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ASSESSMENT OF THE STATE OF ATMOSPHERIC AIR IN AN URBAN ENVIRONMENT DURING A FIRE AT A SOLID WASTE LANDFILL AND COMPARISON WITH AIR QUALITY INDICES

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Abstract

A study of the state of atmospheric air and anthropogenic impact in a typical urban area of Bulgaria - the city of Plovdiv and its surroundings was conducted. The study is based on a specific incident - a fire at a solid waste landfill in the city of Plovdiv. The values of the main pollutants of the atmospheric air above the settlements were monitored (PM10, SO_2, NO_2, O_3, CO and benzene). The chemical and ecological state of the atmospheric air was assessed. Its quality was analyzed using the Air Quality Index (AQI) of the United States Environmental Protection Agency (US-EPA) and the European Air Quality Index (EAQI) of the European Environment Agency. Deviations from the permissible values are observed only for particulate matter (PM10) - irregular higher hourly values above the permissible value, which is for 24 hours. The results are compared with those of the two automatic stations in the city. The possible impact of the excessive values on human health, living organisms, and protected habitats is shown. Measures to improve air quality were discussed.

Key words*: air pollution, air quality index, anthropogenic impact, chemical state, particulate matter.*

INTRODUCTION

Anthropogenic air pollution arises from human activities related to industrial and social development. The majority of the population exposed and affected by air pollution lives in the area of pollution sources. Obviously, attention is being directed towards the urban environment and industrial sites (Allegrini et al., 2023).

Any activity that leads to a deterioration or reduction in the quality of the natural environment is considered pollution. This is the biggest global problem facing humanity and a leading environmental cause of morbidity and mortality (WHO global air quality guidelines, 2021; Directive (EU) 2016/2284; Directive (EU) 2024/2881). Environmental pollution is more common in middle- and low-income countries than in developed countries. The likely reasons for this are poverty, poor legislation, and lack of awareness about forms of pollution. The population's daily encounter with pollution leads to habituation and dulling of attention. People often carry out activities that disrupt the stability and resilience of ecosystems and lead to environmental deformation - deforestation, deliberate arson, and unregulated disposal of agricultural, household, and electronic waste. Exponential population growth and urbanization are increasing this harmful pressure on the environment. Air pollution is well-studied and receiving increasing attention due to increased morbidity and premature mortality. It affects the most vulnerable groups in middle- and low-income countries. Greater awareness of the dangers of pollution and the subsequent limitation and prevention of activities leading to environmental pollution are needed so that the restoration of already affected nature becomes feasible (Ukaogo et al., 2020). Natural and

anthropogenic features and the interaction between them determine air quality in urban environments. Pollution is determined by incoming emissions, dispersion, and transport of pollutants. Factors contributing to the deterioration of air quality in cities include population growth, increased traffic, and the energy and industrial sectors. There is a typical annual, weekly and daily cyclicality (Mayer, 1999).

The harmful impact on human health from air pollution is expressed in the exacerbation of cardiovascular, airborne diseases, diseases of the gastrointestinal tract and endocrine system, an increase in the frequency of allergies and bronchial asthma (with increased dust content). The implementation of sustainable development policies is crucial for limiting emissions and reducing morbidity (Komilova et al., 2023).

Since 1950, the world population has more than doubled, with the urban population more than quadrupling. The number of cars has increased even faster, over ten times. This rapid urbanization is leading to environmental degradation. Urban activities are sources not only of local air pollution, but also have a significant share in transboundary pollution (Fenger, 1999).

Urban regions are the source of one third of anthropogenic greenhouse gases and the majority of air pollutant emissions worldwide. While climate change is a global problem, poor air quality is a local one. Joint action on both climate and air pollution is needed to limit the harmful effects of air pollutants on urban populations and ecosystems (Crippa et al., 2021).

Different countries and regions have different air quality systems. Each system uses its own harmfulness index, permissible pollution concentration, and measurement time. This makes it difficult for users to navigate between the different systems. The Air Quality Index (AQI) of the United States Environmental Protection Agency (US-EPA) and the European Air Quality Index (EAQI) of the European Environment Agency are widely popular and used.

