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STUDY OF THE TECHNOGENIC IMPACT OF MOTOR TRANSPORT ON THE ENVIRONMENT IN CITIES

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ABSTRACT: The purpose of this study is to conduct a thorough analysis of the current state and possible prospects of the technogenic impact of motor transport on the environment in cities. For this purpose, some densely populated cities located in the south of Kazakhstan in sandy areas were investigated, in particular, one of the busiest by motor transport – the city of Shymkent. The scope of the study was determined in accordance with its key elements, namely, regional types of aggregates of technogenic impact and a comparative analysis of the impact of motor transport on the environment in cities. The data of the national air quality monitoring network were obtained through the existing national network of Kazhydromet stations. As a result, only historically-stable indicators were selected, supplemented by the results of field studies by the Research Institute of Transport and Communications (RITC), the Centre for Strategic and International Studies (CSIS), and regional opportunity indices (RCI) determined by the global consulting firm Whiteshield Partners. The study found that some vehicles, such as those with outdated emission standards, high mileage, or failures in engine emission control systems, contribute disproportionately to the total emissions, and reducing the number of heavy vehicles and improving the quality of the road surface can help reduce emissions.

Keywords: Motor vehicle emissions, Air pollution, Quality of life, Road traffic, Heavy load capacity

1. INTRODUCTION

Many countries, especially developing ones, are rapidly urbanizing. According to United Nations estimates, the world's urban population is rapidly increasing [1]. Urbanization has a dramatic impact on economic growth, poverty reduction, and human development [2]. However, the rapid growth of cities is largely fraught with urban air pollution, which poses a major risk to public health worldwide. The urban population breathes polluted air exceeding the permissible standards of the World Health Organisation (WHO) [3]. Every year, millions of deaths worldwide are associated with ambient air pollution (Fig. 1). Various sources contribute to urban air pollution, such as road transport, industry, and households. Among them, vehicle emissions are often the main cause [4].

The rapid growth of the urban population not only increases traffic and emissions but also stimulates the development of medium and high-density housing, especially around transport hubs and shopping malls. High-rise and dense buildings limit the dispersion of pollutants and, thus, further aggravate the problem of roadside air pollution. The concentrations of pollutants at the street level are much higher, despite the fact that traffic on a city street is much easier.

The purpose of this study is to conduct a thorough analysis of the current state and possible prospects of the technogenic impact of motor transport on the environment in cities. For this purpose, some densely populated cities located in the south of Kazakhstan in sandy areas were investigated, in particular, one of the busiest by motor transport – the city of Shymkent (Fig. 2). The object of the study is regional transport data for different historical periods, which would allow the possibility of statistical analysis and comparison using the same methodology.

The study of the technogenic impact of motor transport on the environment in cities is not a new topic and has been conceptualised on a large scale in recent decades [5, 6]. A number of projects are devoted to specific aspects of the technogenic impact of motor transport on the environment in cities [7-9], such as monitoring and modelling methods, computational fluid dynamics, technogenic pollution of the environment by motor transport at street intersections [10], structures of technogenic impact flows, modelling of chemical and dynamic relationships of traffic emissions.

