Spectral analysis and mapping of unregulated and regulated landfills in Bulgaria

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ABSTRACT

The study of unregulated and regulated (legal and illegal) landfills on the basis satellite and field data allows complex monitoring and analysis of waste sites. This approach combines high-resolution satellite imagery to identify and map landfills with detailed field observations to verify data and assess their condition. This provides up-to-date information on the location, volume and potential impact of landfills on the environment, which is critical for effective waste management and nature conservation.

The study covers examples of different NUTS 2 planning areas (under the Regional Development and Improvement Act) such as South East (BG 41) and South Central (BG 42). The data generated is for a period of at least five years. Regulated landfills are of national importance and selected events from the territory of Bulgaria have been investigated and monitored through a complex approach based on satellite data, Unmanned Aerial Systems (UAS) and ground-based spectrometric equipment, a thermal camera and an Automatic recording weather station (AWG).The optical monitoring indices used are Normalized Difference Vegetation Index (NDVI),Tasseled cap transformation (TCT) and Normalized Differential Greenness Index (NDGI). The satellite data used are Sentinel 2MSI, Landsat 9 (OLI/TIRS), Sentinel 3 SLTRS and Sentinel 1SAR.

The study of landfills based on complex methods of remote sensing and validation of the results through ground data brings significant benefits to the administration, society and NGOs. It facilitates the identification and monitoring of illegal landfills and dumps, supports the planning of cleanup measures and pollution prevention. This improves waste management, protects the environment and ensures a healthier life for people, while reducing costs for society and administration in the long term.

Keywords: Landsat 9 (OLI/TIRS), unregulated landfills, NDGI, TCT, Sentinel 3 SLTRS, SAR, Open data, AWG

1. INTRODUCTION

The main task of the methodology thus created in this study is to support and accelerate the digitization processes in the public sector for the study of climate changes at already built regulated landfills, monitoring and prevention of creation of unregulated landfills by using innovative methods and creating a hybrid model for sustainable development of territories by economic regions (NUTS2).

The state policy for regional development creates conditions for a balanced and sustainable integrated development of regions and municipalities in Bulgaria. It is aimed at reducing interregional and intraregional differences in the degree of development and supporting the process of economic, social and territorial convergence within the European Union (EU)[1].

The main task of the research is, through the demonstrated examples, to support the collection of data and information that are accessible and interoperable with other data and used for the needs of the Ministry of Regional Development and Public Works, the Ministry of Environment and Water, the Ministry of agriculture and forests, National Statistical Institute, Eurostat, and also the local administration of territories.

The methodology makes it possible to support decision-making at an expert level, but also for people in management who are not experts. it supports businesses in building plans and, last but not least, it benefits citizens, administration, science and NGOs.

Through this research, a pilot mapping of NUTS2 has started, which complements information on regulated and unregulated landfills based on satellite data, open data, field survey data (in situ) and drone data.

The NUTS 2021 classification is valid from 1 January 2021 and lists 92 regions at NUTS 1, 242 regions at NUTS 2 and 1166 regions at NUTS 3 level [2].

The regulatory framework in Bulgaria, which determines the main documents used when dealing with the topic of waste and its storage sites, is as follows:

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Law on Waste Management and its by-laws, including:
Ordinance No. H-4 of June 2, 2023 on the conditions and requirements that must be met by waste storage or treatment sites, for the deployment of waste treatment facilities and for the transportation of industrial and hazardous waste;
Ordinance No. 1 of June 4, 2014 on the procedure and samples for providing information on waste activities, as well as the procedure for keeping public registers (last amended on April 10, 2023);
Ordinance No. 2 of July 23, 2014 on waste classification (last amended on July 8, 2022);
Ordinance on the management of construction waste and on the use of recycled construction materials;
Ordinance No. 6 of August 27, 2013 on the conditions and requirements for the construction and operation of landfills and other facilities and installations for the recovery and disposal of waste; and other.
European and global documents, policies and regulations play a key role in waste management and pollution control. They cover a wide range of topics including waste minimization, recycling, landfills and pollution prevention. Here are some of the key documents in this area:

European documents:

Waste Directive (2008/98/EC): A key document that sets out the framework for waste management in the EU. It promotes waste prevention, recycling and the use of waste as a resource, as well as the polluter pays principle.
Landfill Directive (1999/31/EC): Regulates the management of landfills in the EU, including technical requirements and measures to prevent pollution.
Packaging and Packaging Waste Directive (94/62/EC): Deals with reducing the impact of packaging on the environment through recycling and other forms of recovery.

Global documents and initiatives:

Basel Convention: An international treaty that regulates the transboundary movement of hazardous waste and its disposal, with the aim of protecting human health and the environment from the harmful effects of hazardous waste.
Stockholm Convention on Persistent Organic Pollutants (POPs): Aims to eliminate or limit the production, use and release of certain persistent organic pollutants.
The UN Sustainable Development Goals: Includes several goals related to sustainable waste management and pollution reduction, such as Goal 12 on responsible consumption and production, which promotes waste reduction through recycling and reducing landfill waste.
These documents are regularly updated to reflect new scientific findings and trends in waste management and environmental protection. They serve as the basis for national legislation and policies aimed at pollution reduction and improvement.
As plastic use becomes more pervasive in our societies, the environmental drawbacks of plastic pollution are expected to become increasingly unsustainable especially in developing countries. After doubling between 2000 and 2019, global plastics use is projected to nearly triple between 2019 and 2060. While improvements in waste management can mitigate increases in the amount of mismanaged waste, annual plastic leakage to the environment is projected to double by 2060, driven by increasing amounts of leakage in rapidly developing economies. Meanwhile, the stocks of accumulated plastics in water bodies is projected to more than triple by 2060[3].
Eliminating plastic leakage is possible but requires co-ordinated and ambitious global efforts. Combining measures that target all phases of the plastics lifecycle can be effective at eliminating plastic leakage globally by 2060. The Global Ambition policy package developed by the OECD Global Plastics Outlook shows that with adequate measures by 2060 plastic use can decline by 1/3 below the baseline, plastic leakage to the environment can almost completely be eliminated and 60% of plastics can be recycled[4].

1.1. Region of interest

Two areas of interest with regulated landfills, but from two different economic regions, were selected. Unregulated landfills from areas close to the regulated ones, which were formed by illegal dumping of garbage, were also examined.
Two regulated landfills from NUTS2 with number BG41 and BG42 from the administrative municipalities of Pernik and Plovdiv and several unregulated landfills near the sites were examined (fig.1).
The Pernik landfill (fig. 2) was designed and built for the purpose of depositing dry solid and/or powder hazardous and non-hazardous waste, mainly waste from ferrous and non-ferrous metallurgy, waste from thermal processes, from surface chemical, physical and mechanical processes, construction waste and waste from the demolition of buildings, contaminated soils, etc.
According to the Law on Waste Management, landfilling is a method in which no subsequent treatment of waste is provided for and it represents storage of waste for a period longer than three years for waste intended for recovery, and one year for waste , intended for disposal, in a way that doesn't pose a danger to human health and the environment.

Figure 1 Maps of NUTS 2 in Bulgaria[1]

Only solid (including powdery), stabilized waste from the Bulgarian industry is accepted at the landfill after its preliminary treatment/stabilization and characterization in accordance with the requirements of Ordinance No. 6/27.08.2013 on the construction and operation of landfills and other facilities and installations for recovery and disposal of waste, and meet the criteria specified in Appendix No. 1 of the cited Ordinance on eligibility for disposal of the relevant class of landfill, Ordinance No. 2/23.07.2014 on waste classification, the Waste Management Act, Guidance for preliminary treatment before waste disposal in Bulgaria (confirmed by Order No. RD – 664 of 29.08.2014 of the Minister of Environment and Water),Guide for carrying out the basic characterization of waste and applying the criteria for acceptance of waste at different classes of landfills (approved by Order No. RD - 156 of 04.03.2015 of the Minister of Environment and Water), as well as according to the Complex Permit for Operation at the depot.

