a decrease in traffic volume was observed in direction 1, as well as an increase in direction 2 for links 10, 13, 16, 17, 18, 19, 21, and 25. A decrease in traffic volumes was observed in both directions on the remaining seventeen links. Notably, more decreases were observed in direction 1 than in direction 2.

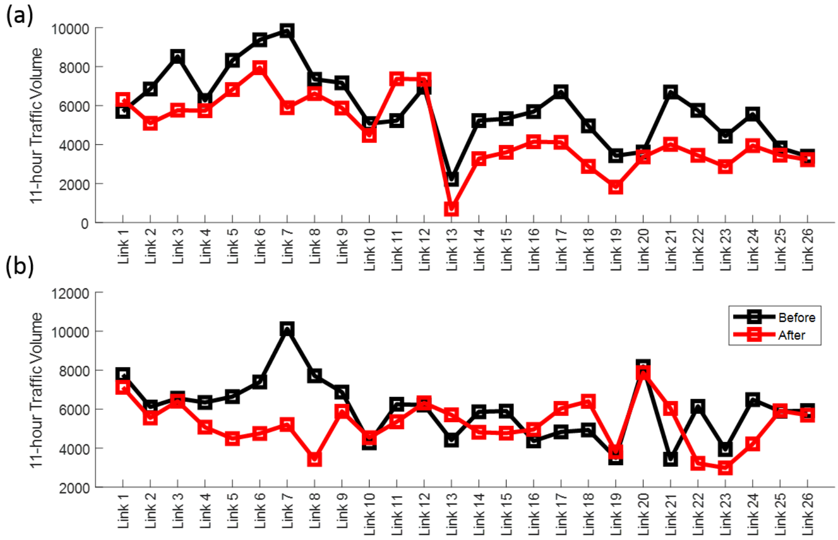

Figure 6. The comparison of 11-hour traffic volume for before and after under assumptions 3: a) direction 1, and b) direction 2.

Another investigation was conducted at different times of day periods. 11-hour traffic counts were collected for three control links. Therefore, it would be clearer to analyze the different times of day investigation using three control links. Figure 7 compares the traffic volumes for each time of day for only control links. As expected, the 11-hour traffic volume on control stations 1 and 2 are lower compared to the before case. On the other hand, the opposite situation is observed for Control Station 3, which is one of the links where no reduction was observed as discussed above.

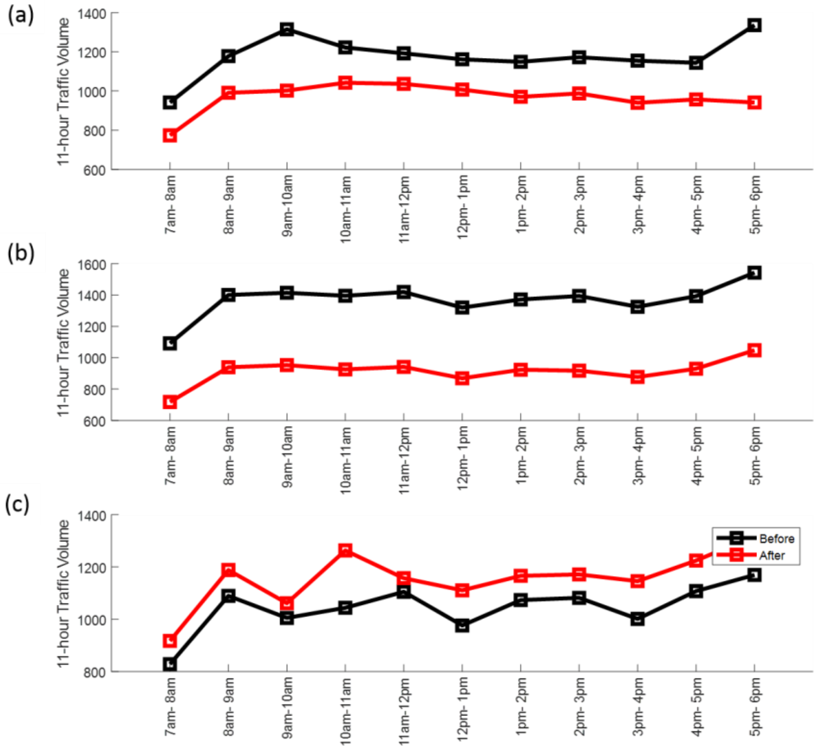

Figure 7. The comparison of 11-hour traffic volume for before and after: a) control link 1, b) control link 2, and c) control link 3.

The paired t-test was conducted to statistically test if the 11-hour traffic volume for the after case is different from the before case. This test was done for direction 1, direction 2 and total under three assumptions, and Table 2 presents the results. The null hypotheses were rejected in all cases with a 95% confidence level. This implies that after the ring road was built, a statistical decrease in urban traffic was observed.

Table 2. Paired *t*-test results under three assumptions.

	Assumption 1	**Assumption 2**	**Assumption 3**
Direction 1	Reject H_0	Reject H_0	Reject H_0
Direction 2	Reject H_0	Reject H_0	Reject H_0
Total	Reject H_0	Reject H_0	Reject H_0

In this study, traffic-related air pollution is also investigated. Emission amounts for two fuel types and seven pollutants are provided in Table 3 using the Equation 6. As anticipated, traffic-related air pollution decreased after the opening of the ring road for each fuel type and each pollutant, with a reduction of around 6.6%.

Table 3. Total emission amount for two fuel types and seven pollutants (in ton).