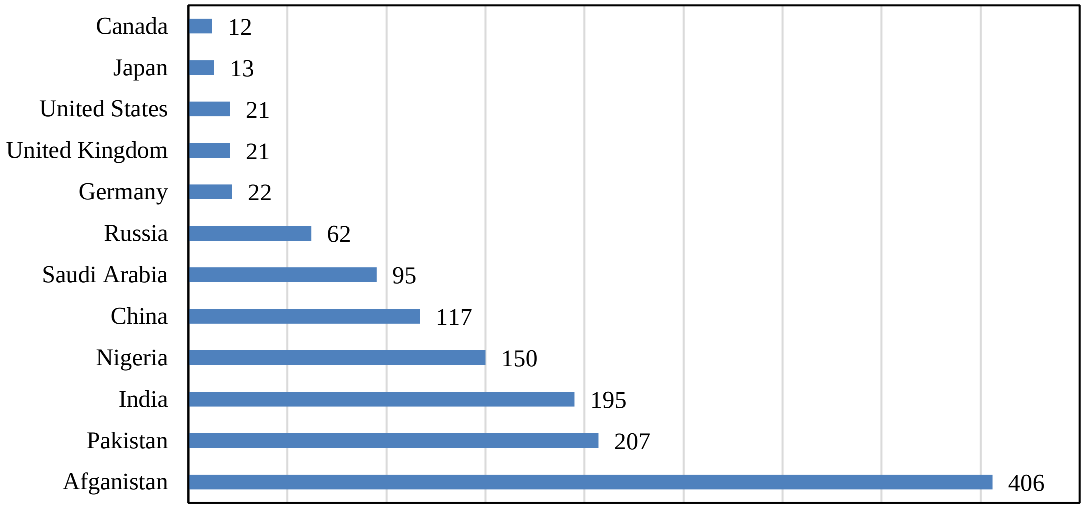

Fig. 1 Age-standardized deaths per 100 000 people attributable to air pollution (2016) [5]

Since road transport is the dominant source of technogenic impact on the urban environment [11], accordingly, measures to ensure road traffic seems to be the most effective strategy for improving the quality of life in cities, for example, considering the arrangement of low-emission zones and charging for congestion (Table 1).

Fig. 2 Shymkent on the map of Kazakhstan

Table 1 Rating of Kazakh cities according to the real-time Air Quality Index

No	City	US AQI
1	Astana, Astana	99
2	Shetpe, Mangghystau	97
3	Ust-Kamenegorsk, East Kazakhstan	96
4	Aktau, Mangghystau	94
5	Omirzaq, Mangghystau	93
6	Temirtau, Karaganda	93
7	Almaty, Almaty Qalasy	81
8	Abay, Karaganda	74
9	Zhetibay, Mangghystau	62
10	Burunday, Almaty Oblysy	61

By investigating the impact of motor transport on the environment, the study aims to identify the main sources of air pollution and their contribution to the total emissions. The findings of this study can provide valuable insights into the development of policies and strategies to reduce air pollution in cities and promote sustainable urban development.

Next, the research significance section highlights the importance of the study and its potential contribution to policy-making and urban planning. The materials and methods section outlines the search strategy developed for the study and the databases used to collect information.

The results section presents data showing the impact of vehicle emissions on air pollution, noise emissions, and the various strategies used to reduce the technogenic impact of vehicles on the environment. The discussion section provides an analysis of the debate on the technogenic impact of motor transport on the environment in the cities of Kazakhstan, using Shymkent as an example. Finally, the conclusions section summarizes the key findings of the study and emphasizes the importance of mitigating the impact of motor transport on the environment in cities.

2. RESEARCH SIGNIFICANCE

The significance of the study is that it compares various potential strategies for reducing the technogenic impact of vehicles on the environment in cities, including traffic management, designing the geometry of urban development and building street barriers, and describing problems and prospects for the future. It is expected that the findings would help policymakers and urban planners effectively plan and manage urban development and ensure a high level of quality of life in cities.

3. MATERIALS AND METHODS

The search strategy in this study was developed and structured by a systematic review. The data of the national air quality monitoring network were obtained through the existing national network of Kazhydromet stations. Air quality monitoring data are published monthly and annually in newsletters on the state of the environment in Kazakhstan. Kazhydromet monitors the air quality in cities and towns, tracking various pollutants [12].

When collecting data on the regions of Kazakhstan, significant obstacles were encountered, in particular, it turned out to be difficult to find regional transport data for different historical periods that would allow for statistical analysis and comparison using the same methodology. It was not possible to use the originally planned variables and determine all possible empirical correlations due to the lack of reliable data. As a result, only historically-stable indicators were selected, supplemented by the results of field studies by the Research Institute of Transport and Communications (RITC), the Centre for Strategic and International Studies (CSIS), and regional opportunity indices (RCI) determined by the global consulting firm Whiteshield Partners [13].

Using the Scopus and Web of Science databases, based on a large amount of information, a list of inclusion and exclusion criteria has been prepared, containing a set of elements and possible effects of motor transport in relation to the urban ecosystem. In all cases, the motor transport variable [14, 15] was used as an independent factor potentially influencing each reported effect of technogenic impact. Finally, proposals and recommendations on managing the technogenic impact of motor transport on the environment in cities were collected.

