Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/15714
DOI URL: http://dx.doi.org/10.21474/IJAR01/15714

RESEARCH ARTICLE

A METHODOLOGICAL APPROACH TO THE DEVELOPMENT AND MAPPING OF THEURBAN LAND COVER OF THE CITY OF SOFIA

Kaloyan Ivanov
Assistant Professor PhD, Climate, Atmosphere and Water Research Institute - Bulgarian Academy of Sciences, Sofia, Bulgaria.

……………………………………………………………………………………………………....

Manuscript Info

……………………….

Manuscript History
Received: 15 September 2022
Final Accepted: 19 October 2022
Published: November 2022

Key words:-
GIS, Methodology, Sofia, Urban Land Cover

Abstract

………………………………………………………………

The present study presents for the first time the development of a methodology for the creation of an urban land cover of the city of Sofia, which will serve the needs of the study of the local climate zones of the Bulgarian capital. For the development of the nomenclature of the land cover, data from an orthophoto image, the Urban Atlas and cadastre of the city of Sofia were used, using a number of geospatial techniques. The end result is a classification of various objects from the urban landscape of the Bulgarian capital, divided into 11 classes and 22 sub-classes, which form the main mesoclimatic factors in the city. The results show a large percentage of low-rise buildings built of bricks with dark rooftops, which implies higher temperatures in the city and the formation of urban heat islands of different sizes and a big percentage of industrial sites (38.3%) which also affects the quality of the atmospheric air in the city of Sofia.

……………………………………………………………………………………………………....

Introduction:-

The urban climate of the city of Sofia is a topic that has been the subject of a number of studies over the years. The lack of high density of the official meteorological network in the city, as well as the lack of a detailed study of the urban landscape to relate to the urban climatological features of the city of Sofia leads to the formation of a gap in these studies. A key point in determining the urban features of the climate in the Bulgarian capital is the study of the biophysical dimensions of the geographical space, presented in the form of a specific land cover. Land cover informs the functional relationship between terrain, climate and soils (Wulder, 2018) and is considered an opportunity to distinguish between different biophysical categories: urban fabric, vegetation, water bodies, industrial sites, settlements etc. The increase of the urban land cover leads to different enviromental impacts such as: increased erosion, trace gas flux, soil compaction, introduction of non-native species, increase in impervious surface etc (Bergstrom, 2004). A number of land cover classifications have been developed worldwide, part of which were also applied for the city of Sofia: The CORINE Land Cover (CLC); the Urban Atlas; Anderson Land Cover Classification system; the Land Cover Classification System (LCCS), developed by FAO to provide a consistent framework for the classification and mapping of land cover.

The main concern regarding the urban climatic mapping is that most of the abovementioned land cover classifications do not fully cover the spatial criteria of an urban climatic study. Their focus is rather in the context of natural science and ecology and could not go down to the local climate level scale to show the specifics of a city like Sofia, related to the type of construction and its spatial planning (Ivanov, 2020). There is an urban masterplan of

Corresponding Author:- Kaloyan Ivanov, PhD
Address:- Climate, Atmosphere and Water Research Institute - Bulgarian Academy of Sciences, 66 Tsarigradsko Shose Blvd., 1784 Sofia, Bulgaria.

Sofia, which is very detailed, with a nomenclature of its classes intended for engineering needs, something that is not necessary for the urban climate mapping.

Accurate information on land cover at a regional scale is important for climate modelling (Liu, 2003). Feranec et al. (2018) analyse and assess the different types of urban fabric and its change, depending on the changing temperature regime in the city of Bratislava by application of the MUKLIMO (Microscale Urban Climate Model) model, using the extended Urban Atlas land cover nomenclature along with the interpretation of the SPOT 4/1998, SPOT 5/2007, Sentinel 2/2016 satellite images. These classes were used as an input data in the model, showing the complex relations between variables, such as the height of buildings and the structure of buildings, used materials, height and types of vegetation on the scale of urban environment.

Mapping urban green spaces based on remote sensing data is an innovative approach that provides additional analysis of the state of the urban climate. Rosina et al. (2016) investigate the urban green spaces using Sentinel-2A data in Slovakia. The spectral resolution and bandwidth of S2A data has the potential to discriminate between a small numbers of spectrally different land cover types using automatic classification methods with reasonable accuracy. In the end there were 15 urban green spaces classes classified, which would help the effective urban planning and policy. The urban green spaces in the city of Sofia, Bulgaria were also obtained by automatic land cover classification, using Sentinel-2A (Vatseva et al., 2016).