The waste subject to disposal should be delivered by specialized transport, suitably packaged and accompanied by a Waste Classification Worksheet, a Protocol from an accredited laboratory for its characterization and eligibility for disposal, a Basic Characterization Report and all other permits according to National environmental legislation[5].

Figure 2 Regulated and unregulated landfills in Pernik, GPS data. Source: Google Earth[6]

Plovdiv generates over 160,000 tons of waste per year, and the capacity of the plant in Shishmantsi is to process 125,000 tons. This makes it necessary to seek a solution by extending the complex permit for the landfill in Tsalapitsa and to continue depositing part of the waste there[7].

The management and operation of the landfill in Tsalapitsa (fig. 3) is entrusted to Plovdiv, although it is located on the territory of the "Rodopi" Municipality. The facility requires special attention because it is located only meters from the Maritsa river, as well as near the two settlements of Kadievo and Tsalapitsa[7].

For this purpose, the Municipality of Plovdiv has identified three strategic measures with which the life of the landfill in Tsalapitsa can be extended without endangering the ecology of the area. One of them is the construction of a retaining wall, since the facility is located near the Maritsa River and the goal is to prevent landslides in the river bed. Joint actions have been agreed with the Agricultural Academy. Tests are already being made of treatment with a special bioproduct, in which the volume of organic waste is reduced by more than 10%. Last but not least, the installation of a separation line is planned to separate and sort the waste on site. Thus, the total amount of garbage that will actually be deposited in the hollows will be significantly reduced[7].

Figure 3 Regulated and unregulated landfills in Tsalapiza, Plovdiv, GPS data. Source: Google Earth[6]

2. DATA AND METHODS

Methods

The landfill monitoring methodology involves the analysis of satellite images to identify potential landfills and subsequent ground inspections to confirm and evaluate in detail the sites discovered. GIS technologies are used for data analysis and visualization. This approach enables rapid and comprehensive mapping of unregulated and regulated landfills, supporting management and regulatory decision-making.
The description of the hybrid model includes the elements of the complex approach, which were detailed in Figure 4.

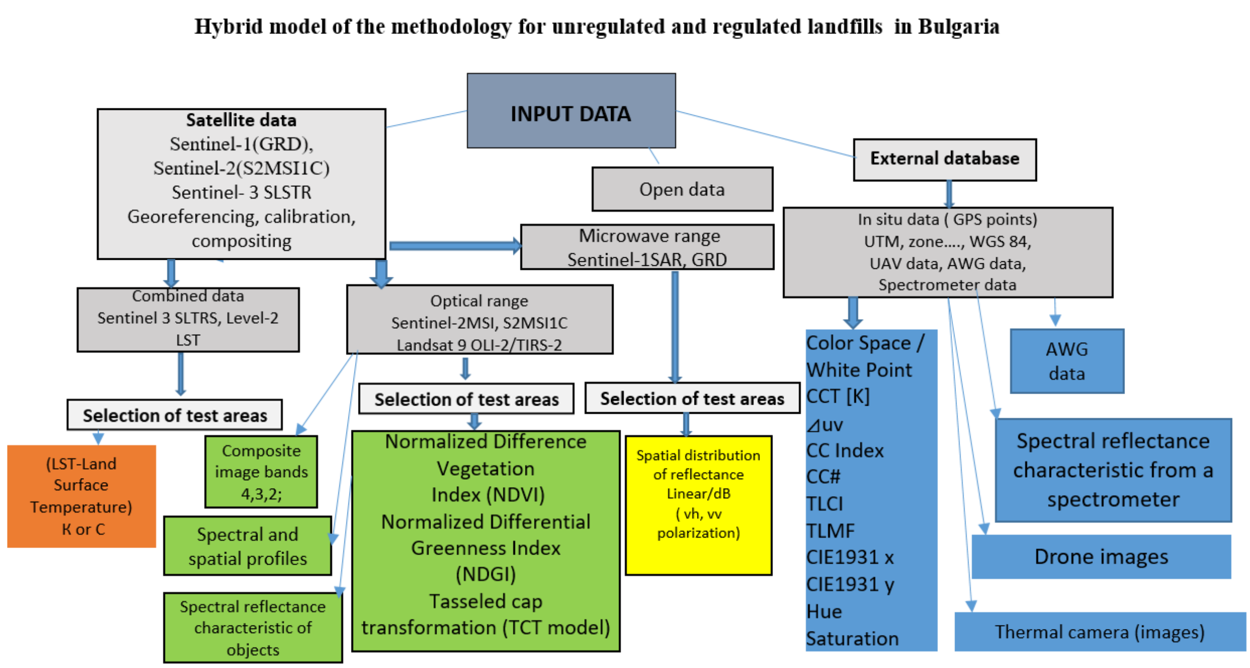


Figure 4 Hybrid model of the methodology for unregulated and regulated landfills in Bulgaria

Data

Satellite data

The satellite data used in the study are from the Sentinel-2-B, Sentinel 3A and Sentinel 3B satellites of the European Space Agency (ESA)[8, 9, 10] Landsat 8 OLI/TIRS and Landsat 9 OLI-2/TIRS-2of the NASA[11] with 30-meter resolution about once every two weeks, including multispectral and thermal data[12] .
Sentinel-2B is a Multi-Spectral Instrument (MSI)[13] recording data in the optical range with different spectral resolutions. Data by dates and satellites used are represented in table 1. The data from Sentinel 3 are from the month of July for the period from 2018 to 2023. The data are from the two satellites S3A and S3B. Sentinel 3 SLSTR Level-2 LST provides land surface parameters at 1 km resolution. In addition, the file is measured with the Land Surface Temperature (LST)[10] value calculated and specified for each pixel (table 1).

Table 1 Satellite images acquisition dates

Satellite	Date	Satellite	Date
Sentinel-2 MSI	**Pernik** **S2A_22/07/2022** **S2A_30/09/2022** **Tsalapiza, Plovdiv** **S2A_19/07/2020** **S2B_24/07/2022** **S2A_29/07/2022** **S2B_25/09/2022** **S2A_07/09/2022** **S2B_14/07/2022**	**Sentinel 3A** **Sentinel 3B**	**the whole** **month of July 2018 to 2023** **LST** **Land Surface Temperature**
Landsat 9 OLI-2/TIRS-2	**11/07/2022** **04/07/2022**	**Sentinel 1A SAR**	**21/07/2023** **28/07/2023**

Landsat 8 and Landsat 9 are Earth observation satellites operated by NASA and the US Geological Survey (USGS) as part of the Landsat program. These satellites play a crucial role in monitoring and studying various aspects of the Earth's surface, including land use, natural resources, environmental changes, and urban development. The two main sensors for Landsat 8 are the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The Operational Land Imager (OLI) produces 9 spectral bands (Band 1 to 9) at 15, 30, and 60-meter resolution. OLI images can discriminate vegetation types, cultural features, biomass, vigor, etc. Then, the Thermal Infrared Sensor (TIRS) consists of 2 thermal bands with a spatial resolution of 100 meters. TIRS measures Earth’s thermal energy particularly useful for tracking how land and water are being used. Landsat 8 also has a panchromatic band that provides higher spatial resolution imagery suitable for various applications, including urban planning and disaster monitoring[11, 14].
The spectral bands of Landsat 9 are similar to Landsat 8, ensuring continuity in data collection and compatibility with historical Landsat datasets[14].
Data from Sentinel-1-A Synthetic Aperture Radar (SAR) is useful for further verification of the area of interest. vv and vh polarization were used. Data by dates are represented in table 1. GRDH format is used, with the wavelength is λ=5,6cm.