The AQI is a number calculated based on measured levels of particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide in ambient air. The values are divided into six levels of air pollution, each of which is in a different color and provides information about possible health effects (Horn & Dasgupta, 2024; Sheikh, 2019). The EAQI also takes into account the main pollutants - particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide and sulfur dioxide, but the values are specific to each pollutant. The ranges of values are divided into six zones according to the impact and relative health risk, as defined by the World Health Organization and related to short-term exposure to the pollutants (European Air Quality Index, 2024).

Both indices should not be compared with the relevant air quality standards in individual countries. They can serve as a guide to the quality of ambient air when traveling, working, or in general for populated areas. At the same time, public awareness of the importance of clean air is being raised and broader support for air quality and emissions regulations is being built. As regulatory restrictions change, both indices change, keeping them current and timely (Sheikh A., 2019; European Air Quality Index, 2024).

Particulate matter is a major factor in air pollution and its harmful effects on human health and living organisms in recent decades. The negative effect is determined by the dispersion, chemical composition and, accordingly, the physicochemical properties of these particles. The presence of heavy metals in road dust in densely populated areas is mainly due to industrial, construction and transport activities (Lei et al., 2024; Ma et al., 2025).

Air quality standards in cities are frequently exceeded. This negatively affects the population and leads to reduced labor productivity, increased economic and medical costs, and shortened life expectancy. Pollutants such as particulate matter, nitrogen dioxide, and ground-level ozone have the most serious impact on human health. Compliance with the recommendations of the World Health Organization would lead to limiting the negative effects of urban air pollution (Air pollution quick country facts, 2024).

Air pollution negatively affects both terrestrial and aquatic ecosystems, thereby deteriorating the environment and reducing biodiversity. Each pollutant has a specific harmful effect.

Ozone, as a secondary air pollutant, damages plants and forest stands, reducing growth rates and yields. The release of ammonia (in agricultural activities) and nitrogen oxides (in combustion processes) leads to nitrogen deposition on land and in water bodies, respectively to eutrophication processes and ultimately to changes in the structure and function of the ecosystem (Impacts of air pollution on ecosystems in Europe, 2024).

Nearly three-quarters of European ecosystems are exposed to harmful levels of air pollution, according to the latest data. This leaves Europeans exposed to concentrations of air pollutants above WHO recommended levels (Health and environment impacts of air pollution exposure remain high across Europe, 2024).

The increase in public health incidents resulting from air quality, as well as environmental degradation, is prompting authorities and experts to improve and seek new ways of monitoring air quality and “adequately” deploying air quality sensors (Chaudhuri & Roy, 2024).

The subject of this study is a typical urbanized urban area, namely that of Plovdiv, the second largest city in Bulgaria. The high density of construction, intensive car traffic and industrial activity are characteristic. The main factors for air pollution in the area under consideration are combustion processes, transport, the condition of the road and adjacent infrastructure. Plovdiv is located in the central part of the Upper Thracian Lowland. The relief is mainly flat, and the hills form an arc along the border with the Rhodope Mountains. The climate is transitional-continental with moderate precipitation and prolonged summer droughts. The prevailing westerly and easterly winds are of relatively low speed. A characteristic feature is the high proportion of calm weather. The dispersion of pollutants is adversely affected by temperature inversions (on about 81% of the days during the year) and the large number of foggy days in winter (Report on the Influence of the Atmospheric Air on the Health of the Population of "Plovdiv Agglomeration" in 2024, 2025).

The air quality in the area is monitored through air monitoring stations, which are part of the National Environmental Monitoring System. There are two automatic measuring stations (AMS) (Regulation No. 12 of July 15, 2010 for standards for sulfur dioxide, nitrogen dioxide, fine dust particles, lead, benzene, carbon monoxide and ozone in atmospheric air):

– AMS "Kamenitsa", classified as an urban background station. It is located in the central part of the city of Plovdiv in an area with mainly residential buildings and medium-heavy car traffic;

– AMS "Trakia" - meets the conditions for a transport-oriented point. It is located in an area with heavy car traffic. The observed pollution is mainly formed by transport and individual heating systems.

MATERIALS AND METHODS

The anthropogenic impact and potential pollution of the Plovdiv region was studied through a typical incident factor - a fire at the Regional Non-Hazardous Waste Landfill. The location of the air monitoring stations, the regional non-hazardous waste landfill and the protected areas in the study area are presented on the map in Figure 1.