Temperature differences between different land cover structures in cities are important to be well studied. The land cover classes affect the formation of the urban heat island in different ways. Eliasson et al. (2003) present how the master plan of a city can be used by modifying it by adding new classes that show their influence on temperature changes during the day and night. Alexander et al. (2016) investigate how different models (in their case SUEWS model) can be applied in the study of urban climate zones and meteorological observations from off-site synoptic stations. More detailed land cover was added to the model in order to examine the impact on model performance with respect to observations of turbulent fluxes of sensible and latent heat. The importance of land use types and patterns at different spatial scales, influencing the temperature distribution in the city of Berlin is well studied by Dugord et. al (2014).

There are a number of Bulgarian studies related to the urban planning in Bulgaria and the spatial relationships between the individual elements of the urban landscape. (Hrelev et al, 1999; Nikiforov et al. 2016; Petrov, 2015)

Travaglia et al (2001) used FAO's Land Cover Classification System (LCCS) for the mapping of several Bulgarian areas, including the Sofia Intermontain Plain. In Bulgaria a detailed common database has been created for the land cover, for the cross-border region - Northern Bulgaria, based on the philosophy of Land Cover Meta Language – LCML (ISO 19144-2) in full compliance with the principles of the directive INSPIRE (ASDE, 2014).

For the future research of local climate zones in the city of Sofia, an interdisciplinary approach is needed, which should unite, modify and create a new type of classification of the land cover, which will serve as a basis for further urban climate research.

Study area

The study area is the city of Sofia (Bulgaria) which is situated in Sofia Valley – a negative form of relief with a length of 75 km and a width of 20 km. It extends in a northwest-southeast direction between Stara Planina from the north and the mountains Viskyar, Lyulin, Vitosha and Lozenska from the south. The average elevation of the valley is 550 m. The field has an area of about 1.200 km^2. It consists of two main parts - a valley bottom and the slopes of the surrounding mountains. The slopes of the surrounding mountains in most places are steep. In the middle of the field in the meridional direction flows its main waterway - the Iskar River (Blaskova, 1983).

The transport and geographical location of Sofia is of special importance (Fig. 1). Four world transport routes were intersected here - the three-continental diagonal highway Northwest-Southeast (London - Budapest - Sofia - Istanbul - Calcutta - Melbourne), the meridional Euro-African highway (Helsinki, Moscow,Sofia, Thessaloniki, Cairo, Cape Town), the diagonal Euro-African highway (Tunisia-Durres-Sofia-Bucharest-Odessa-Omsk) and the emerging transport corridor around the 40^{th} parallel from the Caspian sea through the Black sea to the Adriatic Sea - Poti-Varna-Sofia-Skopje-Durres (GDP, 2009).

Three of the trans-European transport corridors intersect in Sofia Municipality:
- Corridor № 4 - Budapest-Vidin-Sofia-Thessaloniki (Istanbul);
- Corridor № 8 - Durres-Skopje-Sofia-Burgas-Varna;
- Corridor № 10 - Belgrade-Sofia-Plovdiv-Istanbul (GDP, 2009).

Figure 1:- Physical map of the city of Sofia.

Methods:-

Land cover classifications are a form of land cover analyses process, using Geographic information systems and remote sensing technologies in order to simplify the measurement of spatial relationships in visualization and use of land resources (Aplin, 2004). Spatial classification following the natural characteristics of a landscape forms the basis for optimal spatial organization (Perko et al., 2019). Field surveys and analysis of remotely sensed imageryare the most common methods for capturing geospatial information for a land cover. Geographical information involves processing, interpreting or transforming data to derive some sort of interpretation (Comber et al., 2005). From physico-geographical point of view there are many overlay techniques for the mapping of the urban landscapes etc. (Bastian, 2000).There are two main areas of remote sensing-based land cover research which usually overlap each other: environmental management – the control and use of land cover and environmental understanding – the scientific analysis of processes involved in determining the land cover (Aplin, 2004).Land cover classification can be automatic or manual. Both have their pros and cons. For example, automatic classification uses pre-set mathematical parameters to visualize land cover classes, but generally ignore shape, size, position and association of landforms, while manual classification direct its efforts to assess the observer/expert's own assessment on the classification process (King, 2002). The final result of a land cover classification is a popular example of a thematic map (Thomas, 2016).

For the application of the research methods and techniques of the present study, remote methods related to the processing of satellite information and GIS software (ArcGIS 10.8) were used.

