UDC: 007:004.6]:502.3:504.5}:712.253(497.711)"2012/2020"
DOI: 10.37658/GR2053037k

GIS ANALYSIS OF PUBLIC GREEN SPACES IN CENTAR MUNICIPALITY AND THE SITUATION WITH AIR POLLUTION FROM PM_{10} AND $PM_{2.5}$ PARTICLES

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ABSTRACT

Given the harmful consequences of air pollution to the health of the population the presence of air pollutants has been a long-standing national issue. The focus of this paper is on GIS analyses of the Municipality of Centar in terms of the loss of green spaces, including analysis of public green areas and the state of the solid particles in the period from 2012 to 2020. The results of the data analysis revealed that the number of public green areas in the Municipality of Centar has been steadily decreasing. In addition, the fluctuations in solid particles PM_{10} and $PM_{2.5}$ in the measuring stations Centar, and Rectorate, both of which are located within the Municipality's jurisdiction, were investigated.

Keywords: vegetation, solid particles, Municipality of Centar, GIS

INTRODUCTION

In recent years, the city of Skopje, and consequently the municipality of Centar, have seen an increase in immigration. The concentration of people in the municipalities of Skopje is due to the favorable opportunities that the capital can offer, such as employment, accessibility and proximity to institutions, education, and so on. It also carries with it plenty of issues, all of which contribute to greater air pollution. These include issues with the city's traffic system and its functioning, increased waste disposal, the reduction of green public spaces, industrial expansion, and so on. The growing population living in Centar municipality calls for further urbanization as well as construction of residential buildings. As a result of rapid development, urban green spaces are being destroyed. The region of the Municipality of Centar is typically urban and has been entirely urbanized, replacing the previous and current vegetation-covered territories with urban zones with buildings, sidewalks, paved roadways, and other amenities.

On the area of Centar municipality, a total of 986 building permits were issued between 2012 and 2020. (State Statistical Office, 2012 - 2020). The data from the LEAP (Local Environmental Action Plan) for Centar, which covered the years 2019 to 2026, revealed that while the municipality of Centar's urban plans were being produced, the standard for green space per inhabitant was not taken into account and was not computed using the established formulae.

Green spaces play a unique role in cities because they act as direct cleansers of polluted air from a wide range of pollutants. (Dimitrovska 2011). The deposition and dispersion of contaminating particles are influenced by vegetation density. Deposition is the process by which harmful particles from the air adhere to the plant's leaf, thus reducing the air pollution. (Janhäll, 2015).

Numerous research on the good health effects of urban green spaces, including the enhancement of overall human health and the reduction of premature mortality, demonstrate the importance of these areas for people. (Huang, C et al. 2017).

Based on the research by Damjanovikj S., a tree creates a total leaf area of roughly 150m^2 in 100 years and provides as much oxygen as an adult requires for 20 years of life during that time. (Dimovski, 1994)

Tall oak and cedar trees planted 25 meters from main roadways lower PM_{10} and $PM_{2.5}$ particle concentrations by half, while dense grass vegetation reduces particle concentrations by 35%. (Cowherd et al. 2006)

The state of the public green spaces and their vegetative condition are represented in this paper using processed satellite images taken in April. (Cowherd et al. 2006) found that vegetation has a considerable impact on lowering air pollution, particularly during the summer months.

Increased daily temperatures have a particularly beneficial impact on the air quality. This is owing to the fact that the major sources of PM_{10} and $PM_{2,5}$ particles, i.e., domestic heaters, are not used during the winter months. (Macedonian Environmental Information Centre, 2020).

Google Earth Pro's satellite imagery provides a relatively high-resolution image of a specific area, and their approach to enhancing the visibility of satellite photography allows us to understand how public places are maintained, such as the use of public green spaces. (Taylor et al. 2011)

The benefits of green areas in mechanical air filtration have been demonstrated in studies on air filtration by plants.

The strength of purification was reported to fluctuate from 33.5 percent during vegetative hibernation to 50 percent at complete leafing of the stems during vegetation. (Dimovski, 1994). As a result, for the reasons stated above, and in order to maintain public green spaces in the future, it is of utmost necessity that the general population is informed about the important role that the vegetation plays as well as the consequences of air pollution.

