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# Metropolis as a Source of Aerosol Pollution – Assessment of Hazardous Factors and Ways to Minimize Negative Impact

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**Abstract:** The purpose of this article is to study aerosol pollution in a metropolis (Moscow), to evaluate the dangerous factors of aerosol pollution and ways to minimize their impact on the population and ecosystems of the city and surrounding areas. The research has been conducted in January 2015-August 2019 for five locations in the territory of Moscow, and one location 50 km from the metropolis. 10,978 samples have been processed in Moscow and the region, of which 2089 have been samples for station 1, 1597 – for station 2, 1956 – for station 3, 1971 – for station 4, 1704 – for station 5 and 1661 – for station 6. For all six locations in Moscow and the region, the average daily aerosol pollution exceeds 3%, which indicates a fairly safe composition of atmospheric air in the territory of the metropolis. The variability in the PM10 concentration indicators varies significantly between the years, more than three times in comparison with the variability between the seasons ($p \leq 0.05$). Aerosol pollution of the Moscow metropolis is characterized by pronounced seasonality – maximum PM10 concentrations in April and minimal in November-December. The difference between warm and cold seasons can reach 15-20 $\mu g/m^3$. In the annual cycle, a surge in PM10 is observed in April, immediately after snow melts, when there is a sharp change in humidity in the atmosphere of the metropolis.

**Key words:** Aerosol pollution, seasonal fluctuation, metropolis, atmosphere, air masses.

## Introduction

Over the past thirty years, ever-increasing climate changes have been observed, often leading to the degradation of entire landscapes (Bezanilla et al., 2014; Alekseev et al., 2018). Among all the components involved in air pollution, the so-called aerosol pollution has recently attracted the most attention. (Baumgardner et al., 2009). Aerosol pollution can be of anthropogenic nature, as a result of industrial enterprises and vehicles, as well as natural, as a result of various disasters, for example, volcanic eruptions (Cui et al., 2017).

In recent years, in all countries of the world, especially third world countries, an increasing number of man-made disasters have occurred, resulting in a sharp increase in aerosol emissions (Golitsyn et al., 2011; Pomortsev, 2019). The consequences of this are deterioration in human health, mainly due to a sharp increase in mortality from cardiovascular diseases. Other, no less dangerous, consequences include the

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degradation of the living component of ecosystems, shortening or changing trophic chains, emergence of new, hazardous and non-natural substances in the biogenic cycle (Bossioli et al., 2009). It also leads to an increase in the number of cancers.

The distribution of aerosol particles in the atmosphere occurs rather quickly, due to their small size (within 10 µm) and strong winds (Eresmaa et al., 2006). If particles of aerosol origin (up to 10 µm in size) reach a human body, a complex deterioration of health occurs due to the following:

- activation of respiratory system diseases (various forms of bronchitis, etc.);
- cardiovascular diseases; and
- the accumulation of some toxic elements in the -human body (Grabon et al., 2010).

The long-term outcome of such diseases, given their prevalence in cities exposed to aerosol pollution, is a decrease in the economic activity of the population, and a negative change in the birth rate. Such effects determined the inclusion by the World Health Organization of aerosol particles with a diameter of less than 10 µm (PM10) in the list of pollution agents for which air quality is estimated (He et al., 2015).

An example is the period of abnormal heat observed in Moscow (Russian Federation) in the summer of 2010. Then, a stable anticyclone dominated the territory of the city for a long time, which led to the appearance of the following:

- fires on peat bogs around the city;
- smoky atmosphere;
- the formation of smog; and
- a surge in mortality from cardiovascular diseases 2.2 times higher compared to the same periods of the previous five years (Golitsyn et al., 2015).

Aerosol pollution affects such climatic indicators as humidity and temperature. Not only the city is influenced (above which there are aerosol particles) but the surrounding territory as well (Helmis et al., 2012).

