The G-pel method for determining the degree of greening of the area using the city of Penza as an example

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Abstract. The possibility of using publicly available software and a satellite map to determine the extent of vegetation coverage has been studied. It is suggested to apply an express method for determining the proportion of a green area from the total area with an average error for P=0.95 12.4±3.25% using the GIMP software (G-pel method). To assess the reliability of the method, similar results obtained by the overlay grid technique were compared with those of determining the forest cover of the Volga region cities using neural networks with satellite images made by a group of Canopus-V satellites. The deviation of the G-pel method results from the results of determining the forest cover of Volga region cities using neural networks averaged 11%. The difference between the results of the overlay grid technique and the G-pel method turned out to be unreliable.

1 Introduction

Currently, the need for new methodological approaches to the prevention and elimination of the consequences of climate-related emergencies is being substantiated [1].

To this end, approaches are being developed, including the establishment of regional networks and stations incorporated in the national system for monitoring ecosystem fluxes of greenhouse gases RuFlux [2], the use of special national greenhouse gas emission coefficients [3], the assessment of the intensity and efficiency of the organic carbon conversion into CO2, as well as their relationship with climatic parameters [4], the analysis of the structure and properties of metageosystems [5], the use of application programming interfaces of the neural models repository [6], the study of inflow and outflow transformation of organic matter of plants [7], the application of the ROBUL software (Regional Assessment of Forest Carbon Budget) [8], the geoecological studies of the Anthropocene [9].

Current global climate change is increasingly intensifying its manifestations, affecting anthropogenic and natural systems, which leads to a reduced share of forests in forest-steppe territories [10], decreased productivity of arable and hay lands, pastures, deterioration of natural conditions that ensure the development of recreation and tourism [11] and also increases regional climate risks [12], risks to business and economic activity [13].

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One of the key ways to mitigate the anthropogenic load of urban areas is urban greening, as an indicator of its comfort.

The degree of greening of urban areas is calculated by decoding satellite images and determining the proportion of the city area covered with vegetation in the total area of the city. However, the traditional overlay grid technique is labor intensive, and the work with GIS software requires specific knowledge and skills. The data of the state forest inventory do not affect these territories at all and, moreover, they provide significantly underestimated results compared to the results of remote sensing [14].

This research is aimed at developing an algorithm for determining the area and proportion of territories covered with woody and shrubby vegetation using publicly available software and maps of the Google Earth Engine service.

2 Materials and methods

The degree of greening of the territory of all administrative districts of Penza and other cities of the Volga region was analyzed in 2022.

The area of land plots (ha) in Penza was determined from combined satellite and aerial images of the Google Earth Engine service on a scale of 1:9091 using a virtual overlay grid and a report on the administrative division of Penza

The green area (in fractions of a unit) was calculated from the projective cover of the territory shown on the satellite map. To do this, the map was copied in the study sites with a 300x300 pels square using the SnagIt v5.8 software, which corresponds to 49 hectares of land.

The module <Connected dialogs/Histogram+Green filter> of the publicly available GIMP software was used to determine the number of pixels in the green range. Examples of the results of determining the projective cover using GIMP histograms can be seen in Figure 1. The 'value' of a pixel was 1.8 m^2. In this article the method is named 'G-pel' (Green pixel).

To determine the proportion of greenery, the clipping was analyzed in RGB format with the calculation of the number of rasters in the required brightness range of the G channel. The ranges were obtained by visual method as a result of calibration of the G brightness channel on a GIMP histogram of pixel distribution with setting of zones for: trees and shrubs; lawns and grass; roofs, vacant lots and pavements. To do this, according to the recommendations, test sites with a relatively homogeneous territory were used. Using the GIMP software, their analysis was performed to determine the ranges of the G channel of brightness corresponding to the nature of the area's cover.