AIMS

The major objectives of this paper is to examine the changes that happened in the larger public green spaces in the municipality of Centar in the period from 2012 to 2020, as well as the relationship between air pollution with $PM_{2.5}$ and PM_{10} particles and those changes.

METHODS

The applied cartographic method employed the GIS (Geographic Information System) software package QGIS 3.10.7 for accurate spatial representation of public green spaces in the municipality of Centar, as well as the spatial changes that have happened, for the purposes of this paper. Satellite pictures captured by Maxar Technologies to Google Earth Pro were also used in this study, especially for observation and assessment of the condition of the municipality's largest green spaces. The use of satellite imagery in the analysis and mapping of spatial changes had previously been used in the Skopje region (Gorin et al, 2014) for spatio-temporal analysis of changes in land cover using GIS, based on completed photo-interpretation of satellite imagery, where land changes were detected and mapped.

The historical continuity of the published satellite images results in a clear record of the spatial layout of public green spaces, as well as the occurrence of changes. Because the municipality covers only 7.52 km^2, other satellite images such as Landsat and Sentinel-2 is not taken into account due to the resolution.

The Ministry of Environment and Physical Planning of the Republic of Northern Macedonia provided the information for the solid particle study. For the period from 2012 to 2020, data was collected from measuring stations located on the territory of the municipality of Centar.

The graphic method was used to obtain the average annual values in this municipality. These were analyzed, synthesized, and compared using the methods of analysis, synthesis, and comparison.

STUDY AREA

The area processed in the paper is the Centar municipality, which encompasses the central part of the city of Skopje. This includes Macedonia Square, both banks of the Vardar River, and a part of Mount Vodno's northern slopes. The Government, Parliament, Ministries, State Offices, Agencies, and Administrations are among the administrative buildings inside its limits. The Rectorate of the Skopje University "Sts. Cyril and Methodius," as well as numerous faculties and the Administration of the City of Skopje, are located on the area of the municipality of Centar.

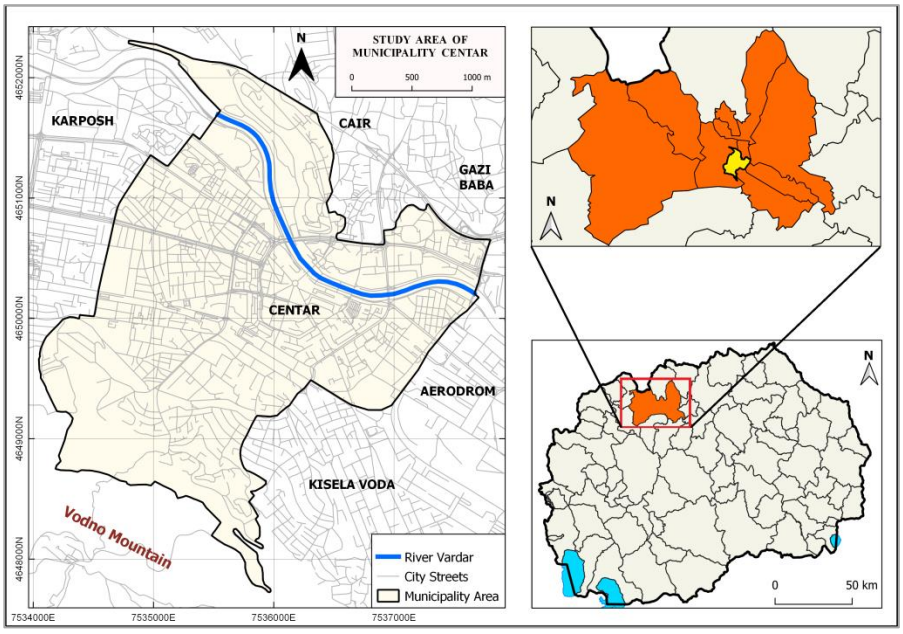

Figure 1. Territory of the study area.