Fuel Type		**CO**	**HC**	**NO_x**	**PM**	**SO_x**
Gasoline	Before	6.458×10^5	7.220×10^4	1.203×10^5	2.005×10^3	2.005×10^3
	After	6.031×10^5	6.742×10^4	1.123×10^5	1.873×10^3	1.873×10^3
Diesel	Before	4.390×10^4	1.341×10^5	1.000×10^6	9.146×10^4	1.219×10^5
	After	4.099×10^4	1.252×10^5	9.395×10^5	8.540×10^4	1.138×10^5

Finally, many other studies have examined the effects of large transportation infrastructure projects in Turkey. These effects can be classified into four categories: changes in the amount of traffic, impacts on air pollution, alterations in land use, public transportation usage. For instance, the opening of the third bridge resulted in a reduction of traffic on the other two bridges across the Bosphorus by 2% to 10% (Kilic and Sen, 2017). The impact of the Amasya ring road on Amasya city traffic was approximately 13%. Moreover, the impact of the Amasya ring road on urban traffic was surpassed that the third bridge in the Bosphorus on the traffic of the other two bridges.

Other studies have also examined the impact of large projects on air pollution quality. For example, after the construction of the third bridge, a decrease in air pollution between 2.1% and 10% was observed on the other two bridges across the Bosphorus (Kilic and Sen, 2017). Another study focused on the air pollution from the Eurasia Tunnel in Istanbul, revealing a reduction of 1-5% in PM10 and NO2 gases (Onay et al., 2019). In essence, it has been observed that the impact of the ring road on traffic-related air pollution, which is around 6.6%, aligns with the findings of these two studies.

Land use is another category to be investigated after large project. For example, a dramatic change in land use has been observed after the construction of Istanbul Airport (Akyürek et al., 2018). Similarly, after the completion of ring road, there were some changes in land use in the city of Amasya. In fact, it was found that the increase, instead of decrease in some links after the construction of the ring road, may be attributed to this change in land use. However, it is crucial to note that this land use change is not necessarily linked to the construction of the ring road. In other words, in this study, no evaluation was made in terms of land use of the ring road. Additionally, the impact on land use can be better observed after a certain period of time. This study was conducted one year after the construction of the ring road.

After the great changes were made in the transportation network, public transportation usage is also expected to change. For instance, after the construction of Marmaray tunnel, rail system usage increased from 3% to 27.7% (Efe and Curebal, 2010). However, in this study, the effect of the ring road on public transportation could not be examined due to the unavailability of relevant data. Travel time is one of the most important results that road users observe. In this study, no analysis was made regarding travel time. However, it is reported that the travel time has decreased from 30 minutes to 7 minutes (Okur, 2020).

CONCLUSION

The road network in the city center is one of the main characteristics for not only economic development but also a comfortable life. Therefore, it needs to be effective and sufficient. However, due to the geographical condition of Amasya in Turkey, the road network cannot accommodate changes. Instead of extending the capacity of the road network in the city center, the ring road was built. In this study, the impact of the newly opened ring road in Amasya city of Turkey on urban traffic and traffic-related air pollution was investigated.

Traffic data was collected manually since other technologies were unavailable in the study area. Therefore, data were collected on only three weekdays for 26 links and 11 hours (from 7 AM to 6 PM) before and after the newly opened ring road. Three assumptions were used to estimate the 11-hour traffic volume, and each one of them gives similar results. Specifically, a traffic volume reduction was observed in 92% of the links (24 out of 26 links). In addition, there was a reduction of more than 20% in 35% of the roads (9 out of 26 links). This reduction was statistically tested, and the traffic volume was statistically decreased after the ring road was built at a 95% confidence level. Similarly, an assessment of traffic-related air pollution was also conducted in this study. Considering seven pollutants, namely CO, HC, NOx, PM, and Sox, a decrease of 6.6% was observed after the ring road opened. Finally, it is important to note that this study considered the traffic amount and air pollution one year after the ring road was opened, and further reductions may be observed in the coming years.

There are several limitations and methodological assumptions arising from data collection procedures, field conditions, and the measurement approach. Firstly, all traffic data were recorded manually since there are no fixed counting stations or advanced sensor systems capable of providing continuous traffic data in the study area. Therefore, estimations were made using some assumptions to fill in missing traffic data. While the manual data collection approach provides rapid data acquisition under controlled conditions, it also has drawbacks such as data accuracy and short measurement time. Additionally, the time and labor intensive nature of manual counts prevented the expansion of sampling periods and limited counts from specific links within Amasya. That is, data collection was limited to August. Annual Average Daily Traffic metric, which represents annual traffic, or similar continuous traffic metrics were not used. Instead, only short-term traffic volumes for the specified period were compared.

In the air-pollution estimation process, emission values derived from traffic data were not directly based on field measurements. They were calculated using fuel and emission coefficients obtained from previous study. These coefficients were not calibrated specifically for the Amasya region, and no localized emission-factor study was conducted to reflect local driving conditions (e.g., stop-and-go frequency, idling durations, and roadway grade profiles), the composition of the regional vehicle fleet, or micro-scale meteorological influences. This is recognized as a significant source of uncertainty that limits the ability of the model to fully represent the actual emission profile of the region, constituting one of the key methodological limitations of the study. In addition, there is only a one-year difference between the "before" and "after" periods. It is assumed that the fuel type distribution in the region remains constant during this period.

Despite methodological limitations, both traffic volumes and traffic-related air pollution changes in this study can be scientifically interpreted and considered meaningful, as the analysis focuses on relative changes between ''before'' and ''after'' periods rather than the precise accuracy of absolute values. Any potential biases and uncertainty arising from both traffic volume estimation and traffic-related air pollution estimation were expected to be same direction and similar magnitude over time. This enable a reliable comparative assessment of the differences between the two periods.

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Conflict of Interest

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Ethical Statement

Ethics committee approval is not required for the study.