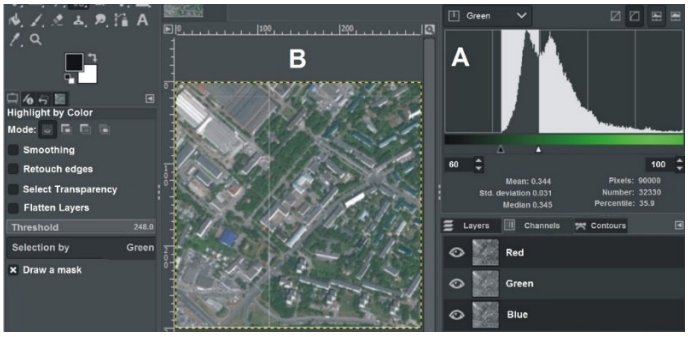

Fig. 1. Example of the determination of a projective cover using the GIMP software (map of Penza, the district of PSUAC). A – a histogram of the green pixels distribution (the cumulative range of the brightness channel for forests and shrubs is set from 60 to 100); B – the analyzed clipping of the map in RGB format. Coverage of the set range is 35.9%.

Twelve districts of the city of Penza and the town of Zarechny in the Penza region were studied.

In each of them, the green space parameters were surveyed (10 points in each, the data were averaged over the area). The data was collected in the areas named: PSUAC, GPZ, Shuist, Pobedy Avenue, Arbekovo, Stroiteley Avenue, Zapadnaya Polyana, Center, Ternovka, Sputnik and the town of Zarechny.

3 Results and discussion

The reliability of results of determining the green area by the G-pel method was validated through the following steps.

A square section of the satellite map of the required scale was cut out. It was copied to GIMP. In GIMP, an image can be split into one or more channels: for an image in RGB mode, these will be red (R), green (G) and blue (B). As the color of vegetation, i.e. green (G), was of interest, so in the menu item of the linear histogram <The inserted layer > one should select <green>.

The GIMP histogram shows the statistic distribution of green pixels by intensity (brightness). The full brightness range is from 0 to 255; on a 300 by 300 pel map clipping, the total number of G-pixels is 90 000, and the total number of pixels is 270 000. The green range includes green contributions to the overall color scheme of the map. Among the objects located on the map, the most widespread in the city are: roofs of houses, asphalt, lawns, trees and shrubs. Using the menu item <Color selection> the brightness ranges of the green component for these objects are defined.

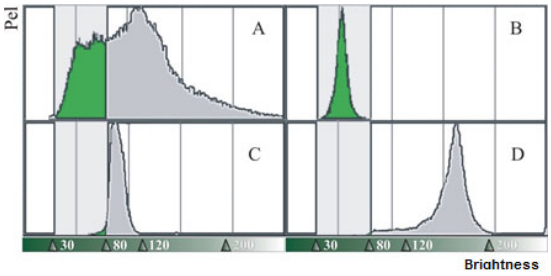

Fig. 2. Screen application of histograms of the G-pixel distribution along the brightness channel (map of a district in the city of Kazan). A – the urban area, trees 29.7%. B – woodland, forest 99.1%. C – fields and meadows with forest belts, forest 4.2%. D – roofs of houses and asphalt (industrial zone), trees 0.2%. Brightness ranges: forest 30-80; grassy vegetation 81-120; roofs, asphalt and wastelands 121-200.

To confirm the ranges, test sites of relatively homogeneous ecosystem sections (urban area, forest, fields and meadows), as well as a range of asphalt and roof surfaces, were studied (Figure 2).

As one can see, the G-pixel distribution histogram of an urban area is the sum of three ranges. Their distribution is similar to the distribution of one-dimensional environmental niches in interspecies competition. Thus, the overlap of ranges (the ratio of the distance between the averages to the relative standard deviation) of forests with shrubs and herbaceous plants is from 2.3 to 3.4, and between herbaceous plants and asphalt from 0.8 to 1. This is also confirmed by Schoener's D index, which reflects the value of the alignment of the environmental niches in a given space and ranges between 0 (no overlap) and 1 (complete overlap) [15]. For forests with shrubs and herbaceous plants, D varies from 0.11 to 0.14; between herbaceous plants and asphalt it measures from 0.41 to 0.55.