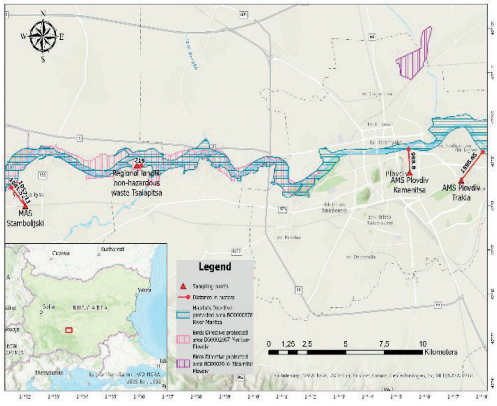


Figure 1. Locations of air monitoring stations, the regional non-hazardous waste landfill and protected areas in the study region

The main typical indicators of ambient air quality in populated areas were analyzed, namely - particulate matter (PM10), sulfur dioxide, carbon monoxide, nitrogen dioxide, nitrogen oxide, ozone, benzene. The indicators, together with their analysis methods and current permissible concentrations for Bulgaria, are presented in Table 1.

Table 1. Measured indicators and main characteristics

Indicator	Unit of measure	Analysis method	Uncertainty	Standard
Particulate matter	μg/m^3	BDS EN 16450:2017	U=14.7%	ADN - 50 AAN - 40
Sulfur dioxide	μg/m^3	BDS EN 14212:2012	U=3.70%	AHN - 325 AND - 125
Carbon monoxide	mg/m^3	BDS EN 14626:2012	U=3.75%	HHPS - 10
Nitrogen monoxide and Nitrogen dioxide	μg/m^3	BDS EN 14211:2012	U=3.74%	AHN - 200 AAN - 40
Ozone	μg/m^3	BDS EN 14625:2012	U=3.60%	HHPS - 180
Benzene	μg/m^3	BDS EN 14662-3:2015	U=4.5%	AAN - 5

Legend: ADN - Average daily norm for the protection of human health; AAN - Average annual norm for the protection of human health; AHN - Average hourly norm for protecting human health; HHPS - Human health protection standard (maximum eight-hour average value within 24 hours); Regulation No. 12 (2010).

Ambient air quality was analyzed using the Air Quality Index (AQI) of the United States Environmental Protection Agency (US-EPA) and the European Air Quality Index (EAQI) of the European Environment Agency. The values of the two indices AQI and EAQI and their corresponding air quality color scales are presented in Table 2 (Horn & Dasgupta, 2024; European Air Quality Index, 2024).

Table 2. Air Quality Index (AQI), European Air Quality Index (EAQI) and the corresponding condition color scale

Air Quality Index (AQI)		European Air Quality Index (EAQI), PM10	
Values	Condition color scale	Values, μg/m^3	Condition color scale
0-50	good	0-20	good
51-100	moderate	20-40	fair
101-150	unhealthy for sensitive individuals	40-50	moderate
151-200	unhealthy	50-100	poor
201-300	very unhealthy	100-150	very poor
300+	dangerous	150-1200	extremely poor

The fire at the Regional Non-Hazardous Waste Landfill, Tsalapitsa, occurred on 1 August 2024 and was contained within a few days. The impact and potential contamination of the Plovdiv area were assessed through the readings of the Stambolijski MAS, Kamenitsa MAS - Plovdiv and Trakia MAS - Plovdiv for the period 1-6 August 2024. The mobile station in Stambolijski is temporarily located for the above-mentioned period in connection with the specific meteorological conditions and the dispersion of possible pollutants.

RESULTS AND DISCUSSIONS

The impact and probable pollution of the surveyed region from the fire at the non-hazardous waste landfill was assessed through the readings of the MAS Stambolijski, AMS "Kamenitsa" - Plovdiv and AMS "Trakia" - Plovdiv for the period 1-6 August 2024. The interval of the measured hourly values for the controlled atmospheric pollutants for the time from 1 August 2024 to 6 August 2024 for the three stations is presented in Table 3.