The methods go through several stages:
1. Assessment of the geographical location of the city of Sofia;
2. Established scale of work M 1:50 000;
3. Processing of satellite images with high resolution – the selected geospatial substrate, which is being worked on is an orthophoto image of the city of Sofia from 2016, due to the element of detail needed for distinguishing between different land cover classes in an urban environment;
4. Development of the nomenclature of the urban land cover;
5. Application of geospatial methods and topological criteria for assessment of the urban land cover of the city of Sofia.

Topology is a complex hierarchy of spatial relationships between objects. With regard to the area sites in GIS, which are the layers of land cover of Sofia, the so-called "polygon topology" is used. Polygon topologies are useful in analyzing ground connections surfaces (Agüero et al., 2020). They can be presented in tabular form, where the results of the topological criteria for the relationship between the vector data are recorded - intersection of lines at the nodes, overlay of polygon layers, clipping out a subset of polygons with another polygon and other topologic relationships (Harmon et al., 2003).

In the study no automatic classification was used, it was done entirely through visual interpretation, the author's expertise and the use of various geospatial classification techniques, which implies a certain amount of subjectivism.This is necessary given the purposes for which the urban classification is created, namely the study of local climatezones in the city of Sofia. Visual interpretation is based on analysis of interpretation elements, of the recorded landscape objects(Bossard et al., 2000).

The main geospatial techniques used in the classification are shown in Table 1.

Table 1:- Geospatial techniques used for the development of the urban land cover of Sofia.

Name	**Goal**
Clipping out a subset of polygons with another polygon	Used for the establishing of local classes polygons such as green urban areas
Overlay of polygon layers	Used primarily for public areas
Dissolving lines between adjacent polygonswith similar characteristics	Used primarily for the industrial sites
Semantic and geometric generalization	Used primarily for the Urban fabrics
Simplification and symbolization	Used within the whole classifiaction process
Field surveys and street view	Used primarily for urban fabrics and industrial sites

In addition to the observation of the orthophoto image of the city of Sofia, for the needs of the research different sources of geospatial information were used, through which the different classes of urban land cover were differentiated. Data from the Cadaster of Sofia City for 2009 and Urban Atlas for 2012 were examined and used in the classification process.

Results:-

The results of the developed methodology led to the receipt of a fully completed nomenclature of urban land cover in coordinate system UTM 34N, WGS 1984. The developed classes are 11 in number, together with 22 sub-classes (Table 2).

Table 2:- Urban land cover nomenclature "Ivanov 2022".

Class	**Sub-class 1**	**Sub-class 2**	**Sub-class 3**
1. Continuous urban fabric (> 80%)	Building materials	Color of rooftops	Building heights
	Sub-class 1.1	**Sub-class 2.1**	**Sub-class 3.1**
	1.1.1 Reinforced concrete; **1.1.2** Panel; **1.1.3** Brick	**2.1.1** Dark-colored; **2.1.2** Light-colored	**3.1.1** Low-rise (< 9 m); **3.1.2** Mid-rise (9-20);

			3.1.3 High-rise (> 20)
2. Discontinuous urban fabric (10-30%)	Building materials	Color of rooftops	Building heights
	Sub-class 1.1	**Sub-class 2.1**	**Sub-class 3.1**
	1.1.1 Reinforced concrete; **1.1.2** Panel; **1.1.3** Brick	**2.1.1** Dark-colored; **2.1.2** Light-colored	**3.1.1** Low-rise (< 9 m); **3.1.2** Mid-rise (9-20); **3.1.3** High-rise (> 20)
3. Discontinuous urban fabric (30-50%)	Building materials	Color of rooftops	Building heights
	Sub-class 1.1	**Sub-class 2.1**	**Sub-class 3.1**
	1.1.1 Reinforced concrete; **1.1.2** Panel; **1.1.3** Brick	**2.1.1** Dark-colored; **2.1.2** Light-colored	**3.1.1** Low-rise (< 9 m); **3.1.2** Mid-rise (9-20); **3.1.3** High-rise (> 20)
4. Discontinuous urban fabric (50-80%)	Building materials	Color of rooftops	Building heights
	Sub-class 1.1	**Sub-class 2.1**	**Sub-class 3.1**
	1.1.1 Reinforced concrete; **1.1.2** Panel; **1.1.1** Brick	**2.1.1** Dark-colored; **2.1.2** Light-colored	**3.1.1** Low-rise (< 9 m); **3.1.2** Mid-rise (9-20); **3.1.3** High-rise (> 20)
5. Green Urban Areas	Trees	Bushes	Grass
6. Industrial sites	Mineral extraction sites	Construction sites	Other
7. Roads	Main	Other	
8. Railways			
9. Public areas	Sport and leisure facilities	Airport	Cemeteries
10. Water bodies			
11. Agricultural land			