Thermal camera data

Two types of thermal cameras were used (fig.5, 6, 7):

- Thermal Camera HT-19 has an IR image resolution of 320x240 and a temperature range of -20°C to 300°C with Measurement accuracy of +/-2°C, 5 types of color palettes and wavelength 8 - 14 μm.
- Thermal camera FLIR to connect to mobile devices phone CAT 62S Pro with: Display infrared (IR), visible and MSX (Multi Spectral Dynamic Imaging), extremely detailed data of the thermal image of the image can be seen; VividIR advanced image processing technology; Thermal sensor with a resolution of 160 × 120 (19,200 points), Temperature measurement range from -20°C to 400°C and accuracy ±3°C or 5% of reading Thermal sensitivity <0.15 °C, Lens surround angle 55 ° × 43 °, Minimum resolution 0.15 m.

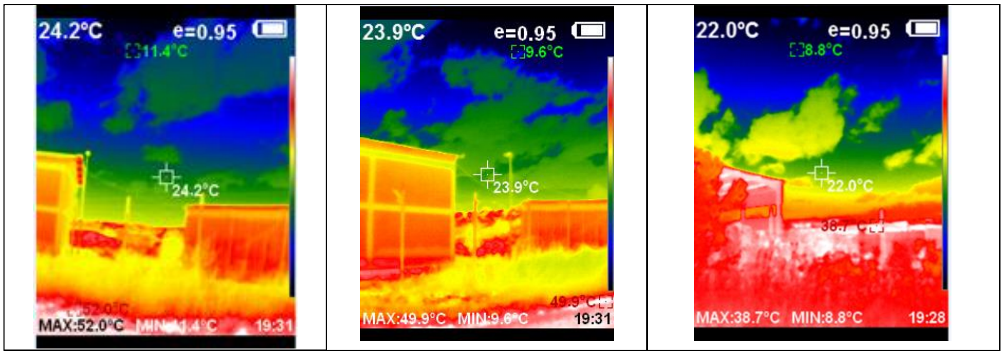
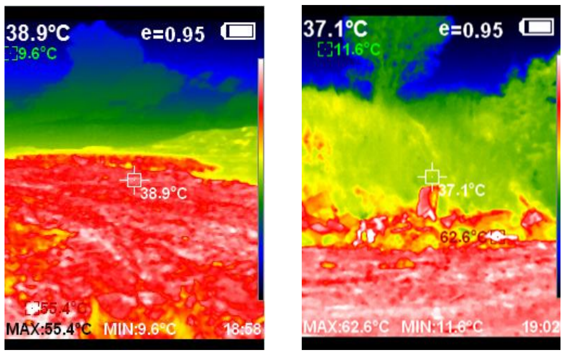


Figure 5 Regulated landfill in Pernik, Thermal Camera HT-19



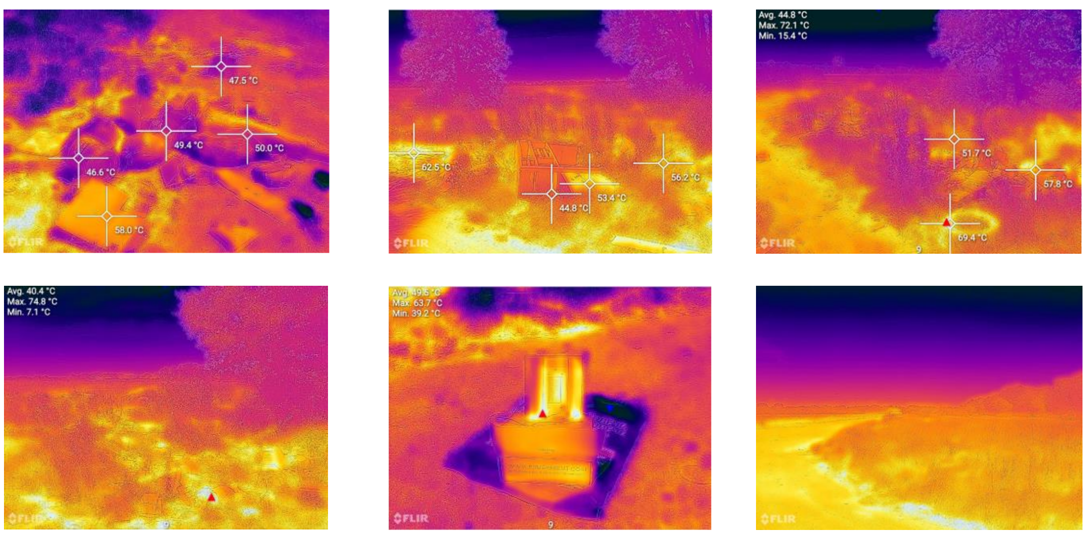


Figure 6 Unregulated landfill in Pernik, Thermal Camera HT-19

Figure 7 Unregulated landfill in Tsalapiza (Plovdiv), Thermal camera FLIR

Drone data

A DJI Fly drone was used to make a photogrammetric model with a resolution of 1 m. The drone photography was used to correctly verify the environment, in which the experiment was made and for the hybrid model. The Drone images are from the days of field measurements 22/07/2023 and 29/07/2023 (fig. 8 a, b).

a) Regulated landfill in Pernik

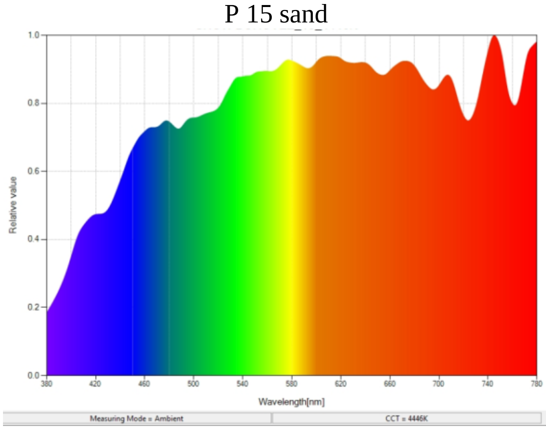
b) Regulated landfill in Tsalapiza (Plovdiv)

Figure 8a, b Photogrammetry of a drone image, Area of interest in Pernik and Tsalapiza (Plovdiv), Author: Adlin Dancheva and Temenuzhka Spasova

Spectrometer data

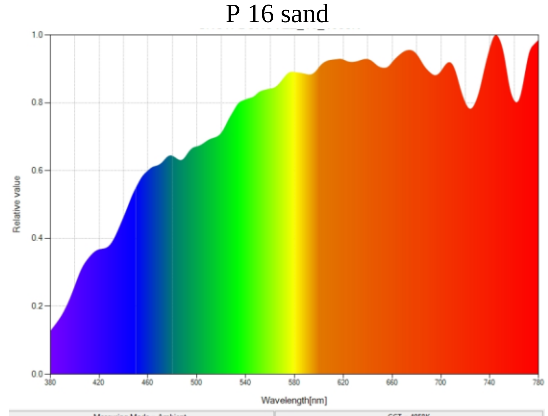
The field spectral surveys were performed using a spectrometer in the visible range (Sekonic Spectrometer C-800), a full-spectrum color meter that can accurately measure any type of light. The data from the spectrometer is with the following parameters: Color temperature, CCT (Correlated Color Temperature), Δuv (Deviation) between the correlated color temperature and the place of emission of the black body, Hue (in degrees), Sat – Saturation is the index to express the intensity or chroma. Using these data, a study of the color characteristics of the objects was conducted. For each spectral reflectance characteristic (SRC), the color characteristics (color coordinates (x,y) and dominant wavelength) in the spectral range 380-780 nm were calculated relative to CIE 1931 and a standard source of electromagnetic radiation[15,16].