The municipality of Centar borders the municipality of Čair on the north side, starting from the territory that encompasses the hill Gradiste and the American Embassy. The route then heads southeast along Nikola Karev Boulevard, passing through the Old Bazaar and the area of the fortress Kale. It owns a portion of Goce Delčev Boulevard as well as the UKIM Rectorate,

which extends east to the Hotel Continental roundabout Continental where it borders the municipality of Gazi Baba. Centar municipality neighbors Aerodrom municipality on the east side, with the International Railway and Bus Station serving as borders, followed by the Tobacco Company and the Ministry of Internal Affairs. On its southeast side, it extends to the municipality of Kisela Voda and the Embassy of the United Kingdom within its borders. On the south side, Centar lines with Karpoš municipality and it extends from the intersection Vodno, covering the northern slopes of the mountain. The western part of the municipality covers the settlement of Vodno, along Franklin Roosevelt Boulevard, all the way to the old part of the City Park in Skopje. Within these boundaries, the municipality covers an area of 7.52 km^2 and borders five neighboring municipalities.

PROCESSING AND ANALYSIS OF SATELLITE IMAGES

The urban greenery and landscape on the territory of Centar is comprised of ruderal (trampled) green, parks and residential (block) vegetation. The urban greenery includes the old part of the Skopje City Park, Journalists' Park, Parc de la Francophonie, Park "Woman Warrior", Urban Park and other smaller parks (LEAP for Centar 2019-2026). But green spaces such as the forest park on Vodno, the green belt near Kale and the Gradište hill, as well as some larger grass areas are not included as urban city greenery. The satellite images from Google Earth Pro, recorded by Maxar Technologies, were used in the spatial display and mapping of green areas. The first satellite image was taken on April 27, 2012, while the second was taken on April 16, 2020. The month of April was chosen because of the intense plant growth period, as well as for greater separation of the urban greenery from the rest of the area..

The next process was the digitalization and mapping of all green areas in 2012 and 2020. However, for the purposes of this paper, a reclassification of urban green areas was carried out in order to improve data collecting and comparison. The complete urban vegetation in the municipality of Centar is split into four classes in this case: class 1 = parks, class 2 = block/residential greenery, and class 3 = lawns, class 4 = park-forest Vodno (the part that is covered by the administrative boundaries of the municipality). This reclassification also includes the green belt on the hill Gradište and near Kale. The renaming of green areas, as well as their calculation, was performed using the GIS software application QGIS 3.10.7.