The most important classes of this land cover, related to urban planning and urban climate - continuous and discontinuous urban fabric in different percentages, are divided into sub-classes: building materials, color of rooftops and building heights. The class is a set of buildings of different sizes, used by public utilities, private housing, scattered blocks, etc. The construction materials from which the buildings in Sofia were built are classified and divided into three sub-groups, in which one type of material predominates:
- reinforced concrete - large constructions of new buildings, built mainly after 1990 and part of old low-rise blocks, built before 1944;
- panel - homogeneous spaces, mainly in larger neighborhoods, built mostly after 1944;
- brick - low-rise, medium and high-rise buildings.

For their classification, Google Street view, Sofia Master Plan and visual interpretation of the orthophoto image made by the author were used. Building materials have different thermal properties, they often have greater capacity to store and later release sensible heat (Oke et al., 2017) and are one of the major factors regarding differentiating local urban climates.

The sub-class “color of rooftops” is classified by a visual interpretation of the orthophoto image processing and is divided into the following sub-groups:

- Dark-colored (black, gray, red)
- Light-colored (white, green)

Rooftops are the part of a building more exposed to the solar radiation. Roofs of different colors absorb and give off heat in different ways, thus having a direct connection with the formation of an urban heat island. Rooftops have a crucial role in the thermal and energy performance of buildings as well as in the mitigation of the urban microclimate(Giuseppe, diE. et al., 2017).

For the “building heights”sub-class, data from the 2012 Urban Atlas was used and was divided as follows:
- low-rise buildings (<9 m)
- mid-rise buildings (10-20 m)
- high-rise buildings (> 20 m)

Building heights differences can have heating or cooling effects on the urban space and local urban climates and can lead to the formation of urban heat islands and the increasing of building energy consumption (Xi et al., 2021). Usually building heights and land surface temperatures have a negative logarithmic correlation (Wang et al., 2021).

The Green Urban Areas class represents areas with vegetation within the urban fabric and urban parks. It is divided into sub-classes: trees, bushes and grass for more detail on the impact on the local climate of the underlying green cover. Abandoned green areas are also included into the sub-class "Grass".

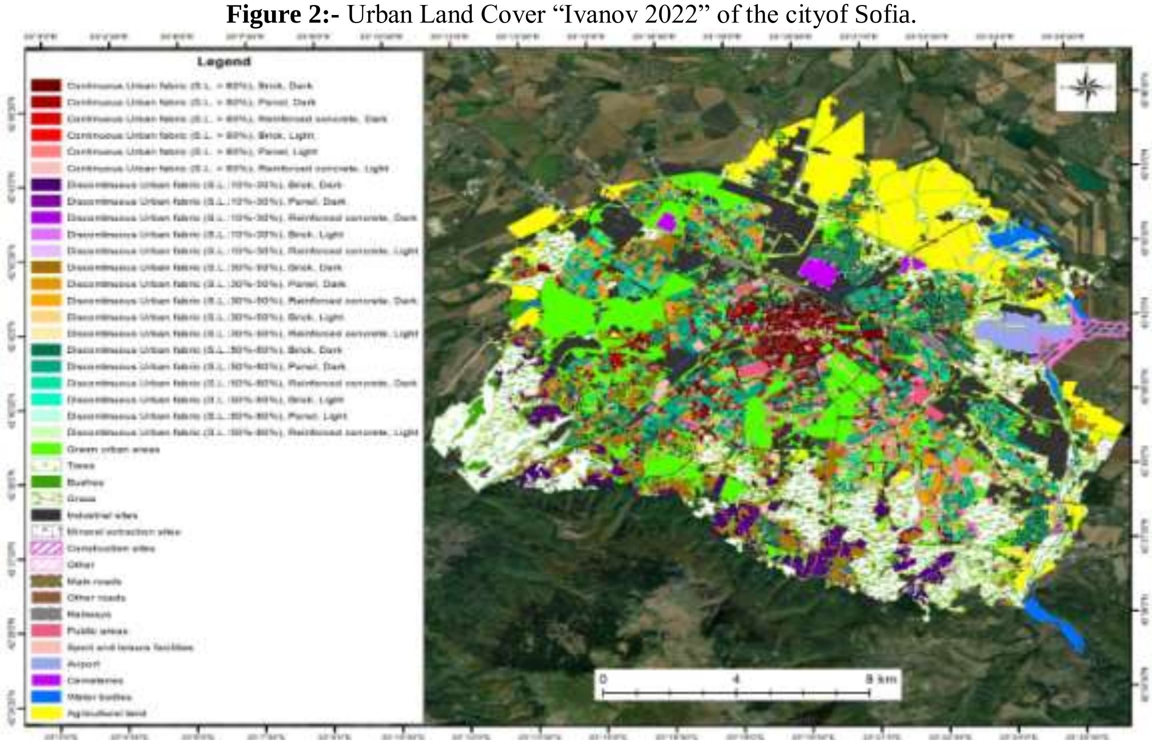
The Industrial sites class is divided into sub-classes: mineral extraction sites, construction sites and others, which includes mostly urbanisolated structures, with a residential or non-residential component.