P 15 sand



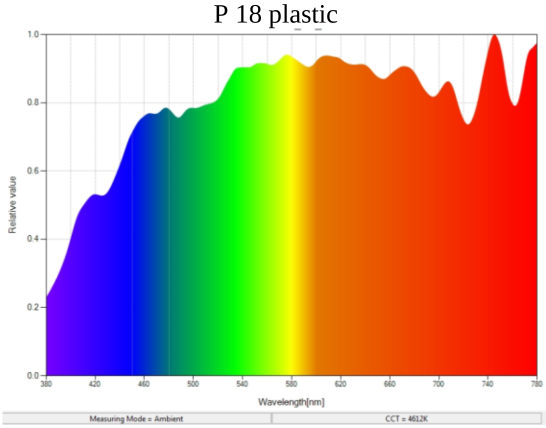
Title, sand _15_4446K
CCT [K],4446
⊿uv,0.0010
CIE1931 x,0.3631
CIE1931 y,0.3673
Hue, 39deg
Saturation,35%

P 16 sand



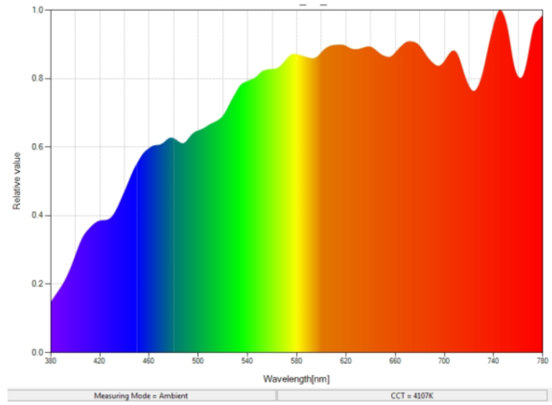
Title, sand _16_4058K
CCT [K],4058
⊿uv,0.0009
CIE1931 x,0.3785
CIE1931 y,0.3775
Hue, 39deg
Saturation,45%

P 18 plastic



Title, plastic_18_4612K
CCT [K],4612
⊿uv,0.0010
CIE1931 x,0.3573
CIE1931 y,0.3631
Hue, 40deg
Saturation,32%

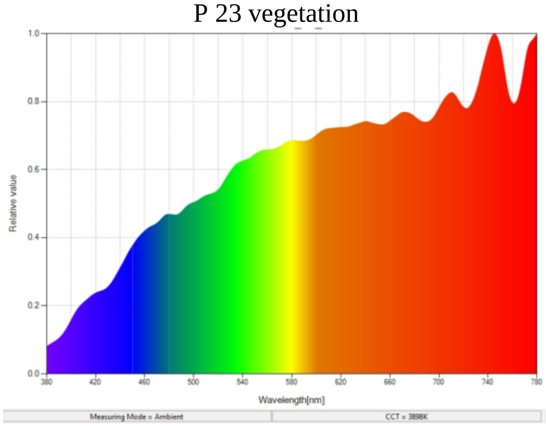
P 20 soil



Title, soil _20_4107K
CCT [K],4107
⊿uv,0.0006
CIE1931 x,0.3762
CIE1931 y,0.3753
Hue, 38deg
Saturation,44%

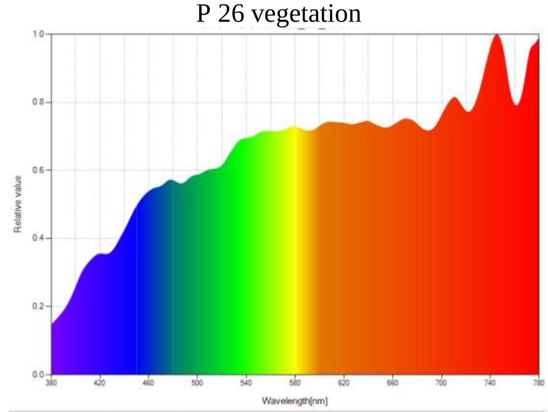
Figure 9 Spectrometer data, 22/07/2023, Pernik

P 23 vegetation



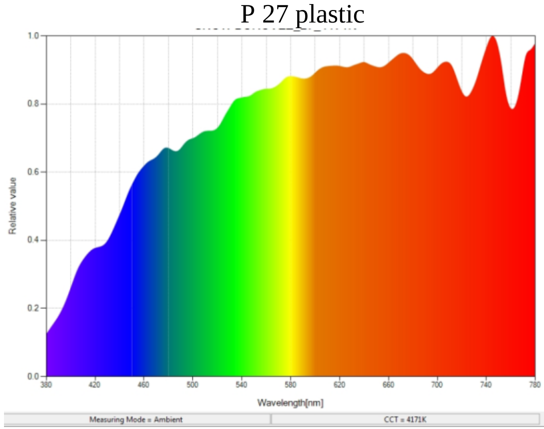
Title, vegetation_23_3898K
CCT [K],3898
⊿uv,0.0027
CIE1931 x,0.3872
CIE1931 y,0.3868
Hue, 40deg
Saturation,52%

P 26 vegetation



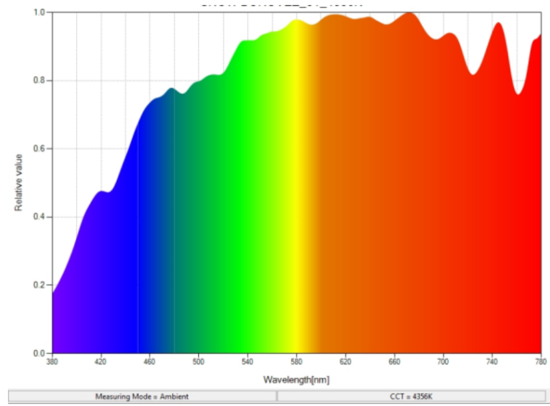
Title, vegetation _26_4334K
CCT [K],4334
⊿uv,0.0018
CIE1931 x,0.3677
CIE1931 y,0.3722
Hue, 40deg
Saturation,39%

P 27 plastic



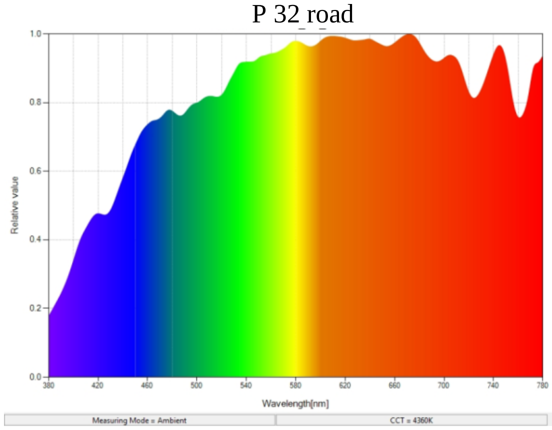
Title, plastic_27_4171K
CCT [K],4171
⊿uv,0.0015
CIE1931 x,0.3741
CIE1931 y,0.3760
Hue, 40deg
Saturation,43%