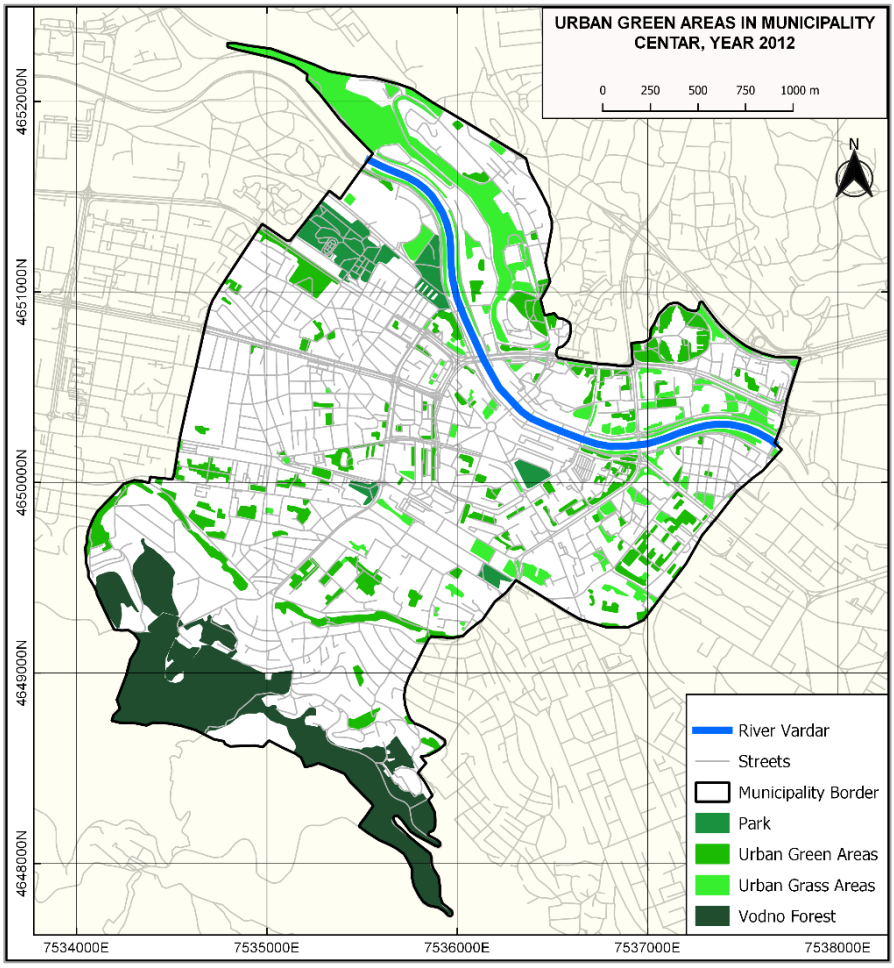

Figure 2. Green spaces, Centar municipality, 2012.

Based on the calculations, the total green ranges on the domain of Centar domain covered 1,689,805 m2 (168.98 hectare) in 2012, accounting for around 22.47 percent of the municipality. According to the reclassification, parks cover 9.4% of the vegetative territory, block (residential) greenery occupies 27%, lawns make up the majority of the remaining 25%, and Vodno park-forest occupies 38.6% of the total green space on the municipality of Centar's territory.

On the green areas of Centar municipality, spatial and structural changes can be seen in satellite photos captured by Google Earth Pro on April 27, 2020. The entire green spaces on the municipality's area constitute 1,592,867 m^2 (159 hectares), or around 21.18 percent of the total territory of Centar.

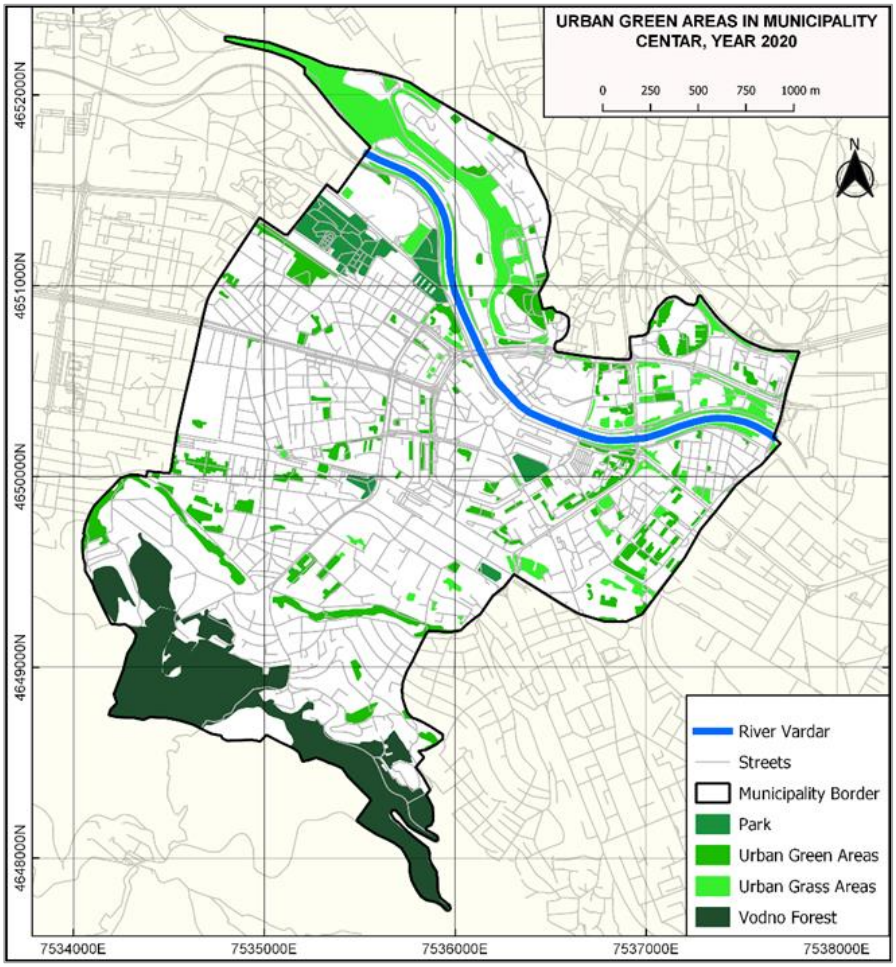

Figure 3. Green spaces, Centar municipality, 2020.