Scientific research on this subject is devoted to daily, seasonal and perennial cycles of aerosol pollution with particles of various diameters (2, 5 and 10 µm, or PM2, PM5, PM10) in the USA, the EU and other industrialized regions (Kikegawa et al., 2014; Lotteraner and Piringer, 2016). The main task that researchers set for themselves is to determine the causes of aerosol pollution in their regions. Such detailed studies are possible due to the presence of hundreds of monitoring stations that collect data. In the United States, the network includes 740 monitoring stations (U.S. Environmental Protection Agency, 2019). In France, about 400 (The European Environment Agency, 2019), in Germany there are about 270 (Air Pollution, Transport, Noise and Industrial Pollution, 2019). For the Russian Federation, similar measurements are carried out at three locations – the metropolises of Moscow, St. Petersburg, as well as in the city of resort value Sochi. The study of aerosol pollution has been carried out in Moscow over the past 10 years; however, the data presented are fragmentary and cover either one year or several seasons (Environmental Situation of Moscow, 2019; Golitsyn et al., 2011, 2015; Isaev, 2006; Lokoshchenko, 2015; Raputa et al., 2008; Sitnov, 2009, 2011). The relevance of similar studies for the Russian Federation is very high, given the fact that Russia is one of the industrialized countries. There are insufficient data on megacities of Russia; most of the studies are devoted to aerosol pollution on the material of industrial centres of Siberia. Besides, the proposed methods affect only particular cases, for example, monitoring pollution by studying snow cover.

All this determined the relevance of the current work. The purpose of this study is to analyze aerosol pollution in a metropolis (Moscow, Russian Federation), along with evaluating the dangerous factors of aerosol pollution and ways to minimize their impact on the population and ecosystems of the city and surrounding areas.

In this paper, the daily and seasonal and annual cycles of PM10 for the city-metropolis of Moscow, as well as the city of Krasnodar, are presented to compare the average concentration of aerosol particles in these cities.

## Materials and Methods

### Materials

The studies have been conducted in January 2015-August 2019 for five locations in the territory of Moscow, and one location 50 km from the metropolis in the satellite city of Zelenograd. The authors have selected these five stations because they are located either near the metropolis or within it, but not near highways or industrial enterprises (where the effect of aerosol pollution is obvious). The number of samples and other data are presented in Table 1. For Krasnodar, 345 samples have been taken in one station located in the city centre (station 7, Table 1).

In total, in Moscow, the authors have processed 10,978 samples, of which 2089 samples for station 1,

**Table 1: Sampling locations, the number of samples in the urban metropolitan area of Moscow**

| *Category* | *Station 1* | | *Station 2* | | *Station 3* | | *Station 4* | | *Station 5* | | *Station 6* | | *Station 7* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *C* | *W* | *C* | *W* | *C* | *W* | *C* | *W* | *C* | *W* | *C* | *W* | *C* | *W* |
| Total number of measurements | 855 | 1234 | 652 | 945 | 845 | 1111 | 773 | 1198 | 1041 | 663 | 679 | 972 | 145 | 200 |
| The average concentration of PM10 | 19 | 25 | 18 | 34 | 18 | 25 | 21 | 27 | 20 | 32 | 17 | 27 | 12 | 17 |

*Note:* C – cold season, W – warm season. Station: 1 – Moscow State University, 2 – Maryinsky Park (Moscow), 3 – Satellite City Zelenograd, 4 – Spiridonovka, 5 – Ostankino, 6 – Kozhuhovo, 7 – Krasnodar, city center.

1597 – for station 2, 1956 – for station 3, 1971 – for station 4, 1704 – for station 5 and 1661 – for station 6.

## Methods

The authors have used data obtained from stations of an automated network for monitoring atmospheric pollution. Data received from station sensors are generated into text files that are in access mode. Subsequently, these data are subject to change in other formats for statistical processing. For measurements, TEOM analyzers have been used. The authors have selected this type of analyzer due to the fact that it has a smaller error in comparison with another widely used method – gravimetry. The latter has found wide application in the EU countries. The data obtained are grouped in graphical form; as a result, a map of the spatial distribution of aerosol particles in the atmosphere is obtained (Figure 1).

The authors' chosen method allows one to receive information every hour. All data are formed into arrays, grouped by season (cold-warm), days and other parameters necessary for statistical analysis. Each season is divided into two parts - the cold season (November-March) and warm (April-October).