This indicates that in the reflection spectrum, the environmental niches of forests with shrubs and herbaceous plants (they are lighter in color) overlap slightly, while grass and asphalt overlap significantly, which is due to their close spatial location and mosaic distribution. Therefore, the error in determining the proportion of forests compared to the share of grassy vegetation by the G-pel method will be small.

It should be noted that in the process of work, in order to determine pixels related to green spaces in different cities, it was necessary to change the brightness ranges, since the satellite Yandex map is often like a 'patchwork quilt' made up of areas of different color scales (probably due to shooting by different satellites). Therefore, for the accurate identification of trees and shrubs, the brightness range should be corrected by calibration. So, the distribution of ranges on the example of the Penza map is as follows: from 0 to 60 – black shades, practically not found; from 61 to 100 – woods and shrubs; from 101 to 110 – herbaceous vegetation; 111 and greater – asphalt and roofs of various colors.

When setting the required range, GIMP displays the number of map pixels that are included in this range <Number>, as well as their share (per cent) in the total number of pixels in the selected green channel, the average value and the standard deviation.

Thus, the proportion of pixels in the selected range will correspond to the proportion of the area occupied by the surfaces having a green component of this brightness in the color scheme.

The results obtained by the G-pel method were compared with the data acquired in 2022 by experts from the Terra Tech JSC, a subsidiary of the Russian Space Systems JSC, using the Russian satellite images shot by the Canopus-V satellites. The comparison showed that the greening of the Penza city center (in fractions of a unit) is 0.301 (Table 1), and it is commensurate with similar data obtained using neural networks for the Volga region cities having over one million inhabitants. For example, in the city of Samara, this indicator was 0.303, in a megalopolis and a city of the steppe zone (Kazan and Volgograd) it is significantly less – 0.117 and 0.159, respectively.

Table 1. Average projective coverage of green spaces in various neighborhoods of Penza.

No	Name of neighborhood	Indicators		
		G(61-100), pel.	Fractions of a unit from G	Thousands m^2/ha
1	PSUAC	27990.9±533.9	0.311±0.012	3.12±0.12
2	GPZ	23220.5±954.7	0.258±0.028	2.58±0.28
3	Shuist	27090.6±742.8	0.301±0.016	3.01±0.17
4	Pobedy Avenue (close)	27450.7±697.0	0.305±0.014	3.05±0.14
5	Pobedy Avenue (remote)	27540.0±562.9	0.306±0.012	3.06±0.12
6	Arbekovo	27180.5±939.7	0.302±0.014	3.02±0.14
7	Stroiteley Avenue	27270.9±734.3	0.303±0.013	3.03±0.13
8	Zapadnaya Polyana	27990.3±650.5	0.311±0.012	3.11±0.12
9	Center 1	26910.0±597.2	0.299±0.015	2.99±0.12
10	Center 2	26730.2±512.4	0.297±0.012	2.98±0.12
11	Ternovka	28080.7±327.2	0.312±0.011	3.12±0.11
12	Sputnik	26460.1±696.8	0.294±0.013	2.94±0.13
13	The town of Zarechny	28350.2±612.7	0.315±0.012	3.15±0.12
Average for the city of Penza		27090.5±981.2	0.301±0.014	3.01±0.14

The application of the G-pel method to specify the greening extent of the above listed locations gave the following results (Table 2). The deviation of forest cover from the average was from 5.4 to 26.1%, on average 11%, which is acceptable for environmental studies.

Table 2. Indicators of greening of city centers obtained by various methods.

Indicator	City			
	Penza	**Samara**	**Volgograd**	**Kazan**
Range	61-100	61-100	61-100	81-120
Cover, fractions of a unit from pel. G	0.299±0.015	0.321±0.011	0.143±0.012	0.092±0.011
G-pel method error for $P_{(0.95)}$ / %	0.026 / 8.7	0.019 / 5.9	0.021 / 14.4	0.019 / 20.6
Cover (data from Terra Tech JSC, fractions of a unit	-	0.303	0.159	0.117
G-pel method deviation from the average value of the cover, %	-	5.4	12.7	26.1
Cover, according to the overlay grid, fractions of a unit	0.264±0.017	0.300±0.021	0.121±0.014	0.113±0.020
Difference as per Student / its reliability for degree of freedom 20	1.53 / <0.95	0.84 / <0.95	1.08 / <0.95	0.88 / <0.95

Comparison of the results of determining the coverage by isolating the G-range of brightness from the total number of RGM G-pixels and the data obtained using the virtual overlay grid on the same satellite maps showed greater accuracy of the G-pel method than in the previous case. So, the coefficient of difference (see Table 2) for various cities measured from 0.84 to 1.53, in all cases the difference turned out to be unreliable.