As per the earlier reclassification, parks encompass 9.7% of the vegetation territory, block (residential) greenery covers a quarter of it, i.e., 25% of the green areas, lawns cover 24.4% of the greenery, and the park-forest Vodno includes the most, i.e., 40.9% of the total green areas on the municipality of Centar's territory. According to the computed statistics, overall green areas on the territory of the municipality of Centar fell by 127,241 m^2 (12.7ha) between 2012 and 2020, although green spaces were replaced with new surfaces as a replacement for confiscated natural green areas owing to fast urbanization. Fresh grass, bushes, and green spaces among residential apartment blocks with new plantings cover a total of 30,303 m^2 (3.3 hectare) in the newly created spaces.

Table 1. Total green areas in Centar municipality 2012-2020.

Tabular summary of the total green area in Centar.			
Vegetation class	2012	2020	Reduction
Parks	165.628 m^2	161.493 m^2	4.135 m^2
Vodno Forest	585.322 m^2	585.322 m^2	/
Lawns	459.779 m^2	423.961 m^2	35.818 m^2
City greenery	522.651 m^2	465.666 m^2	56.985 m^2
TOTAL GREEN AREA	1.733.380 m^2	1.636.442 m^2	96.938 m^2

With this we come to the conclusion that between 2012 and 2020, the municipality of Centar lost 96,938 m^2 of vegetation, or approximately 9.7 hectares. In terms of the municipality's total territory, this equates to 1.29 percent, or 5.7% of the first estimated green spaces from 2012. The green spaces among the blocks of apartments suffered the greatest loss of urban green space, accounting for nearly 56,985m^2, followed by lawns, which lost 35,818 m^2.

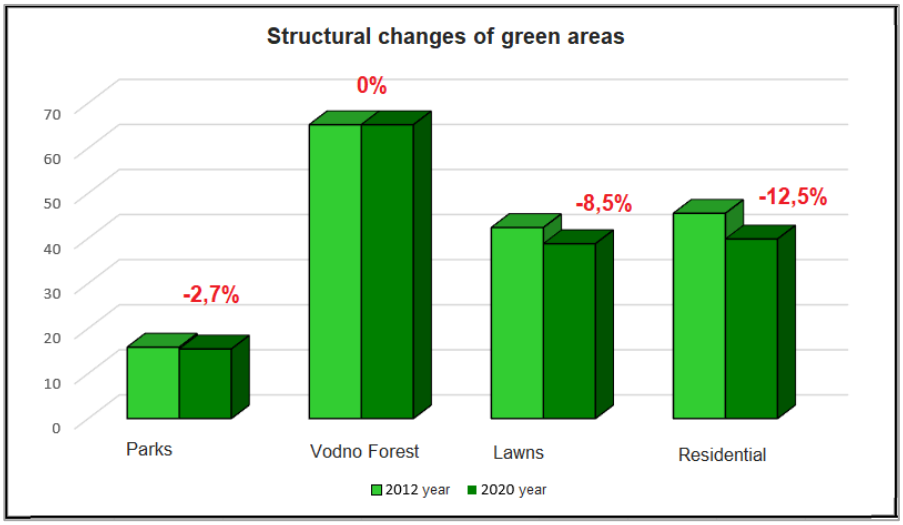

Chart 1. Changes in the spatial structure of the green spaces.