The Public areas class includes the sub-classes:1. Sport and leisure facilities - football stadiums with the appropriate infrastructure, tennis courts, athletic halls etc.;2. Airport and 3. Cemeteries.

Topology validation has been performed and all inconsistencies in the vector layer have been corrected.

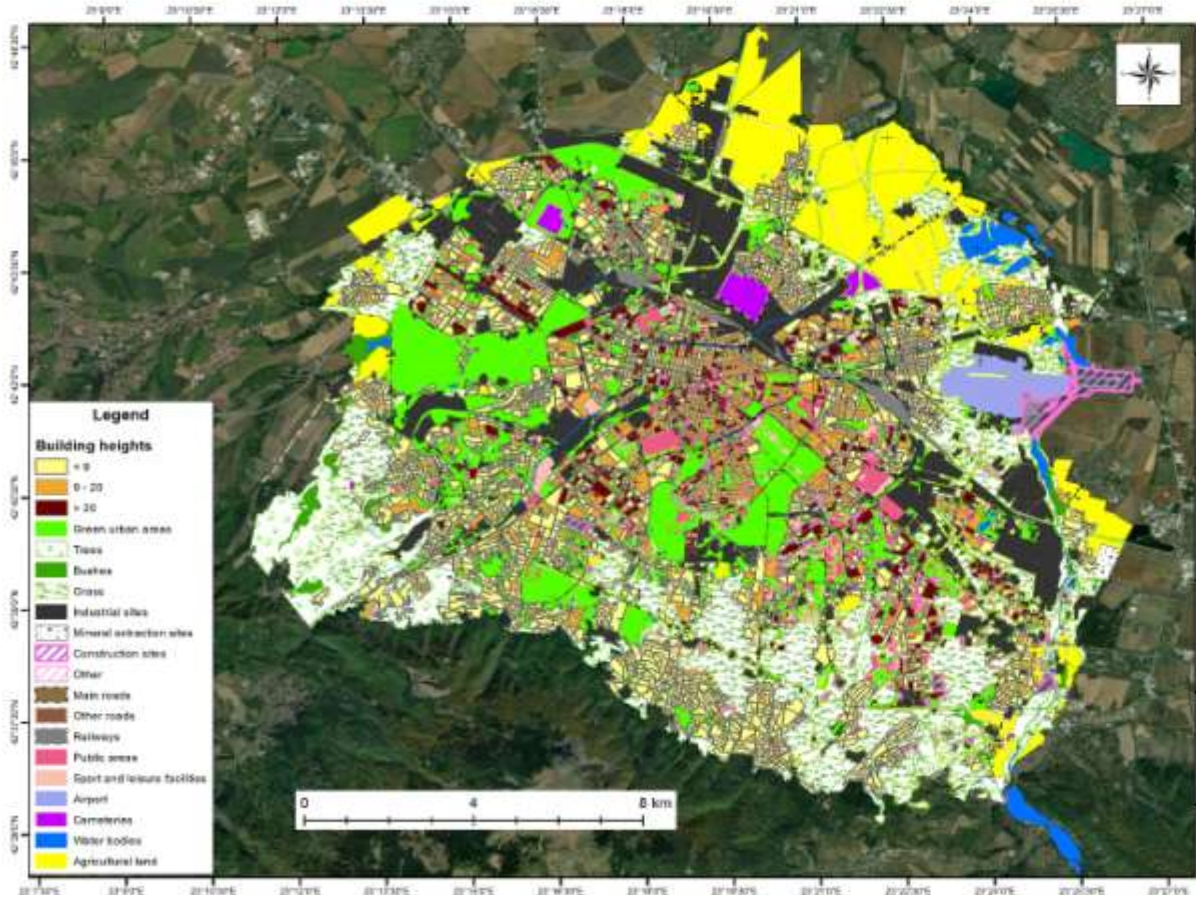
The final result of the obtained nomenclature of the urban land cover is a vector map of the city of Sofia (Fig. 2).