4. RESULTS

The composition of the fleet and driving conditions play an important role in regulating vehicle emissions. As for the composition of the fleet, diesel heavy-duty vehicles on average emit a significant proportion of nitrogen oxides and black carbon on motorways, despite their small percentage among the total number of road vehicles [16] (Table 2).

Table 2 Average emission factors for and vehicles with different types of fuel

Fuel	g CO_2/km
Green hydrogen	26
Gray hydrogen	144
Electricity	117

Estimates can vary greatly depending on the country and region, so many experimental studies report high concentrations of pollutants on roads with a large number of diesel vehicles. It was found that a small part of dirty vehicles, for example, with outdated emission standards, high mileage, or failures in engine emission control systems, can be characterised by more significant emissions than the rest [17]. Driving conditions can affect the quality of roadside air in two ways, namely the level of emissions and turbulence caused by the vehicle.

Vehicles with a heavy load produce more emissions, and, consequently, are characterised by increased air pollution on sections of roads with a slope uphill, with acceleration after traffic lights or bus stops, and with frequent acceleration and deceleration when stopping and then starting traffic in conditions of congestion. Turbulence caused by a vehicle is an important factor in assessing the quality of roadside air, due to the close proximity of emission sources comparable to the size of the vehicle [18]. Compared to idling motor vehicles, moving motor vehicles cause turbulent flows that significantly increase the dispersion of emissions, resulting in lower emission levels (Fig. 4).

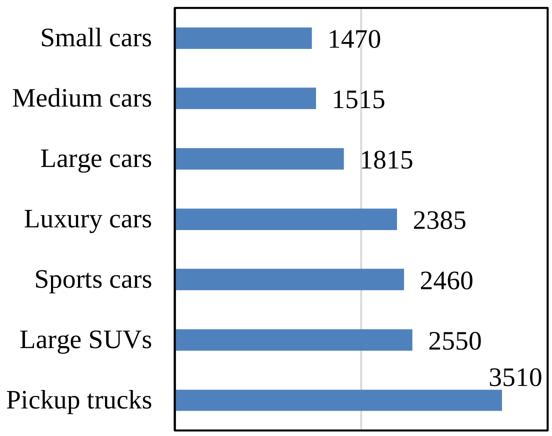

Fig. 4. Global average emissions of passenger cars in 2022 (in kg CO_2/year) [5]

In addition, one-way traffic is more favorable for the dispersion of emissions than two-way traffic due to the so-called piston effect. Notably, moving vehicles create high emissions due to abrasion and resuspension processes [19]. Reducing the number of heavy vehicles and improving the quality of the road surface can help reduce these non-exhaust emissions.

Urban areas are usually divided into blocks. In these conditions, intersections of roads become important places for air exchange and redistribution of emissions. These processes are complicated by wind, height and symmetry of buildings, and atmospheric stability. These features affect wind-induced turbulence and, consequently, air quality. The air exchange rate is very sensitive to the geometry of the building because a round roof and a building with balconies have better and worse ventilation, respectively. With regard to the asymmetry of buildings, pronounced symmetrical or pronounced asymmetric buildings cause a decrease in the concentration of pollutants at the pedestrian level. Ultimately, the presence of street barriers, such as trees, overpasses, noise barriers and cars parked on the roadsides, also changes the overall airflow fields.

Weather conditions can have a significant impact on motor vehicle emissions. Hot and cold weather increases energy consumption in buildings and vehicles due to the widespread use of air conditioners, which leads to increased emissions. Hot weather also contributes to higher O_3 generation through photochemical reactions [20]. Weather conditions include various meteorological parameters such as wind speed and direction, temperature, humidity, and sunlight. Among them, wind speed and direction are of paramount importance for the dispersion of emissions. Higher wind speeds usually contribute to wind-induced turbulence and remove vehicle emissions faster, resulting in improved roadside air quality. Winds parallel to the axis of the street are favorable for the removal of emissions.

However, parallel winds generate limited vertical flows, so a potential problem is the accumulation of emissions in the leeward area. On the other hand, winds perpendicular to the axis of the street are unfavorable for the dispersion of emissions and cause an inhomogeneous distribution of emissions due to vortices created by the roof of the building. Such flow patterns usually lead to higher concentrations of pollutants on the downwind side [21]. However, with different configurations of buildings, the opposite scenario may be observed. Paradoxically, oblique winds, rather than parallel or perpendicular ones, can create both the best and the worst conditions for removing pollutants since a slight change in wind direction can significantly change the airflow outside and the distribution of pollutants.