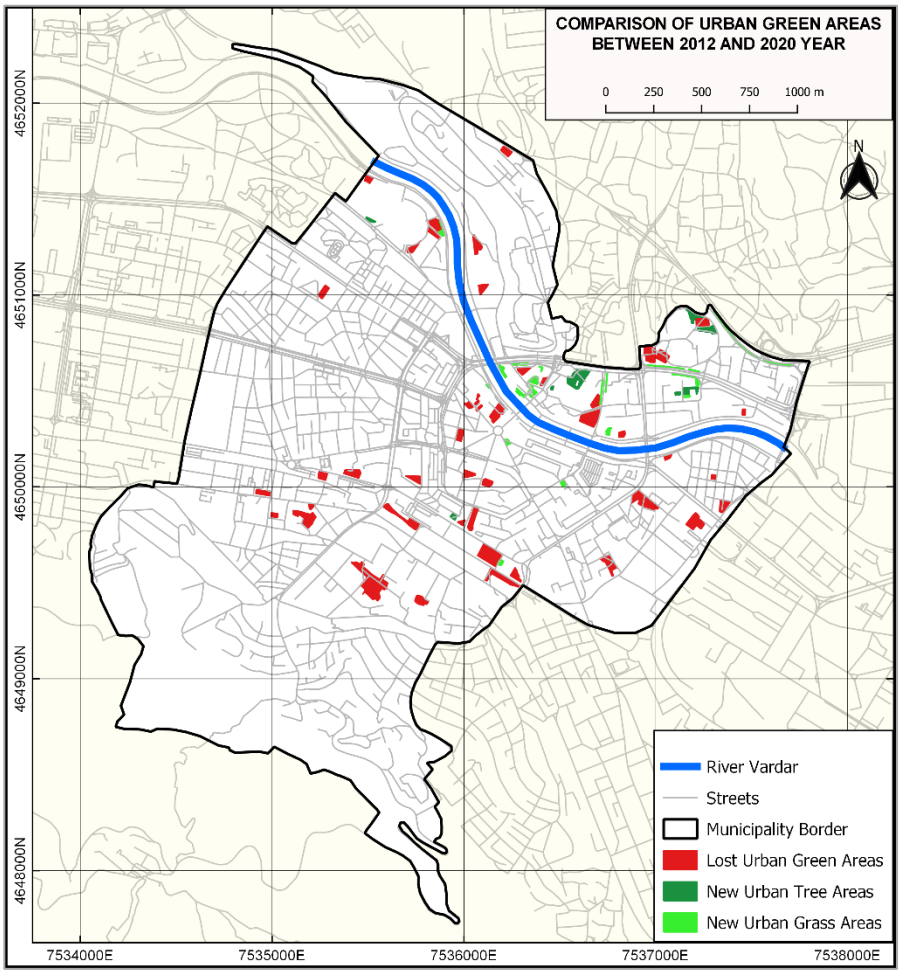

Figure 4. Comparison of green areas 2012-2020 year.

In the formerly created reclassification, the city greenery consists of parks, residential (among the residential buildings) and boulevard vegetation. According to the calculated statistics there are 552,804m2 of urban greenery (areas with a substantial number of perennial trees). As indicated by the last census conducted in 2002, there are 45,362 residents in Centar municipality, which leads us to the conclusion that the norm for green space per capita is 12.1 m^2, i.e., that is twice less than the European average. It is apparent that the municipality does not meet the recommended 25m2 of urban greenery per capita (Wustemann et al. 2016). It does, however, satisfy the World Health Organization's requirements of at least 9 square meters of urban green space per inhabitant. (WHO, 2009).

ANALYSIS OF PM_{10} and $PM_{2.5}$ CONCENTRATIONS IN CENTAR MUNICIPALITY

Smoke, dust, construction activities, landfills, industrial sources, electricity generation, volcanic activity, and other natural and anthropogenic causes are all sources of the solid particles PM_{10} and $PM_{2.5}$. PM_{10} particles can be solid or liquid, can have a diameter of 10 μg, and can last for several days in the air. (iQAir 2020). The diameter of PM_{10} and $PM_{2.5}$ particles differs, with $PM_{2.5}$ particles having a diameter of 2.5 μg or less and posing a larger health risk since they penetrate deeper into the lungs and bloodstream when inhaled. Their chemical and physical composition vary which is based on geographical location, climatic circumstances, and sources of occurrence. (iQAir 2020).

As indicated by the statistics from the (MoEPP Annual Report - Air 2019), the main cause of air pollution with solid particles in the Skopje valley is residential heating during the winter months.

Two measuring stations are stationed on the territory of the municipality of Centar, through which the air quality is regularly monitored and controlled by the Ministry of Environment and Physical Planning, by processing data within the network of monitoring stations for monitoring the concentrations of solid particles. Data from the measurement stations Centar and Rectorate for the period from 2012 to 2020 were used and processed for the study of PM_{10} particles, while data from the measuring station Centar for the period from 2012 to 2020 were examined for the analysis of $PM_{2.5}$ particles. (https://air.moepp.gov.mk/?page_id=290).