The average error of the method was 12.4±3.25%. It can be noted that the G-pal method, when compared with the overlay grid technique, often gives somewhat overestimated results, which is probably due to the above-mentioned overlap of the distributions of G-ranges of surfaces similar in color. The difference between the results in relation to the overlay grid technique turned out to be about 5%.

When using the G-pel method, the time to determine the area of overgrowth on a satellite map without taking into account the "setting" of the software was 1 minute only, and this is incommensurable with the traditional approaches.

The projective green cover in various districts of Penza was calculated using the above-mentioned methodology. It was found (see Table 1) that the satellite town of Penza – Zarechny – has the greatest greening extent of urban areas (3.15 thousand m^2/ha). In terms of the number of inhabitants (65 502 people as of 1.10.2022, an area of 27.6 km^2), it equals 132.7 m^2/person. In Penza, the newly built districts of the city (GPZ and Sputnik) distinguished themselves by the lowest greening indicators: 25.8% and 29.5%, respectively, which is 86% and 98% of the average level of greening in the city – 30.2%. The "old" districts have the highest indicators – Zheleznodorozhny (PGUAS point), Zapadnaya Polyana and Ternovka. There, the degree of greening of the urban area (in residential areas, not including wooded suburbs that are formally part of the city) is more than 31%.

For Penza as a whole (see Table 1), the specific greening factor amounted to 337.7 m^2/person, taking into consideration that 520 300 inhabitants live on an area of 288 km^2 and including the woodlands within the city limits, while the regulatory value for recreation areas is at least 100 m^2/person. If only the built-up area is included in the calculation (according to the authors' data it is about 45% of the administrative territory of the city), then the value decreases to 72.8 m^2/person, which also complies with the regulations (at least 25% of the area occupied by housing).

The ratio of zones with different greening factors in the administrative boundaries of Penza districts where the G-pel method was applied is shown in Figure 3. Zheleznodorozhny district has the greatest greenery value (939.8 m^2/person), since it includes a large forest area in the eastern part of Penza, which makes up about 65% of its area (Table 3).

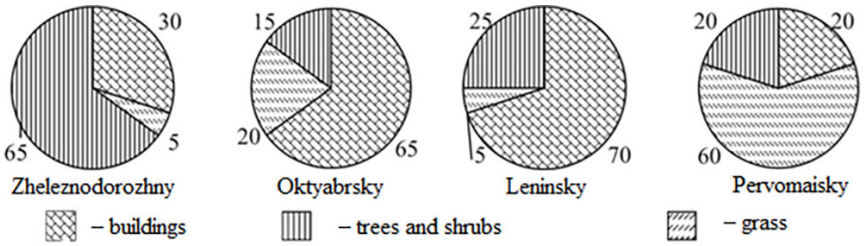

Fig. 3. The ratio of zones within the administrative boundaries of Penza districts.

But even without taking into account the forest area, its specific greening factor is about 113 m^2/person. The lowest greenery rate is observed in Pervomaisky district, which includes the city center and the new Sputnik neighborhood (97.8 m^2/person) where rapid construction is underway.

It can be seen that the heterogeneity of the ratio of buildings/trees/grass and shrubs in the city areas is very high. Zheleznodorozhny district is in the first place in terms of forest cover, followed by Leninsky, Pervomaisky and Oktyabrsky districts. In terms of the ratio of undeveloped vs built-up area, Pervomaisky district is in the lead, but there are few woodlands in it and its main part consists of fields and wastelands.

Table 3. Degree of greening in the districts of Penza.