P 31 road



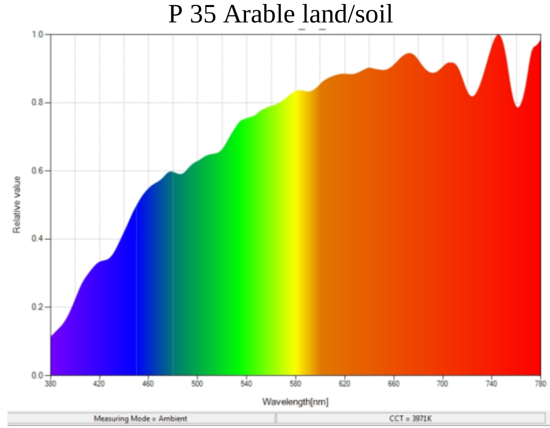
Title, road _31_4356K
CCT [K],4356
⊿uv,0.0012
CIE1931 x,0.3666
CIE1931 y,0.3702
Hue, 40deg
Saturation,38%

P 32 road



Title, road_32_4360K
CCT [K],4360
⊿uv,0.0012
CIE1931 x,0.3664
CIE1931 y,0.3700
Hue, 40deg
Saturation,38%

P 35 Arable land/soil



Title, Arable land/soil_35_3971K
CCT [K],3971
⊿uv,0.0005
CIE1931 x,0.3821
CIE1931 y,0.3790
Hue, 38deg
Saturation,47%

Figure 10 Spectrometer data, 29/07/2023, Tsalapiza (Plovdiv)

Automatic recording weather station (AWG) and Ground Control points (GCP)

For the purpose of the study, the following Ground Control Point (GCP) locations were generated and applied: 5 GCP, generated on 22/07/2023, and 3 GCP – on 29/07/2023. The points were generated via OruxMap in offline mode (table 2).

Table 2 Ground Control Point (GCP), OruxMap[17].

GPS	Latitude	Longitude	Date
1	**42.56878˚N**	**23.15718˚E**	**22/07/2023**
2	**42.63726˚N**	**23.10485˚E**	**22/07/2023**
3	**42.63055˚N**	**23.08356˚E**	**29/07/2023**
4	**42.14878˚N**	**24.58636˚E**	**29/07/2023**
5	**42.14890˚N**	**24.58661˚E**	**29/07/2023**

Another type of data, which at this stage is part of the catalogue, was derived from the Automatic recording weather station (AWG), fig.11, presented in detail in table 3. The data were generated from an in situ study done by Iliyan Popov and Boris Shirov by OXYMET [18, 19, 20, 21].

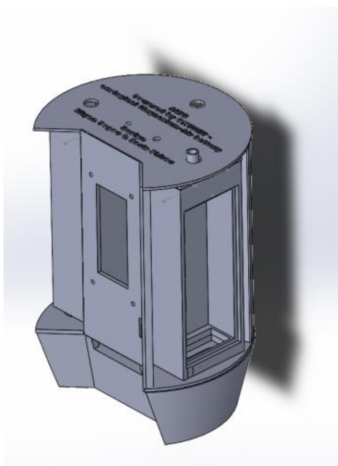



Figure 11 AWG with Environmental battery [18,19,20,21]

Table 3 Raw Data from Automatic recording weather station (AWG), an Ecological Magnesium-Air battery[21]

	Date	Time UTC	GPS La	GPS Long	GPS Alt	Sattelite	Luminanc	UV Ir	Barometric	Temp	Altitude	Atitud	Humic
2	7/29/2023	10:56:33 AM	42.14873	24.586339	172.5	12	96	0	1008.33	27	41.04	3.73	33.1
3	7/29/2023	10:56:54 AM	42.14873	24.586336	172.8	12	96	0	1008.81	28	37.03	6.76	33.2
4	7/29/2023	10:57:15 AM	42.14873	24.586338	172.2	12	95	0	1008.72	29	37.78	9.58	33.3
5	7/29/2023	10:57:36 AM	42.14873	24.586338	172.1	12	95	0	1008.7	29	37.95	12.16	33.4
6	7/29/2023	10:57:57 AM	42.14873	24.586336	173.5	12	95	0	1008.67	28	38.2	14.53	33.5
7	7/29/2023	10:58:18 AM	42.14872	24.58633	174	12	94	0	1008.67	27	38.2	16.68	33.5
8	7/29/2023	10:58:39 AM	42.14872	24.586336	174.7	12	95	0	1008.66	28	38.29	18.64	33.6
9	7/29/2023	10:59:00 AM	42.14871	24.586339	176.2	12	96	0	1008.67	27	38.2	20.42	33.6
10	7/29/2023	10:59:21 AM	42.14871	24.586341	176.8	12	95	0	1008.67	28	38.2	22.04	33.6
11	7/29/2023	10:59:42 AM	42.14871	24.586341	175.9	12	91	0	1008.66	28	38.29	23.51	33.7
12	7/29/2023	11:00:03 AM	42.14875	24.586481	176.6	12	95	0	1008.61	29	38.7	24.9	33.8
13	7/29/2023	11:00:24 AM	42.14874	24.586328	175.6	12	95	0	1008.69	28	38.04	26.09	33.9
14	7/29/2023	11:00:45 AM	42.14861	24.586172	176.9	12	96	0	1009.04	26	35.11	26.91	33.9
15	7/29/2023	11:01:06 AM	42.1486	24.586154	176.6	12	99	0	1009.24	27	33.44	27.5	33.9
16	7/29/2023	11:01:27 AM	42.1486	24.586158	176.6	12	99	5	1009.13	27	34.36	28.13	34.2
17	7/29/2023	11:01:48 AM	42.14861	24.586164	175.8	12	99	2	1008.84	27	36.78	28.91	34.4
18	7/29/2023	11:02:09 AM	42.1486	24.586166	176	12	99	4	1008.42	27	40.29	29.95	34.8
19	7/29/2023	11:02:30 AM	42.1486	24.586168	175.1	12	99	4	1008.14	26	42.63	31.1	35.1
20	7/29/2023	11:02:51 AM	42.14861	24.586177	175.1	12	99	4	1007.66	26	46.64	32.51	35.6
21	7/29/2023	11:03:12 AM	42.14862	24.586177	176.7	12	99	4	1007.21	26	50.41	34.14	36
22	7/29/2023	11:03:33 AM	42.14862	24.58617	176.3	12	99	4	1006.6	26	55.51	36.08	36.5
23	7/29/2023	11:03:54 AM	42.14862	24.586183	174	12	96	4	1006.18	25	59.03	38.17	37

Open data

In the study, a test field study was done by AWG only in the area of Tsalapitsa, Plovdiv. For the needs of the experience, the data has been validated by national monitoring stations.
Open data from the nearest monitoring stations in Pernik of the Executive Environment Agency in Bulgaria were used. The data are from the System for informing the population about the quality of atmospheric air[22] and from the Open Data Portal in Bulgaria[23].
On the day of the field research in Pernik and Plovdiv, the data are as follows (fig. 12, 13).