The following chart (Chart 2.) shows a constant exceedance of the allowed average annual concentrations of PM_{10} particles at the two measuring stations in the municipality of Centar, where, according to the Ministry of Environment and Physical Planning, the allowed limit values are 40 μg/m3 PM_{10} per year. The yearly limit levels for $PM_{2.5}$ particles are 25 μg/m^3. .(https://air.moepp.gov.mk/?page_id=118).

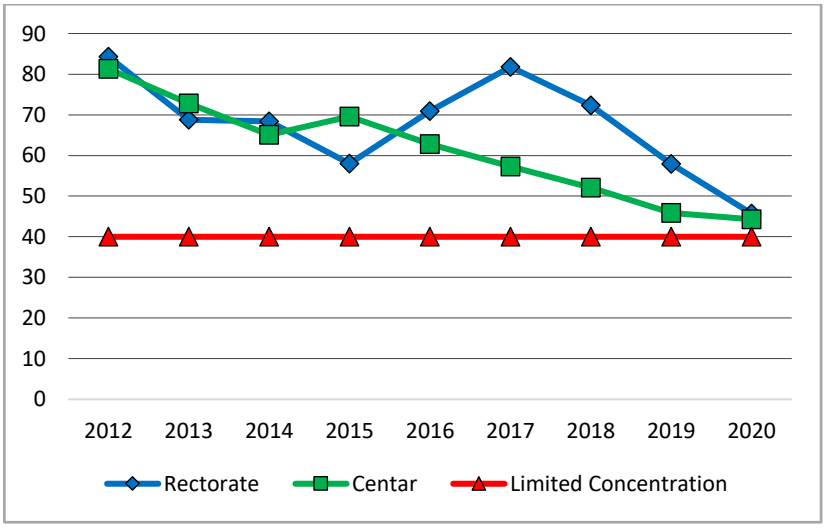

Chart 2. Average annual concentration of PM_{10} particles from the stations Centar and Rectorate, 2012 - 2020.

In 2012, the biggest exceedance of the permissible values was measured at the measurement station Rectorate. That is, there was an average yearly value of 84.3μg/m^3. At the same measuring station as in 2012, identical levels were recorded in 2017, with an average annual value of 81.8μg/m^3 PM_{10}. In 2012, the average yearly value at the measurement station Centar exceeded the permissible values by the most, reaching 81.3 g / m3. PM_{10} particle concentrations were found to be higher on a yearly basis in 2015. In general, more deviations from the permissible values were detected at the measuring station Rectorate. Despite the fact that we surpassed the allowed limit values from 2012 to 2020, there has been a gradual drop in the values of solid particles in the last three years, namely 2018, 2019, and 2020.

The following chart 3., which shows the presence of $PM_{2.5}$ particles in the measurement station Centar from 2012 to 2020, indicates that the greatest concentrations of $PM_{2.5}$ particles were reported in the air in 2012, when the average annual value reached 51.2μg/m^3. The lowest concentrations of $PM_{2.5}$ particles in the air were recorded in 2016, i.e., the average annual value with $PM_{2.5}$ particles was 27μg/m^3. There was further increase in 2017, when the average yearly value of $PM_{2.5}$ particles reached 38.5μg/m^3.