District	**Zheleznodorozhny**	**Leninsky**	**Oktyabrsky**	**Pervomaisky**
Sites	PSUAC, GPZ, Shuist, the town of Zarechny	Center 1, Zapadnaya Polyana	Pobedy Avenue, Arbekovo, Stroiteley Avenue	Center 2, Ternovka, Sputnik
Area of the district, ha	14550	2750	8170	5000
Residential area, ha	4365	1787.5	5719	1000
Forest area, ha	9457.5	412.5	2042.5	1000
Green space in the district, ha	10752	958	3781	1301
Average greening, m^2/ha	7778	4353	4872	6507
Share of the greenery in the district, %	73.9	34.8	46.3	26.0
Population, number of persons	114408	90479	182336	133077
Specific greening factor of the district, m^2/person	939.8	105.8	207.4	97.8
Residential area greening, m^2/ha	2965	3050	3040	3013
Residential area greening, %	29.7	30.5	30.4	30.1
Specific greening factor of the residential area, m^2/person	113.1	60.3	95.4	22.6

According to the requirements of the building regulations, the green area of the neighborhood (block of houses) with multi-apartment residential buildings (excluding the land plots with general education and preschool educational facilities) must be at least 25% of the total area of the neighborhood (block of houses) or at least 100 m^2/person, taking into account recreation areas. In Penza, this standard is not always met (see Table 3).

If one assumes that the greening factor of forests is 100%, then based on the ratio of overgrowth zones and the area of neighborhoods in Pervomaisky district, including the Center 2, Ternovka and Sputnik points, the greening factor is 26% of their populated territory. However, taking into account the recreation areas, the per capita indicator of tree species landscaping is 97.8 m^2/person. A similar situation is observed in the GPZ neighborhood.

It is caused by the insufficient greening of the central urban areas and the relatively new Sputnik neighborhood, in which the indigenous degree of greening was very low, and the trees planted after construction have not yet grown. The Sputnik and Ternovka neighborhoods are historically located in the forest steppe area (see Figure 2), there are a lot of woodless industrial zone in them, so only the areas with old buildings closer to the city center turned out to be green.

Leninsky district is close to the lower threshold of the greening standard value. The city center showed a weak wooded area. In general, the per capita greening limit value was observed only thanks to the significant green space in the Zapadnaya Polyana neighborhood, which includes the park named after V. Belinsky.

Despite the lowest proportion of residential greening among the districts (29.7%), Zheleznodorozhny district is characterized by a high specific greening value. Low-rise buildings in old neighborhoods with overgrown trees inside the courtyard area prevail in this district.

4 Conclusion

On the example of the city of Penza, it is suggested to apply an express method for determining the proportion of a green area using the GIMP software (G-pel method).

To assess the reliability of the method, similar results obtained by the overlay grid technique were compared with those of determining the forest cover of the Volga region cities using neural networks with satellite images made by a group of Canopus-V satellites.

1. Analysis of the results of determining the area of green spaces by the G-pel method showed sufficient validity of the indicators obtained. The average error of the method is 12.4±3.25%. The difference between the value obtained by traditional methods and the G-pel method turned out to be unreliable.
2. The deviation of the G-pel results from those of determining the forest cover of the Volga region cities using neural networks with satellite images from Canopus-V satellites averaged 11%.
3. Applying the proposed method, it has been identified that the residential areas in Pervomaisky district, in the center of Penza, in the GPP and Sputnik neighborhoods do not comply with the regulatory greening limit of “at least 100 m^2/person, including recreation areas”.

The G-pel method can be used to determine the area of plantations when estimating the carbon assimilation capacity of a stand of trees in sparse plantations by the ROBUL algorithm. The use of conventional methods for determining the area of plantings in cities and other areas similar in nature to overgrowth, when the landscaped area is scattered (up to stand-alone trees), is extremely labor-consuming.

Limitations of the possibility of using the G-pel method are: operator color blindness, satellite map of the non-summer growing season, the presence of green roofs on the studied area.

Potential application of G-pel method might have the following constraints: operator's color blindness, satellite map of the non-summer growing season, and green roofs of buildings in the studied area.

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