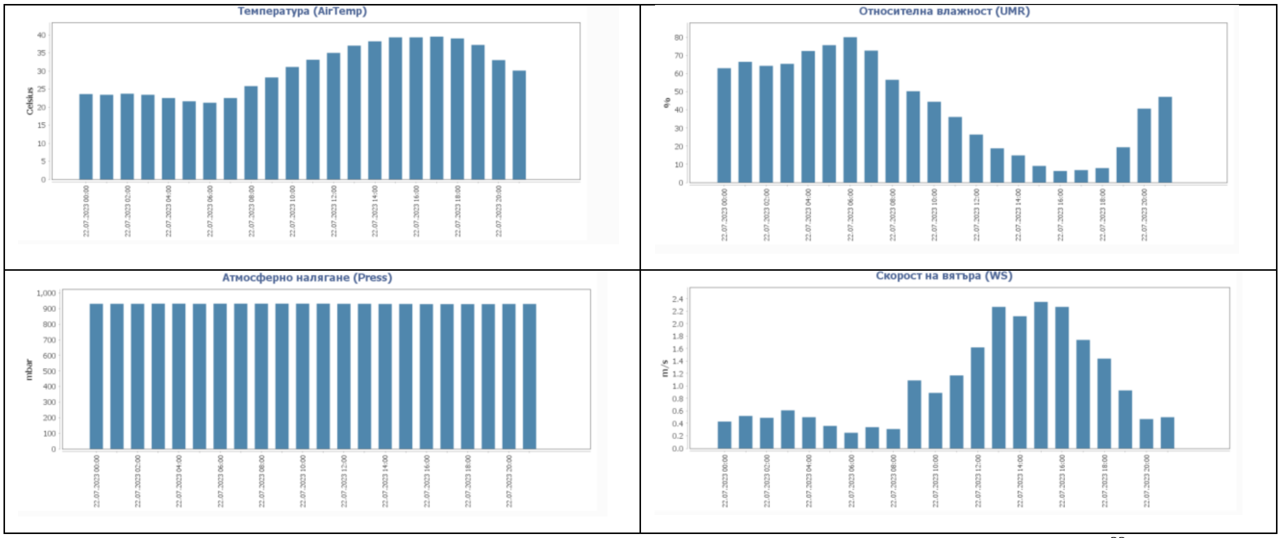


Figure 12 Monitoring parameters, Pernik - AIS Center, Longitude: 23.032191, Latitude: 42.610335[22]

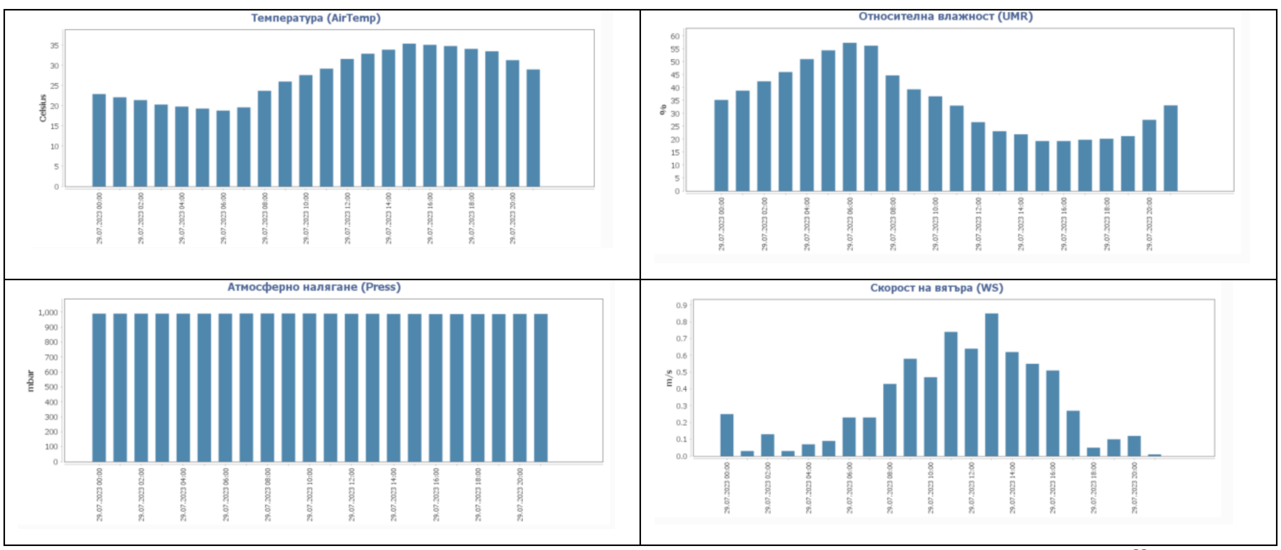


Figure 13 Monitoring parameters, Plovdiv - AIS Kamenitsa Longitude: 24.765239, Latitude: 42.142889[22]

2.2.1. Data processing of satellite images

Multiband composite images were created by combining the available channels for Sentinel 2MSI, Landsat 8 and Landsat 9 satellite images. These images were essential for subsequent analysis and processing, as they allowed for the extraction of indices values[24, 25, 26]. Thus, the territories of regulated, unregulated landfills and the territories around them are visualized and suitable for subsequent processing.

2.2.2. Index classification

Index classification from satellite images was applied for analyzing the spectral characteristics of satellite imagery, with the aim of identifying and mapping certain features or properties on the Earth's surface. This involves the calculation of various spectral indices, which are derived from the reflectance values of different bands of the satellite imagery. These indices were used to highlight specific features, such as vegetation density, water content, soil moisture, which can be used for various applications[24] including environmental monitoring and management of wetlands. Index classification from satellite images can be performed using various software tools and techniques, including remote sensing software, machine learning algorithms, and image processing techniques[24].

For the purposes of this research, the following indices were used (table 4):

Table 4 Calculation formulas and description of the optical indices used in the study

Index	Formula	References
NDVI Normalized Difference Vegetation Index	$\frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$	Rouse et al. (1973)[27] NDVI is the most widely used spectral index for vegetation monitoring and evaluation of the photosynthetic activity. NDVI is strongly correlated with climate variations and can serve as an effective measure of climate-related vegetation changes
TCT Tasseled cap transformation Kauth-Thomas Transformation	Brightness, Greenness, Wetness	Kauth and Thomas (1976)[28]; Crist and Cicone (1984)[29]
NDGI Normalized Differential Greenness Index	$NDGI = \frac{GR_n(t_2) - GR_n(t_1)}{\lvert GR_n(t_2)\rvert + \lvert GR_n(t_1)\rvert}$	Nedkov (2017)[30]; NDGI estimates slight positive and negative changes in the vegetation green mass for a given period. NDGI ranges from +1 to −1, as NDGI < 0 indicates a negative change, and NDGI > 0 indicates a positive change.

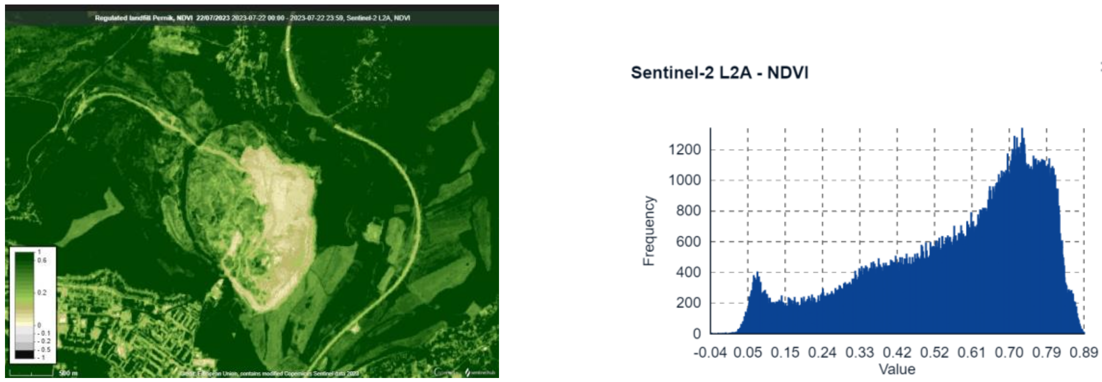
NDVI has been the most widely used spectral index for vegetation monitoring and evaluation of the photosynthetic activity of the crops. NDVI corresponds to the differential response of chlorophyll absorption and internal spongy mesophyll layer reflectance from plant leaves in the visible red and NIR regions. It has been found that NDVI fluctuations over time are strongly correlated with climate variations and can serve as an effective measure of climate-related vegetation changes [21].