Sunlight has a significant impact on the quality of roadside air. It heats the facades of buildings and the surface of the earth. The thermal effect of solar heating creates buoyancy, which controls the airflow and dispersion of emissions. Other weather parameters, such as ambient temperature and humidity, have a relatively minor effect on emission dispersion and are rarely studied. Chemical reactions do not change the airflow but can significantly affect the composition of pollutants. Most vehicle emissions, such as carbon monoxide CO, carbon dioxide CO_2, and hydrocarbons CH, can be considered inert. However, nitrogen oxides react with O_3 within tens of seconds and, therefore, should be considered chemically active when assessing the quality of roadside air. O_3 it is not emitted directly by motor vehicles but is a secondary pollutant as a result of photochemical reactions with nitrogen dioxide and volatile organic compounds in the troposphere.

Nitrogen oxide emissions predominate in diesel vehicles, mainly in the form of NO, which usually leads to lower concentrations of O_3, but higher concentrations of NO_2 on roadsides than in the environment (Fig. 5).

The reactions of nitrogen oxides with O_3 are influenced by all the factors discussed above, including weather conditions, mainly wind, temperature and sunlight, traffic conditions and geometric proportions that affect the access of sunlight, and street airflows [22]. In addition, vegetation can have a significant impact on reactive pollutants. Vegetation is able to reduce air pollution by depositing emissions on the surface of the leaves and absorbing gaseous emissions through the stomata of the leaves (Fig. 6).

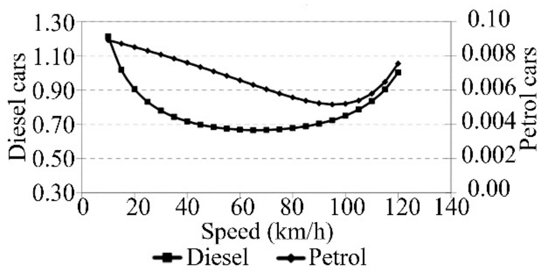

Fig. 5. Emissions of nitrogen oxides for petrol and diesel powered cars

Fig. 6. Anthropogenic emissions generate aerosols and surface ozone.

The level of polluting emissions significantly depends on the types of vegetation and on environmental conditions. Therefore, urban planning measures to ensure traffic, especially in relation to diesel cars, such as careful selection of trees, are the key to combating chemically active pollutants in urban environments [23]. Since cars are the dominant sources of air pollution in the urban environment, traffic control measures such as low-emission zones and congestion charges seem to be the most effective strategy for improving roadside air quality. These strategic measures are under the full control of urban planners and politicians. The correct design of the geometry of streets can significantly improve the dispersion of emissions and, thus, eliminate the occurrence of pollution hotspots.

5. DISCUSSION

The debate on the technogenic impact of motor transport on the environment in the cities of Kazakhstan, using Shymkent as an example, needs to consider the notion that in Kazakhstan, Shymkent is equated to Texas. This cultural trope is usually repeated thoughtlessly. The assumption is likely, according to which, the opinion that Shymkent is equated with Texas comes from the southern location of the region in Kazakhstan, located along the border with Uzbekistan, which is comparable to southern Texas in the United States of America, along the border with Mexico. There is another version according to which it is hot in both places, the landscapes in both places are similar, and on the geographical map, the silhouette of the South Kazakhstan region is partly similar to the contours of Texas. There may be some truth in all this; however, the trope is mostly common in the cultural landscape of modern Kazakhstan, as a means of describing and, in some respects, stigmatizing Southerners.

The Government of Kazakhstan aims to create four urban agglomerations around the cities of Almaty, Astana, Shymkent, and Aktobe. This type of restructuring of national and regional economic development is intended to change the political landscape in which local authorities manage urban development, including the motor transport sector in cities. In 2016, guided by public opinion, the city of Shymkent was awarded the status of the most comfortable city to live in Kazakhstan, ahead of Almaty and Astana.