Figure 2:- Urban Land Cover “Ivanov 2022” of the cityof Sofia.



In order to better visualize the urban fabrics, the map of the heights of the buildings is presented separately (Fig. 3).

Figure 3:- Building heights of the Urban Land Cover “Ivanov 2022” of the cityof Sofia.



Discussion:-

The methodology for the urban land cover in Sofia was first developed taking into account the need to study the local climate zones in the Bulgarian capital. The presented successive steps in the approach have their positive sides and their limitations. One of the minor shortcoming of the validation could be the author's interpretation of the classification of apartment blocks in Sofia built before 1944. Most of them were built of bricks with specific mica, but some of them have reinforced concrete structures. Determining this difference visually is a daunting task. The characteristic that should be noted from the point of view of the residential buildings in the Bulgarian capital is that the light-colored rooftops are too small a percentage of the total percentage of roof constructions in the city (Table 3).

Table 3:- Area measurements of the urban land cover classes from ULC “Ivanov 2022”.

Class	**Sub-class 1**		**Sub-class 2**		**Sub-class 3**	**Area total (km^2)**
1. Continuous urban fabric (> 80%)	Building materials		Color of rooftops		Building heights	**7.66**
	Sub-class 1.1	**Area (km^2)**	**Sub-class 2.1**	**Area (km^2)**	**Sub-class 3.1**	**Area (km^2)**

	1.1.1 Reinforced concrete; **1.1.2** Panel; **1.1.3** Brick	**0.02** **1.39** **6.26**	**2.1.1** Dark-colored; **2.1.2** Light-colored	**7.6** **0.08**	**3.1.1** Low-rise (< 9 m) **3.1.2** Mid-rise (9-20) **3.1.3** High-rise (> 20)	**2.8** **2.2** **1.6**
2. Discontinuous urban fabric (10-30%)	Building materials		Color of rooftops		Building heights	**9.45**
	Sub-class 1.1	**Area (km^2)**	**Sub-class 2.1**	**Area (km^2)**	**Sub-class 3.1**	**Area (km^2)**
	1.1.1 Reinforced concrete; **1.1.2** Panel; **1.1.3** Brick	**0.0006** **0.02** **9.4**	**2.1.1** Dark-colored; **2.1.2** Light-colored	**9.4** **0.1**	**3.1.1** Low-rise (< 9 m) **3.1.2** Mid-rise (9-20) **3.1.3** High-rise (> 20)	**8.5** **0.6** **0.06**
3. Discontinuous urban fabric (30-50%)	Building materials		Color of rooftops		Building heights	**16.9**
	Sub-class 1.1	**Area (km^2)**	**Sub-class 2.1**	**Area (km^2)**	**Sub-class 3.1**	**Area (km^2)**
	1.1.1 Reinforced concrete; **1.1.2** Panel; **1.1.3** Brick	**0.07** **3.3** **13.7**	**2.1.1** Dark-colored; **2.1.2** Light-colored	**16.8** **0.2**	**3.1.1** Low-rise (< 9 m) **3.1.2** Mid-rise (9-20) **3.1.3** High-rise (> 20)	**13** **2.3** **0.6**
4. Discontinuous urban fabric (50-80%)	Building materials		Color of rooftops		Building heights	**25.4**
	Sub-class 1.1	**Area (km^2)**	**Sub-class 2.1**	**Area (km^2)**	**Sub-class 3.1**	**Area (km^2)**
	1.1.1 Reinforced concrete; **1.1.2** Panel; **1.1.3** Brick	**0.03** **10.9** **14.4**	**2.1.1** Dark-colored; **2.1.2** Light-colored	**25.3** **0.06**	**3.1.1** Low-rise (< 9 m) **3.1.2** Mid-rise (9-20) **3.1.3** High-rise	**14.9** **4.5**

					(> 20)	**3.3**
5. Green Urban Areas – **31.8**	Trees	**13.7**	Bushes	**1.7**	Grass	**37.6** **84.8**
6. Industrial sites	Mineral extraction sites	**0.7**	Construction sites	**4.5**	Other	**0.6** **38.3**
7. Roads	Main	**8.8**	Other	**8.8**		**17.6**
8. Railways						**2.37**
9. Public areas	Sport and leisure facilities	**1.6**	Airport	**2.8**	Cemeteries	**1.7** **14.1**
10. Water bodies						**4.3**
11. Agricultural land						**23.4**