Furthermore, changes in NDVI values correlate with the NDGI and TCT model[30], which were selected for this study.

In present study, we used TCT matrix proposed by involving all spectral bands of the Sentinel-2 sensor. Utilization of all spectral information increases significantly the degree of identification of the three main components of the Earth's surface - soil, vegetation and moisture[21]. The outputs from TCT are multi-band images containing three layers – Wetness (TCW), Brightness (TCB), and Greenness (TCG). After their generation, decomposition on each of them is being applied. The next step is the calculation of the Wetness component[21].

NDGI Normalized Differential Greenness Index (NDGI)[31] is an index for assessing the dynamics of vegetation. The NDGI index is derived from the Greenness component from orthogonal image transformation (TCT). Satellite images from Sentinel 2 were used. The approach to define NDGI is based on orthogonalization of satellite images using the Greenness component is based on the spectral reflection characteristics of vegetation. NDGI indicates the dynamics of the change in the state of vegetation using different time periods. NDGI ranges from +1 to -1 and is applicable to assess the development of the vegetation process[21].

Calculated NDVI for the two areas of interest (AOI) from the Copernicus Data Space Ecosystem page[8] (fig. 14) in the form of open data and information was used.



a) Regulated landfill in Pernik, 22/07/2023

b) Regulated landfill in Tsalapiza (Plovdiv),29/07/2023

Figure 14 a, b Normalized Difference Vegetation Index, Copernicus Data Space Ecosystem[9]

3. RESULTS

From the maps and LST data (fig.15) for a five-year period (only from the month of July) and from the field research days, it is clear that the areas of interest aren′t in populated areas, but fall in places where temperatures are higher for morning and evening images. Areas can clearly be defined as falling into heat islands for both examples. It can be seen that around the landfills, despite the presence of vegetation and forests, values for the landfill in Pernik above 36 °C are observed for 22/07/2023 according to LST data (fig. 15 a, b), which can also be confirmed by the open data of the the Executive Environment Agency stations (fig. 12).

The thermal camera data taken for both areas of interest in the middle of the day (fig. 5, 6, 7) completely match the Sentinel 3 data, which have a resolution of 1 km. For each of the captured thermal camera images for the area of the regulated landfill in the Pernik region, mean and maximum values close to those of Sentinel 3, which have already been studied in detail in a previous study by the authors[21], are observed. Much of the garbage is covered with soil or sand, and another part is baled and covered with equipment to keep out direct sunlight. This is not the case with the open and unregulated landfills (fig. 6, 7), where temperatures above 55-60°C were measured at individual sites.

For the territory around the unregulated landfills of Tsalapiza (Plovdiv), the temperature from the thermal camera (fig. 7) is even higher, but also much more accurate due to the specifics of the FLIR camera model. Individual objects have a temperature of 72 to 74°C, the average temperature from the thermal camera is 37-38°C.

The LST of 29/07/2022 is also characterized by high values and in places in the Plovdiv region it reaches values above 50°C (fig. 15 c). It is natural that these values can be confirmed by the field research, which was carried out on one of the hottest days for Bulgaria.

These temperatures in the area are combined with the low air humidity (fig. 12, 13, table. 3, Open data) as in field survey hours when values were around 30% and low wind speed further contributed to the strong odor in the area of the two landfills.

Most of the Plovdiv region falls into a heat island according to LST data (fig. 15c, the evening values are also high and are above 20-25°C for both areas (fig. 15b, d).

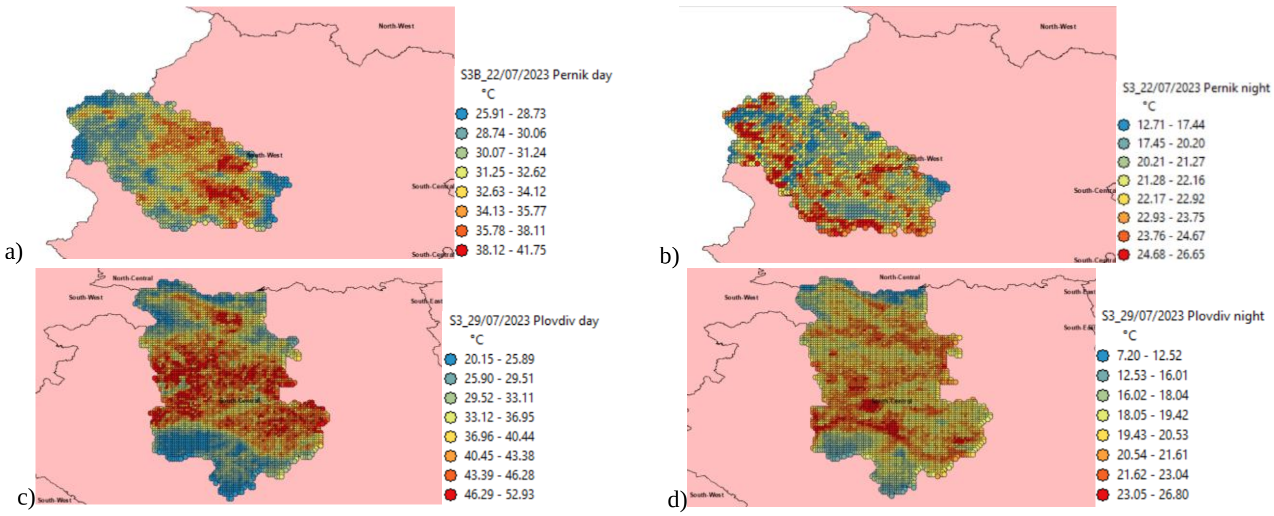
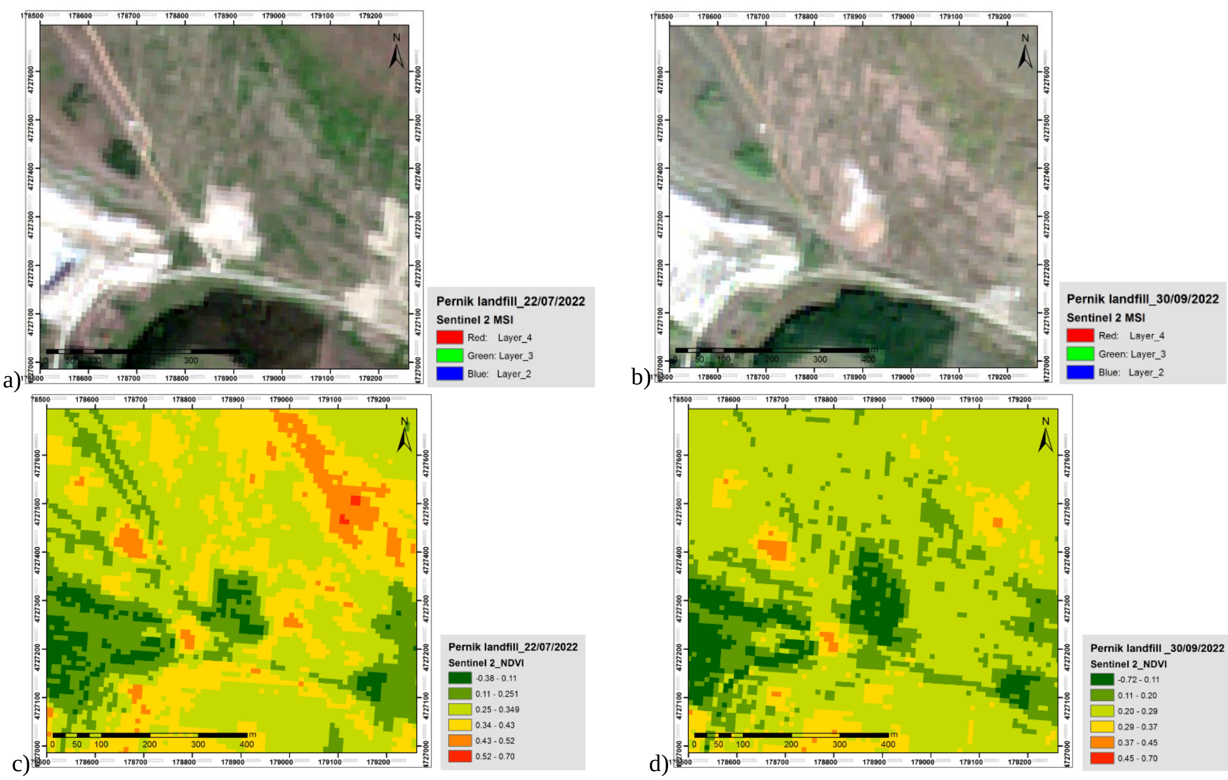