Table 3. Interval of measured hourly values for controlled atmospheric indicators for the time from August 1, 2024 to August 6, 2024, for the three automatic stations

Indicator	Value range		
	AMS - Trakia	AMS - Kamenitsa	MAS - Stambolijski
Particulate matter, μg/m^3	12 ÷ 348	9 ÷ 139	7 ÷ 45
Sulfur dioxide, μg/m^3	2 ÷ 14	8 ÷ 49	7 ÷ 35
Carbon monoxide, mg/m^3	0.2 ÷ 0.7	0.1 ÷ 0.6	0.2 ÷ 0.6
Nitrogen monoxide, μg/m^3	5 ÷ 13	0.5 ÷ 8	1 ÷ 5
Nitrogen dioxide, μg/m^3	15 ÷ 56	4 ÷ 37	8 ÷ 40
Ozone, μg/m^3	-	25 ÷ 160	31 ÷ 131
Benzene, μg/m^3	0.01 ÷ 4.23	0.02 ÷ 0.16	-

Hourly values higher than the maximum permissible concentrations are observed only for the PM10 indicator - the deviations are present for the two automatic stations in the city of Plovdiv. The high maximum values (close to the permissible values according to legislation) for nitrogen dioxide, ozone and benzene should not be ignored.

The average daily concentrations of PM10 for the three measuring stations and the EAQI and AQI levels are presented in Table 4.

The reported values correspond to good status according to both indices, with the exception of the value reported for AMS Trakia on 02.08.2024 - moderate status according to EAQI.

The hourly exceedances of the 24-hour average limit for PM10 (50 μg/m^3) and the assessment of the condition according to EAQI and AQI are presented in Table 5.

Table 4. Average daily particulate matter concentration for the three measuring stations and EAQI and AQI levels

Data	Value					
	AMS - Trakia		AMS - Kamenitsa		MAS - Stambolijski	
	PM10, EAQI µg/m³	AQI	PM10, EAQI µg/m³	AQI	PM10, EAQI µg/m³	AQI
1.08. 2024	18	17	19	18	-	-
2.08. 2024	45	42	39	36	19	18
3.08. 2024	26	24	27	25	23	21
4.08. 2024	22	20	21	19	15	14
5.08. 2024	16	15	16	15	12	11
6.08. 2024	20	19	17	16	15	14

Table 5. Hourly exceedances of the 24-hour average limit for PM10 (50 µg/m³)

Date	Hour	Value			
		AMS - Trakia		AMS - Kamenitsa	
		PM10, EAQI µg/m³	AQI	PM10, EAQI µg/m³	AQI
1.08. 2024		–	–	–	–
2.08. 2024	06:00 07:00 08:00 09:00 10:00	50 348 119 151 67	46 197 83 99 57	71 106 139 132 –	59 76 92 89 –
3.08. 2024	21:00 22:00	55 –	51 –	59 54	52 50
4.08. 2024	01:00 02:00	124 58	85 52	– –	– –
5.08. 2024		–	–	–	–
6.08. 2024		–	–	–	–

As can be seen from the data in Table 5, hourly exceedances of PM10 are observed on August 2, 3 and 4, 2024 for AMS - Trakia and August 2 and 3, 2024 for AMS - Kamenitsa. For AMS - Trakia, the exceedances are a total of eight, while for AMS - Kamenitsa, there are a total of six. The highest and highest values were recorded in the first half of the day on August 2, 2024. Out of the total 14 exceedances obtained, 7 values indicate poor air quality (4 in AMS - Trakia and 3 in AMS - Kamenitsa); 5 values indicate very poor air quality (2 in AMS - Trakia and 3 in AMS - Kamenitsa), and 2 values indicate extremely poor air quality according to EAQI (both in AMS - Trakia).

What is the impact of elevated PM10 values on the flora, fauna and health of the population in the study region? This impact has been assessed based on the Law on environmental protection, the Atmospheric air purity law, the Law of Health and Regulation No. 12/2010 on the standards of harmful substances in the ambient air of populated areas (Law on environmental protection, 2002; Law of Health, 2005; Atmospheric air purity law, 1996; Regulation No. 12, 2010).

No exceedances of the standards for the protection of human health were registered for the measured indicators in the days from 01.08.2024 to 06.08.2024, according to the presented results for the controlled pollutants of the atmospheric air for the three monitoring stations - MAS - Stamboliyski, AMS - Kamenitsa - Plovdiv and AMS - Trakia - Plovdiv. Fourteen of the reported hourly PM10 values exceed the daily average (Tables 3 and 5).