Compared to Shymkent, the largest cities of the Republic of Kazakhstan, Almaty, Astana, and Aktobe, occupy large areas, but the population density in them is relatively low. The city authorities of the Republic of Kazakhstan are deliberately going to increase urban areas, striving for the development of urban transport systems. However, according to public opinion, territorial expansion is not very effective in overcoming the problems of intensification and modernisation of urban road transport infrastructure. Large cities, in particular, Shymkent, failed to solve problems related to environmental indicators, primarily with air pollution. In particular, Shymkent is among the leading cities in terms of the highest mortality rates caused by the technogenic impact of vehicles on the environment.

The government of the Republic of Kazakhstan has chosen Shymkent as a key area for public investment in logistics infrastructure, aiming to create a multimodal transport hub. In 2019, the Continental Logistics company began operating in Shymkent, capable of handling cargo turnover of up to 600 000 tonnes of cargo per year. Shymkent is also the largest multi-transport hub of the country, bordering China and Uzbekistan. An important vector of the polemic addressed to the problem of the technogenic impact of motor transport on the environment in cities is air pollution as a possible means of spreading and causing susceptibility to COVID-19 respiratory infection. Claims about the relationship between air pollution and increased susceptibility to respiratory diseases [24], and now to COVID-19. It should be recognised that the reduction of road transport during the pandemic led to a reduction in emissions of pollutants into the atmosphere, in particular, nitrogen dioxide NO_2, PM10 particulate matter, ground-level ozone O_3, sulphur dioxide SO_2 and carbon monoxide CO, and contributed to a significant improvement in air quality, especially in large Asian cities, such as Shymkent.

An essential aspect of the polemic addressed to the problem of the technogenic impact of motor transport on the environment in cities is the generation of potentially toxic wastewater during the washing of motor vehicles [25-27], since a large amount of water is consumed for washing, chemicals are used. Wastewater after washing motor vehicles contains a wide range of impurities, in particular, petroleum hydrocarbons, primarily gasoline, diesel fuel, engine oil, phosphorus and nitrogen, surfactants, bitumen, and heavy metals. The discharge of pollutants into surface water bodies leads to the degradation of the quality of water used for domestic, industrial, agricultural, and recreational purposes. Due to the dirt washed off the car body, the waste water after washing is greasy, oily, and very turbid. Oil and fat in reservoirs block sunlight, impair photosynthesis and prevent the replenishment of oxygen reserves in reservoirs.

Oil and grease contained in wastewater after washing vehicles increase the biological and chemical oxygen demand, temperature and pH of water, leading to the degradation of the aquatic habitat, reduced productivity and loss of biodiversity. Washing the attached dirt, sand, and debris from vehicles forms dissolved and suspended solids in the wastewater. Suspended solids form a stressful environment for aquatic flora and fauna, conditioned by an increase in biological oxygen demand and turbidity of the aquatic environment, reduce the available habitat and clog the gills of fish and invertebrates. Heavy metals that are associated with car body parts, fuel and lubricants enter the wastewater when washing car brake linings, tires, along with car exhaust gases and liquid leaks [28, 29]. The current study provided additional support for these findings.

Washing a motor vehicle in natural reservoirs should be strictly prohibited. Vehicles should be washed on private lawns or in car wash centers. It is absolutely unacceptable when a sewage treatment plant designed to separate oil, grease, and sludge does not work in the car wash center when the channels to the separation chambers are clogged with garbage, plastic bottles, and sludge [30, 31]. The volume of wastewater discharged into surface water bodies should also be monitored since if the volume and speed of streams or rivers are insufficient to handle wastewater flows, great damage to the environment can be caused. With regard to the level of pollution of water bodies, sustainable strategies should be developed to protect surface waters from sewage pollution after car washing. Wastewater should be treated using available technologies, and the levels of pollutants in them should be controlled by setting standards before discharge into surface water bodies.

In the context of the technogenic impact of motor transport on the environment in cities, it is impossible to ignore the polemical statement about the light and noise effects of motor transport, and the effects through energy waves, which are studied by K. J. Gaston et al. [23], M. Ketzel et al. [15] and other professional specialists. The subject of controversy in this issue is the statement about the need to measure threshold values 10%, 1%, 0.1%, 0.01%, and 0.001% of the power of the source of the energy-wave and light-noise impact of vehicles on the environment in cities, substantiated by the fact that the logarithmic scale is more representative of the perception of energy-wave and light-noise pollution by the body.