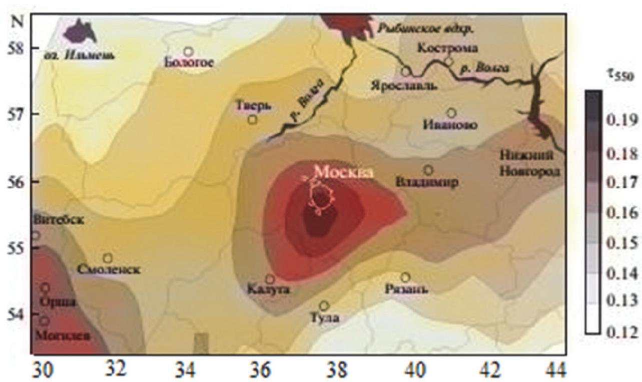


**Figure 1: Map of the spatial aerosol distribution in the atmosphere above Moscow and other Russian cities in 2000-2009 (according to Sitnov, 2011).**

## Statistical Analysis

Statistical data have been processed using Origin v. 8.0 software and Excel2010 statistics analysis package. The authors have calculated for each parameter the arithmetic mean, the error of the mean, the Pearson correlation coefficients between the data series (features), and the reliability of the results at $p \leq 0.05$.

## Results

The maximum level of aerosol pollution for stations 1, 5, and 6 has been recorded (Table 1). All of them are located in the industrially developed areas of the metropolis of Moscow, or in areas with high traffic. The level of aerosol pollution is on average 0.5 times higher than the similar load indicators for the remaining locations ($p \leq 0.05$). The data in Table 1 also shows that there is a significant ($p \leq 0.05$) difference in the values of aerosol pollution between the cold and warm seasons. In the warm season, pollution indicators are one third higher than those for the cold season. This pattern holds true for both Krasnodar and Moscow. In Krasnodar, the average concentration of aerosol particles is lower than in Moscow by 0.5 times during the cold and warm season ($p \leq 0.05$).

For all locations, a repeatability analysis (in %) of the daily concentration of aerosol particles has been performed (Table 2). For most cases, there has not been significant excess of the established norms of 60 PM10, $\mu g\ m^3$ (Hygienic Standards, 2014).

For all six locations in Moscow, this indicator does not exceed 3%, which indicates a fairly safe composition of atmospheric air in the territory of the metropolis.

For Krasnodar (location 7), significant differences have been recorded compared to Moscow – the average values of aerosol pollution are mainly at the lowest concentrations, from 0.1 to 50.0 $\mu g\ m^3$. This indicates a better state of atmospheric air in Krasnodar compared to Moscow.

**Table 2: Repeatability (in %) of the average daily concentration of PM10 in Moscow at six stations and at one station in Krasnodar for the period January 2015-August 2019**

| *PM10, µg m3* | *Station 1* | *Station 2* | *Station 3* | *Station 4* | *Station 5* | *Station 6* | *Station 7* |
|---|---|---|---|---|---|---|---|
| 0.1-10.0 | 9 | 13 | 18 | 9 | 11 | 11 | 17 |
| 10.1-20.0 | 36 | 43 | 38 | 34 | 39 | 44 | 52 |
| 20.1-30.0 | 23 | 26 | 26 | 27 | 28 | 22 | 15 |
| 30.1-40.0 | 16 | 11 | 10 | 15 | 13 | 12 | 10 |
| 40.1-50.0 | 6 | 3 | 5 | 8 | 6 | 4 | 6 |
| 50.1-60.0 | 6 | 3 | 1 | 3 | 1 | 3 | 0 |
| 60.1-70.0 | 1 | 0 | 2 | 3 | 2 | 2 | 0 |
| 70.1-80.0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 |

At the same time, it is necessary to take into account that the peculiarity of the formation and negative impact on human health from aerosol particles is a combination of several weather factors. In the event of pollution, a concentrated effect occurs on the human body, as well as on the biota.

Pearson correlation coefficients have been obtained (Table 3), which are in the range of 0.55–0.84 for the daily mass concentration of PM10 aerosol particles, and 0.42–0.63 for a single concentration.