Reinforced concrete buildings, especially those built after 1990, are predominantly with a light-colored rooftop. Some of the panel blocks, mostly those that have been properly rehabilitated, also have light-colored rooftops, as a result of EU programs and projects. Most of the rooftops of the panel buildingshave a dark color, which characterizes their batum asphalt coating. The brick buildings in the city are mostly with red tile rooftops, which theoretically have a high percentage of absorption of solar radiation (Giuseppe, diE. et al., 2017).

The results of the area analyzes lead to the conclusion that the city of Sofia is dominated by low-rise buildings and brick buildings. The Industrial sites are a large percentage (38.3% in total), a remnant of the totalitarian regime, with only the parks in the capital being 31.8%. The total area of the Green Urban Areas (84.8%) includes abandoned grasslands, as well as forests and bushes belonging to the southwestern, higher part of the city, located on the slopes of Vitosha Mountain. The class Agricultural land also could have a great influence on local climate zones in the city of Sofia, especially in the northern part of the city, with a large percentage (23.4%) of the total area, which suggests its greater importance as an urban mesoclimatic factor.

Conclusion:-

The presented methodology for the urban land cover of the city of Sofia is innovative and would be suitable for future research implemented by various experts in the field of urban climatology, urban geography, urban planning, etc. The development of the methodology is carried out for the first time in Bulgaria and is designed for research of the local climatezones in the Bulgarian capital. In the process of the analyses the following sequences were found:

1. Residential buildings in the city of Sofia are represented mainly by brick, low-rise buildings with a height of less than 9 m with a distribution density of 50-80%, with dark, red rooftops. Theoretically, this predetermines a large accumulation of solar radiation, its subsequent emission and increase in the intensity of urban heat islands.
2. The Industrial sitesclass in the Bulgarian capital occupies a large percentage of the total area of the city, which has a negative effect on the distribution and concentration of air pollutants.
3. Green Urban Areas occupy a smaller percentage of the total area in comparison with the Industrial sites, but together with the sub-classes Forests, Bushes and Grass have a greater expansion, theoretically providing a cooling effect, especially during the warm half of the year inside their territories.
4. The Agricultural landclass could have a local influence on the mesoclimatic features of the city of Sofia, related to its northern parts.
5. The classification and the used set of geospatial techniques have their limitations, mainly related to the subjective approach, but the methodology is a unique basis, not developed so far, for the future research of local climate zones in the city of Sofia.

Acknowledgement:-
This study is supported by the Bulgarian Ministry of Education and Science under the National Research Programme "Young scientists and postdoctoral students" approved by DCM # 577 / 17.08.2018.