The light effect equivalent to 0.1 lux is comparable to the light of the full moon in a clear sky, which is known to have an impact on the environment. Noise exposure above 30 dB, affects human sleep. The logarithmic scale is recognised as necessary for the study of the technogenic impact of motor transport on the environment in cities because exponential and inverse quadratic decay functions have long tails that approach, but never reach zero. This study emphasizes the need to measure and quantify the negative effects of motor vehicles on the environment, while the current study focuses on identifying practical steps that can be taken to reduce emissions and improve the sustainability of urban development.

In the research context of the polemic addressed to the problems of the technogenic impact of motor transport on the environment in cities, the development of professional and psychological aspects of the driver-vehicle-road-environment system is of particular interest [24], in which the reliability of the driver's work takes priority. According to the data presented in the studies of the listed researchers, the condition of the driver of the vehicle affects the reliability of their work, the probability of an accident. This refers to the fact that most road accidents are caused by the erroneous behaviour of drivers in critical situations.

The organised work of the motor transport system, in the context of the global development of various factors of the technogenic impact of motor transport on the environment in cities, largely depends on the psychophysiological qualities of the driver. In the system-forming paradigm of driver-vehicle-road-environment, the driver is seen as the key link, because the work of a motor vehicle driver in cities involves high loads on the nervous and emotional systems of the body. In the process of perceiving a large data stream, the driver must not only recognise information, but also transform, analyse, and make decisions.

The driver's participation in the operation of the vehicle under normal conditions is fundamentally different from driving a heavy-duty vehicle in the harsh mountainous and high-altitude conditions of Shymkent, inevitably associated with frequent and abrupt maneuvers, with a complex geometric pattern of a gravel road in plan and profile. The effectiveness of the driver of a heavy-duty vehicle consists of a large number of factors, such as energy, materials, the environment and road safety [32, 33]. Not all of the above factors are significant for the influence of mountain and high-altitude operating conditions of cargo vehicles on environmental efficiency in the urban conditions of Shymkent. The priority is the mountainous and high-altitude environment of Shymkent, in which heavy-duty vehicles are operated because it is characterized by the paramount importance of skills, knowledge, and experience of driving in the difficult urban conditions of Shymkent.

Summing up the brief findings, it is necessary to note the importance of scientific polemics on the technogenic impact of motor transport on the environment in cities. A comprehensive study of the issue has shown that there is no alternative to such an approach to urban development management, which is able to effectively overcome the problems of intensification and modernisation of urban transport infrastructure. The technogenic impact of motor transport on the environment in cities forms a zone of road impacts. Understanding the extent of these impacts plays a crucial role in determining where environmental protection, for example, from further road construction, environmental mitigation, for example, pollution reduction, and environmental improvement, habitat creation, will bring the greatest benefits to human health.

In the context of the processes of the impact of motor transport on the environment in cities, technogenic air pollution acts as a possible means of spreading and causes of susceptibility to COVID-19 respiratory infection. It is necessary to develop sustainable strategies for protecting surface waters from sewage pollution after car washing, and protecting the urban environment from light-noise and energy-wave effects. Of particular interest is the development of professional and psychological aspects of the driver-vehicle-road-environment system.

6. CONCLUSIONS

This study examined the current and potential impact of motor transport on the environment in cities, specifically in densely populated cities located in the south of Kazakhstan. The city of Shymkent, one of the busiest cities for motor transport, was investigated. The study found that certain vehicles, such as those with outdated emission standards or high mileage, contribute disproportionately more to emissions than others. The study recommends reducing the number of heavy vehicles and improving road quality to reduce emissions not related to exhaust gases.

The study acknowledges limitations, including a lack of data on the objective degree of the impact of vehicles on the environment in Kazakhstan and an assumption about the distribution of roadway capacity. However, the study is a significant step towards evidence-based decision-making in policy development in Kazakhstan, and it highlights the importance of further research on the role of transport and logistics in the sustainable economic development of Central Asian regions. As cities continue to grow rapidly, future research should focus on a narrow set of urban planning issues to effectively address the impact of motor transport on the environment in the context of limited urban resources.

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