The average daily values indicate good air quality according to the AQI - air pollution poses a low or low risk. According to the EAQI, the values obtained correspond to good (9 values), sufficient (24 values) and only one - to moderate condition.

The hourly values exceed the daily average in 14 of the 288 results (4.86%) obtained for the two stations AMS - Trakia and AMS - Kamenitsa. This excess is from 1.01 to 6.97 times. According to AQI, 11 values indicate a moderate state of ambient air quality with a risk for very sensitive people with respiratory diseases and only one value for an unhealthy state, in which everyone can begin to experience health consequences, and members of sensitive groups may have more serious health

consequences. Despite the fact that the relative share of the results for the most part indicates a good state of ambient air quality (according to AQI), the excesses obtained are not negligible.

Near the assessed sites are Protected Area BG0002016 "Ribarnici, Plovdiv"; Protected Area BG0000578 "Maritsa River" for the protection of natural habitats and wild flora and fauna; Protected Area BG0002087 "Maritsa, Plovdiv" for the protection of wild birds (Figure 1). The increase in particulate matter levels is expected to worsen the living conditions of species and their ability to inhabit the protected area (Biodiversity Law, 2002; NATURA 2000).

In the region of the city of Plovdiv and the surrounding area in 2024, according to the Regional Inspectorate for Environment and Water and the Regional Health Inspectorate, five more fires occurred requiring measurements with a mobile automatic station for atmospheric air quality. Summary information on the quality of ambient air in the studied region is presented in the annual reports of both organizations. Table 6 presents the calculated annual average value (AAV) and the registered number of exceedances of the permissible values for basic indicators for the two measuring stations in the city of Plovdiv - AMS - Trakia and AMS - Kamenitsa for a three-year period - from 2022 to 2024 (Regional Report on the State of the Environment in 2024, 2025; Report on the Influence of the Atmospheric Air on the Health of the Population of "Plovdiv Agglomeration" in 2024, 2025). Exceedances of permissible values are observed mainly for particulate matter (of the average daily values for all three years for both stations), as well as for nitrogen dioxide (of the average annual values for 2022 and 2023 for AMS - Trakia). The observed exceedances of the average daily norm for PM10 in the AMC - Trakia exceed the permissible number, according to the legislation, of 35 times within the calendar year. The recorded maximum hourly values for benzene also exceed the permissible annual average standard.

For the incident we investigated - a fire at a solid waste landfill, no daily average values for PM10 higher than the maximum permissible concentration were observed, but high hourly values exceeding the daily average norm.

According to the Regional Inspectorate for Environment and Water and the Regional Health Inspectorate, the origin of air pollution in the region should be sought primarily in the production of electricity and heat, domestic heating and motor vehicle transport. In recent years, a positive trend towards a decrease in the number of registered exceedances and high values of pollutants at monitoring points has been observed (Regional Report on the State of the Environment in 2024, 2025; Report on the Influence of the Atmospheric Air on the Health of the Population of "Plovdiv Agglomeration" in 2024, 2025).

Table 6. Summary results for exceedances of basic assessment indicators for ambient air quality for AMS - Trakia and AMS - Kamenitsa for the period 2022-2024