**Table 3: Pearson correlations for indicators of daily mass concentration and indicators of a single concentration in Moscow, at $p \leq 0.05$**

| *Station number* | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| *Average daily mass concentration* | | | | | |
| 2 | 0.68 | 1 | - | - | - |
| 3 | 0.63 | 0.69 | 1 | - | - |
| 4 | 0.55 | 0.76 | 0.57 | 1 | - |
| 5 | 0.76 | 0.82 | 0.65 | 0.77 | 1 |
| 6 | 0.68 | 0.73 | 0.74 | 0.60 | 0.84 |
| *Average single concentration* | | | | | |
| 2 | 0.54 | 1 | - | - | - |
| 3 | 0.52 | 0.51 | 1 | - | - |
| 4 | 0.51 | 0.57 | 0.42 | 1 | - |
| 5 | 0.63 | 0.70 | 0.59 | 0.62 | 1 |
| 6 | 0.55 | 0.54 | 0.48 | 0.55 | 0.63 |

As can be seen from Table 3, the correlation for the PM10 concentration practically coincides in locations 1, 6, and 3. This is due to the fact that location 1 is on the leeward side of the city centre (location 6), which determines the transfer of aerosol particles between them. Point 3, despite the large distance from the centre of the metropolis, also experiences a high load of aerosol pollution. The high values of the correlation coefficients of the daily concentration of PM10 also indicate the multifactor formation of aerosol pollution. Namely, due to the movement of particles.

Fluctuations in the concentration of aerosol particles over several hours are more dependent on local sources. Therefore, the values of the correlation coefficients for single measurements are significantly lower than for average daily fluctuations ($p \leq 0.05$). The fact that station 1 (Moscow State University) correlates with other stations (Table 3) indicates a close relationship in the circulation of air masses, as well as aerosol suspension between these locations. The maximum number of observations compared with other stations indicates the mandatory inclusion of this station in all future observations. The data obtained from this station can be used to describe the processes of aerosol pollution PM10 for the whole metropolis.

The data for this station for different years have been analyzed (Figure 2). As can be seen from Figure 2, the highest concentrations of PM10 for the studied region are in the warm season, with a maximum in April and less pronounced maximum values at the end of summer.

From this it follows that the variability in the PM10 concentration indicators between the years varies significantly more (in three times) in comparison with the variability between the seasons ($p \leq 0.05$). The exception is March, when these indicators are approximately at the same level. For example, the difference in PM10 pollution level between the minimum and maximum indicators for April 2015, 2016, 2017, 2018 and 2019 amounted to more than 20 units, which coincides with the average pollution values in winter. For spring months of 2015-2017, the recorded maximums coincide with weather anomalies (early spring), which are increasingly observed throughout the planet. This coincides with the late snow melting

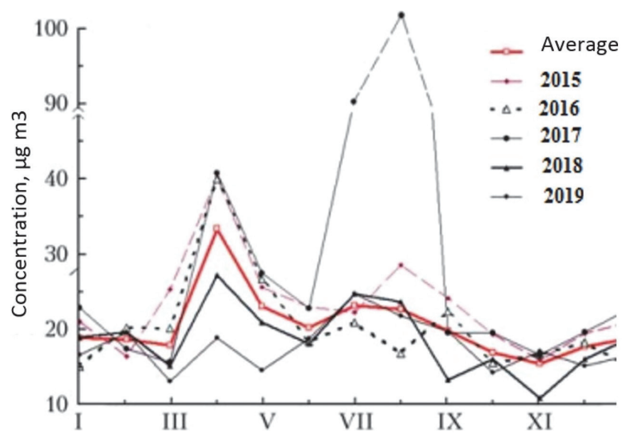


**Figure 2: The average concentration of PM10 in Moscow in 2015-2019.**

in April 2019, when a minimum of PM10 values was observed. In 2019, more rainfall has been detected, especially compared to 2015.

Comparison of the data obtained for the Moscow metropolitan area with analogs of other European metropolitan areas shows that in Moscow the opposite trend is observed – in other cities, in the cold season, the level of aerosol pollution PM10 is vice versa higher.

The concentration indicators of gases involved in anthropogenic pollution, in particular, nitrogen dioxide, have significant differences from PM10 (Figure 3C). There are general patterns - maximum indicators in April, minimum in November-December. At the same time, there are differences in diurnal concentration fluctuations – the maximum concentration of $NO_2$ in the evening in the summer, until midnight.