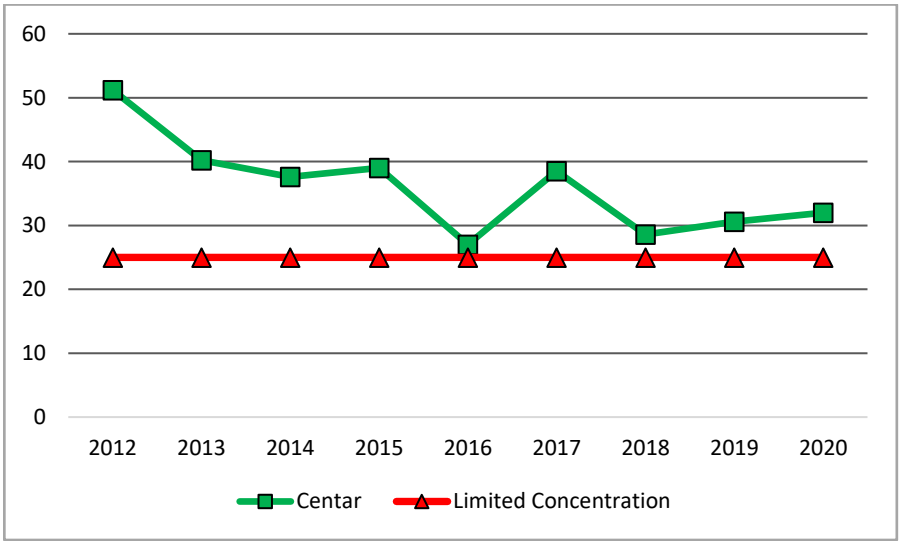

Chart 3. Average annual concentration of $PM_{2.5}$ particles from the station Centar, 2012 - 2020.

We can see considerable fluctuations in solid particle concentrations from 2015 to 2020, with concentrations decreasing in 2018, 2019 and 2020. Despite the tendency of decreasing concentrations of solid particles during the period under review, they are still over the MAC (Maximum Allowable Concentrations), which may be due to other anthropogenic activities and microclimatic conditions of Skopje Valley. The municipality of Centar's position and the climatic conditions of the Skopje valley influence solid particle concentrations, but development and, as a result, the loss of public green space additionally impair the natural air circulation and ventilation in the municipality, as well as the city.

Vegetation helps to reduce air pollution, especially during the summer months. The activity entails keeping solid particles, as well as dust, ash, and other mechanical pollutants, on the

leaves and other vegetative parts, from polluted air. After that, rinsing with air water or water used to irrigate the soil causes a gradual fall and deposition of those impurities on the soil surface. (Dimovski, 1994).

However, if the reduction of public green spaces and hence increased urbanization continues in the municipality of Centar, it may cause a rise in the presence of solid particles in the air in the future and during the summer months.

According to a 1978 study by Smith on the effect of woody plants on air pollution, solid particles and aerosols are removed from plants in three ways: deposition due to gravity, blown away by whirling winds, and accumulation due to precipitation. This is true for plant species with bigger leaf areas and volumes, as well as leaves with uneven surfaces, whereas evergreen and deciduous plant species with numerous branches and herbaceous structures allow particles to be removed over the winter months. (City of Skopje, 2015)

From the above, we can conclude that vegetation has an important role in reducing air pollution and concentration of PM particles in the air, and thus the Municipality of Center and the City of Skopje should pay more attention to maintaining the current greenery and creating new green areas.

CONCLUSION

It can be seen from the processed satellite images and the calculated data for the values of solid pollutants that the area with urban vegetation is steadily shrinking. The vegetation within residential blocks with mature and old trees is being replaced by newly constructed structures or grassy spaces that have a smaller role in air filtration. (Cowherd et al. 2006). Significant fluctuations in particle matter are also observed throughout the calendar year. In the summer, when home heating is reduced because of increasing daily temperatures, vegetation, in addition to other factors, plays the most essential role in influencing changes in solid particle concentrations.

Due to a lack of data from the measuring stations prior to 2012, a comprehensive and concise study of the trend of changes in solid particle concentrations and the impact of vegetation on them is not possible. In contrast, future continuous monitoring of data from measuring stations is essential to track the trend of PM_{10} and $PM_{2.5}$ in order to determine whether the variations are due to cyclical effects primarily caused by the climatic characteristics of Skopje valley, or due to measures taken to reduce air pollution, such as subsidies for purchased bicycles, electric scooters, and the replacement of old heating systems. Other actions taken by the City of Skopje, some of which were also taken in the Municipality of Centar, included the installation of green roofs and green walls, as well as connecting of families to central heating.

As a proposed solution, further municipal subsidies and actions should be directed at financing the development of energy efficient buildings, which would reduce the need for heating during the winter months, which is regarded as the most significant source of air contamination with particulate matter. Other initiatives that could have a greater impact include municipal assistance for a continuing trend of developing green roofs and walls, as well as the ground floor arrangement of green areas with more plant species. With the growth of the city and the subsequent building of new settlements, new prospects for the future layout of public green areas will emerge.

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