AMS	AMS - Trakia		AMS - Kamenitsa	
Indicator PM10 Standard: AAN - 40 μg/m³, ADN - 50 μg/m³ (exceeded no more than 35 times per calendar year)				
year	AAV, μg/m³	Number of exceedances of the ADN	AAV, μg/m³	Number of exceedances of the ADN
2022	**37.20**	**64**	**28.36**	**32**
2023	**32.09**	**42**	**26.79**	**28**
2024	**30.06**	**45**	**28.66**	**31**
Indicator SO_2 Standard: AHN - 325 μg/m³, ADN - 125 μg/m³				
year	AAV, μg/m³	Number of exceedances of the ADN	AAV, μg/m³	Number of exceedances of the ADN
2022	**5.53**	**0**	**12.55**	**0**
2023	**5.08**	**0**	**10.04**	**0**
2024	**5.54**	**0**	**11.53**	**0**
Indicator CO Standard: HHPS - 10 mg/m³				
year	AAV, mg/m³	Number of exceedances of the standard	AAV, mg/m³	Number of exceedances of the standard
2022	**0.52**	**0**	**0.34**	**0**
2023	**0.53**	**0**	**0.33**	**0**
2024	**0.48**	**0**	**0.00**	**0**
Indicator NO_2 Standard: AHN - 200 μg/m³, AAN - 40 μg/m³				
year	AAV, μg/m³	Number of exceedances of the AHN	AAV, μg/m³	Number of exceedances of the AHN
2022	**42.48**	**0**	**6.97**	**0**
2023	**43.09**	**0**	**2.15**	**0**
2024	**35.84**	**0**	**17.51**	**0**
Indicator Ozone Standard: HHPS - 180 μg/m³				
year	Maximum measured 8h value, μg/m³	Number of exceedances of the standard	Maximum measured 8h value, μg/m³	Number of exceedances of the standard
2022	**NA**	**-**	**130.16**	**0**
2023	**NA**	**-**	**119.32**	**0**
2024	**NA**	**-**	**132.17**	**0**
Indicator Benzene Standard: AAN - 5 μg/m³				
year	AAV, μg/m³	Maximum measured hourly average concentration	AAV, μg/m³	Maximum measured hourly average concentration
2022	**0.41**	**10.69**	**0.79**	**15.85**
2023	**0.53**	**9.23**	**0.81**	**25.53**
2024	**0.34**	**13.60**	**1.18**	**26.57**

The specific meteorological conditions in the region (a large number of days with calm weather - wind speed below 1.5 m/s, temperature inversions and fog on the rivers) are a prerequisite for the retention and accumulation of pollutants. The adverse climatic conditions in the region - more than 50% of the days in the year with calm weather and over 75% of the days in the year with inversion processes, lead to the retention of the formed relatively high background concentrations of PM10.

Particulate matter is a major air pollutant. It is emitted directly into the atmosphere by transport, energy and domestic activities (primary emissions) or is formed in the air from metal oxides, polyaromatic hydrocarbons, sulfur dioxide, nitrogen oxides, ammonia and other gases (secondary emissions). Its harmful effects on health depend mainly on the size and chemical composition of the suspended particulate matter, on other chemical compounds adsorbed on their surface and on the part of the respiratory system in which it is deposited. Particulate matter enters the body mainly through the respiratory system, with larger particles being retained in the upper respiratory tract, while finer particles reach the lower parts of the respiratory system, leading to tissue damage in the lung. Children, the elderly and people with chronic lung diseases, respiratory diseases or asthma are particularly sensitive to high PM10 values. The harmful effect of particulate matter pollution is more pronounced when sulfur dioxide is present in the ambient air. Their synergistic effect on the respiratory organs and exposed mucous membranes is manifested by irritation and depends on the duration of exposure.

There is a relationship between high PM concentrations and mortality, hospitalizations for respiratory diseases, and person-days of bronchodilator use. It is assumed that acidic particles with nanosizes smaller than 100 nm cause acute respiratory problems in sensitive people. Particles with a diameter smaller than 10 μm can pass into the thoracic airways of people. PM pollution can lead to the development of asthma, aggravate respiratory diseases, provoke and progress chronic diseases such as emphysema, lung cancer and others. Adverse effects on human health, flora and fauna occur not only at high concentrations, but also at values close to or even below the permissible norm (Chuturkova, 2015).

CONCLUSIONS

High values, including exceedances of the maximum permissible concentrations of air quality indicators, have a negative impact on the health, lifestyle and work of the population. These high values and exceedances are a consequence of both single incidents (such as the fire in question) and permanent anthropogenic load from the energy and transport sectors. Reducing the harmful impact of particulate matter as a major pollutant requires taking adequate measures. These may include: modernization, quality maintenance and washing of road surfaces; control of construction activities; landscaping of open areas; construction of insulating plant belts on busy streets with intensive transport traffic; tolerating the replacement of solid fuels used for heating with central heating, electricity and natural gas; increased control over landfills and unregulated burning of solid waste.

In order to limit air pollution and, accordingly, the harmful effects of dust particles, specific actions are required on the one hand by administrative and control authorities, and on the other - by citizens.

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