In April, when the concentration of PM10 is maximum, during the day the concentration of nitrogen dioxide is minimal, which is the opposite of the concentration of PM10 at the same time of day (Figure 3B).

The concentration of carbon monoxide (CO, Figure 3A) in the first half of the day is even higher than that of PM10, but in general, the picture for this pollutant is similar to that of PM10.

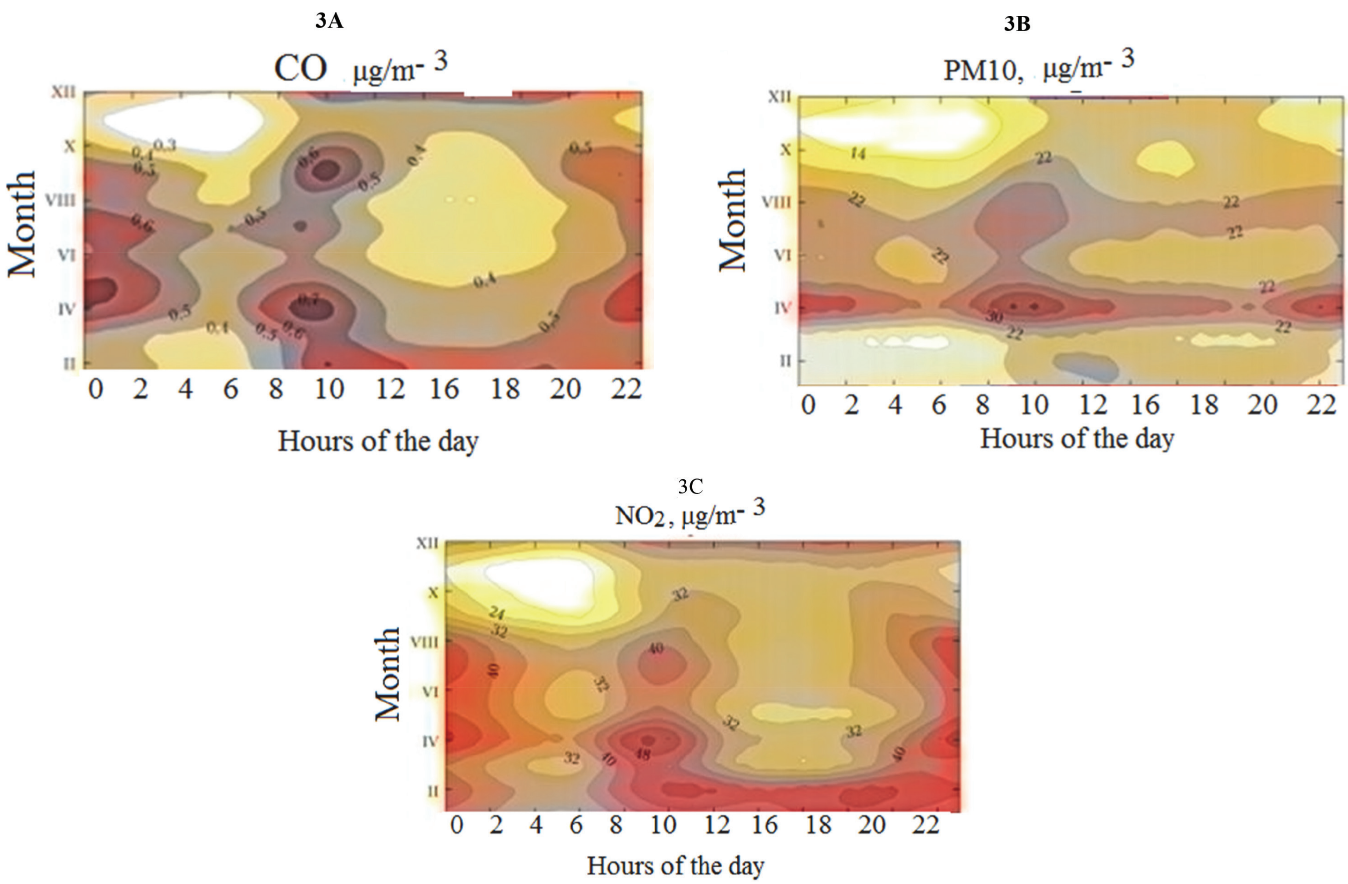


**Figure 3: Examples of seasonal-daily variability of carbon monoxide (3A), aerosol particles with a diameter of up to 10 µm (3B), and nitrogen dioxide (3C). Station 1, 2015-2019. The ordinate axis, Roman numerals—months from January, the abscissa axis—hours of the day.**