References:-
1. Agüero, C. A., di Mauro, G., Vignerte, J., Anaut, D., Strack, J. Topology Tools for Network Analysis on GIS Platforms. International Journal of Electrical Engineering & Technology, 10(6), 2020, p. 13.
2. Alexander, P.J., Bechtel, B., Chow, W.T.L., Fealy, R., Mills, G. Linking urban climate classification with an urban energy and water budget model: Multi-site and multi-seasonal evaluation, Urban Climate, Volume 17, 2016, pp. 196-215.
3. Aplin, P. Remote sensing: land cover. Progress in Physical Geography, vol 28, 2, 2004, pp. 283-293.
4. ASDE. Web-GIS harmonized SDB for Integrated risk and Territory management and citizen protection – BG-RO. Common Strategy for Sustainable Territorial Development of the cross-border area Romania-Bulgaria CBC Project MIS-ETC 171, 2014.
5. Bastian, O. Landscape classification in Saxony (Germany) — a tool for holistic regional planning, Landscape and Urban Planning, Vol. 50, Issues 1–3, 2000, pp. 145-155.
6. Bergstrom, J.C., Goetz, S.J., Shortle, J. S.(eds.) // Land use problems and conflicts: Causes, consequences and solutions. London, New York, 2004, p. 63.
7. Blaskova, D. Climate and microclimate of Sofia / Bulgarian Academy of Sciences, Sofia, 1983, p. 10.
8. Bossard M., Feranec J., Oťaheľ J. CORINE land cover technical guide – Addendum 2000 Technical report, 40. European Environment Agency, 2000, p. 24.http://www.eea.europa.eu/publications/tech40add
9. Comber, A., Fisher, P., Wadsworth, R. What is Land Cover?Environment and Planning B: Planning and Design, Vol. 32, issue 2, 2005, p. 3.
10. Dugord, P., Lauf, S., Schuster, C., & Kleinschmit, B. (2014). Land use patterns, temperature distribution, and potential heat stress risk - The case study Berlin, Germany. Comput. Environ. Urban Syst., 48, pp. 86-98.
11. Eliasson, I., & Svensson, M. (2003). Spatial air temperature variations and urban land use - a statistical approach. Meteorological Applications, 10(2), pp. 135-149.
12. Feranec, J., Szatmári, D., Holec, J., Garaj, M., Kopecká, M., Šťastný, P. Influence of land cover / land use changes on urban heat island: Case study of Bratislava // Inproceedings International Geographical Union Commission on Land Use/Cover Change Asahikawa, 2018, pp. 29-42.
13. GDP, General Development Plan of Sofia Municipality // Directorate of Architecture, Abbreviated report, December, 2009, p. 7.
14. Giuseppe, di E., Pergolini, M., Stazi, F. Numerical assessment of the impact of roof reflectivity and building envelope thermal transmittance on the UHI effect // Energy Procedia Journal, vol. 134, 2017, p. 405.
15. Harmon, J., Anderson, St. The Design and Implementation of Geographic Information Systems publisher: J. Wiley, 2003, p. 88.
16. Hrelev, St., Kalinkov, K. Urbanism, Economical University – Varna, 1999, pp. 1-262.
17. Ivanov, K. Urban mapping of the city of Sofia. Poster. Second CAWRI-BAS Conference "Climate, atmosphere and water resources in the face of climate change", Sofia, 15-16 October 2020.
18. King, R.B. Land cover mapping principles: a return to interpretation fundamentals. International Journal of Remote Sensing 23, 2002, pp. 3525-3545.
19. Liu, J.Y., Zhuang, D.F., Luo, D. and Xiao, X. Land-cover classification of China: integrated analysis of AVHRR imagery and geophysical data. International Journal of Remote Sensing 24, 2003, pp. 2485–500.
20. Nikiforov, Iv., Nikiforova, M. Urban planning in Bulgaria during the XXth and XXIst century, Slavena, 2016, pp. 1-504.
21. Oke, T. R., Mills, G., Christen, A., Voogt, J. A. Urban climates // Cambridge University Press, ISBN: 9781107429536, 2017, pp. 169, 224.
22. Perko, D., Ciglič, R., Hrvatin, M. The usefulness of unsupervised classification methods for landscape typification. Acta geographica Slovenica, 59-2, 2019, pp. 7-26.
23. Petrov, K. Geourbanism and urban development, University of National and World Economy – Sofia, 2015, pp. 1 – 188.
24. Rosina, K., Kopecka, M. (2016): Mapping of urban green spaces using Sentinel-2A data: methodical aspects. Bandrova, T., Konecny, M. (Eds), 6th International conference on cartography and GIS: Proceedings, Vol. 1, 2. Sofia: Bulgarian Cartographic Association, pp. 562–568.
25. Thomas, D. The dictionary of physical geography // 4th edition, John Wiley & Sons, 2016, p. 523.

26. Travaglia, C., Milenova, L., Nedkov, R., Vassilev, V., Milenov, P., Radkov, R., Pironkova, Z. Preparation of Land Cover Database of Bulgaria through Remote Sensing and GIS // working paper 6, FAO, 2001, pp. 1-68.
27. Vatseva, R., Kopecka, M., Otahel, J., Rosina, K., Kitev, A., Genchev, S. (2016): Mapping urban green spaces based on remote sensing data: case studies in Bulgaria and Slovakia. Bandrova, T., Konecny, M. (Eds.): In 6th International conference on cartography and GIS: Proceedings, Vol. 1, 2. Sofia: Bulgarian Cartographic Association, pp. 569–577.
28. Wang M., Xu, H. The impact of building height on urban thermal environment in summer: A case study of Chinese megacities. PLoS ONE 16(4), 2021, p. 7.
29. Wulder, M. A., Coops, N., Roy, D., White, J., Hermosilla, T. Land cover 2.0. International Journal of Remote Sensing, 39:12, 2018, pp. 4254-4284.
30. Xi, C., Ren, C., Wang, J., Feng, Z., Cao, S.-J.Impacts of urban-scale building height diversity on urban climates: A case study of Nanjing, China,Energy and Buildings,Volume 251,2021, p. 2.