## Discussion

It is not possible to overestimate the harm caused by aerosol pollution to the ecosystem (Li et al., 2014). Thus, when impurities fall out, a number of toxic compounds, including heavy metals, get onto the soil surface (Lotteraner and Piringer; 2016, Xu et al., 2018). Along with the circulation of the atmosphere, as shown by the data on location 3, aerosol particles are transported over long distances, depending on the strength and direction of the wind for at least 50 km. When falling on the surface of the soil, heavy metals and other toxic compounds enter the groundwater, poisoning it. These factors negatively affect human health, as well as the state of ecosystems, in particular, their living component (Münkel, 2007; Ermakov, 2017). An additional negative factor is that water with toxic compounds enters the root system of plants, as well as in the mycelium of fungi. When these plants and mushrooms are eaten, food poisoning is possible.

Particles of aerosol suspension with microscopic sizes (2-10 μm) enter the stomata on the leaves of plants, clogging them and contributing to the disruption of their functioning (Perez and Raga, 1998). As a result, this can lead to defoliation and subsequent death of the plant.

Even without taking into account the toxic composition, the dust itself, in connection with its finely divided form, has a negative effect on human health (Piringer et al., 2007). Even with a dust concentration of 0.08 mg per $m^3$, people feel discomfort. In the interval from 0.25 to 0.5 mg, pulmonary diseases worsen. If there is a dust concentration of more than 0.5 mg per $m^3$, the probability of sudden death syndrome increases several times, and all people experience a sharp deterioration in well-being. With the inevitable penetration of dust into the pores of the skin, into the gaps of the sebaceous and sweat glands, a rash appears, the general condition of the skin (dryness) worsens, cracks appear (Teschke et al., 2009). The mucous membranes of the respiratory tract, as well as the eyes, are most affected by dust (Salamanca et al., 2013, 2014). In the latter case, chronic conjunctivitis may form. The respiratory tract is irritated by dust, which can lead to the development of various diseases - bronchitis, asthma and other (Stremme et al., 2009).

Some industries, such as microelectronics, can also be affected by dust (Xu et al., 2018). Due to increasing aerosol pollution at such plants, more and more attention is paid to cleaning technologies (Salamanca et al., 2014).

The highest concentration of PM10 occurs under the so-called adverse weather conditions (Schaefer et al., 2009). Their list includes high air temperature and weak circulation of air masses in the lower atmosphere. Such a situation is not uncommon in cities, especially in megacities, while transport makes a significant contribution to the formation of aerosol impurities. In contrast to the average aerosol pollution in Moscow, in other European cities, there is a fairly stable PM10 presence in the atmosphere, in the range of 20-23 μg per year. In summer, these values vary slightly and are in the range of 23-26 μg (Schatz and Kucharik, 2016). Thus, the average aerosol pollution indicators in Moscow show large fluctuations in the aerosol suspension content compared to European megacities.

Long-term exposure to high temperatures as well as low rainfall and humidity contribute negatively to animal activity. Thus, the number of invertebrates in deciduous forests in the record hot summer of 2015 was several times lower than in the previous two years (with normal precipitation and average monthly temperature) (Stukalyuk, 2017). Adverse weather conditions, namely, prolonged high air temperature and low rainfall have a negative effect on the biota, and also contribute to the emergence of a stable area of aerosol pollution, enhancing the negative effect.

## Conclusions

Aerosol pollution in the metropolis of Moscow is characterized by pronounced seasonality - maximum PM10 concentrations in April and minimal in November-December. The difference between warm and cold seasons can reach 15-20 μg/$m^3$. In the annual cycle, a surge in PM10 is observed in April, immediately after snow melts, when there is a sharp change in humidity in the atmosphere of the metropolis. The greatest difference in concentration indicators is characteristic for April-May, up to 30 μg/$m^3$.

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