Figure15 LST, Pernik a, b and Plovdiv c, d, Sentinel 3SLTRS



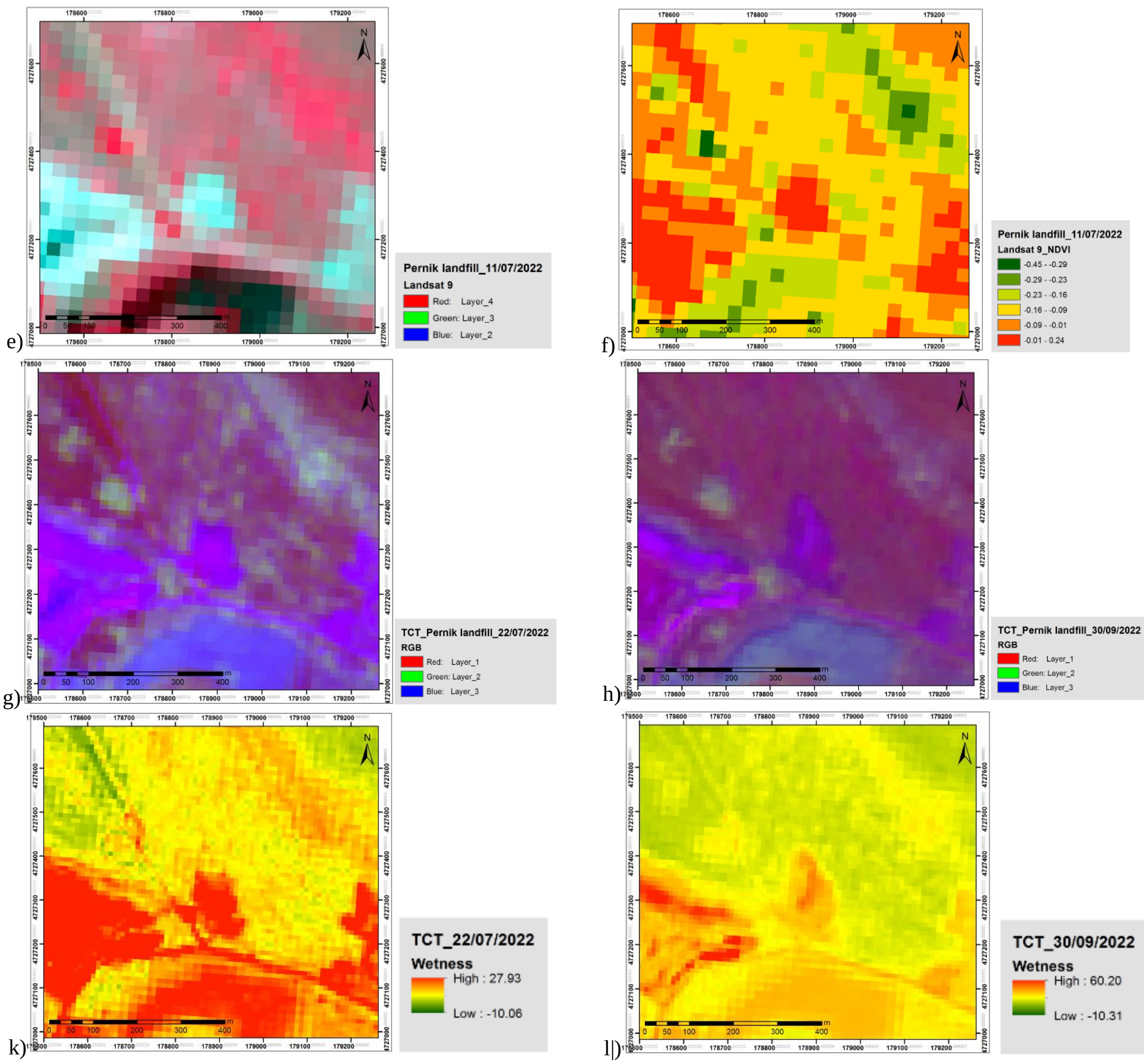


Figure 16 Optical data and indices, Sentinel 2 and Landsat 9, Pernik landfill

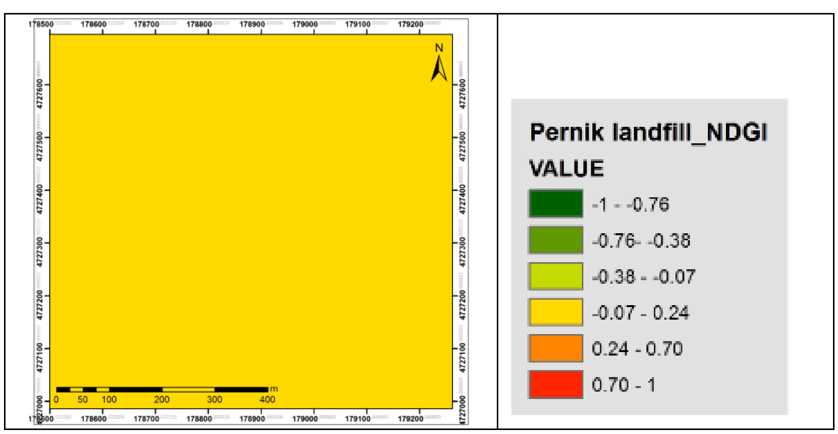


Figure 17 NDGI (Normalized Differential Greenness Index), Pernik landfill

Regarding the data of Sentinel 2 and Landsat 9, it is clearly noticeable that in the area of the landfill in Pernik, the NDVI values from the summer and autumn seasons in 2022 doesn′t exceed zero or are no more than + 0.2 (fig. 16 c, d, f). Open data from the Copernicus program for 2023 (fig. 14) were also used for validation, although they have a lower resolution than the one shown in figure 16 c, d, f.

There is no arable land in the area of the Pernik landfill or near it, which is exactly the opposite for the landfill in the Tsalapitza area of Plovdiv region (fig. 14b, 18c, d,).

NDVI values around zero (0) are typical for the territory of the landfill in Tsalapitza. In places, the value reaches below zero (0). From the NDVI values for the Tsalapitza landfill (fig. 14 b) from 29/07/2023, when a field survey (in situ) was also carried out, the values are around 0 (zero) and close to 1 (one).

This is due to facts (drone image (fig 8b) that a pipe is located on the landfill site, which is periodically used to irrigate the landfill. On the field survey day at around 14:00, a fire was noticed (fig 8b), which was extinguished immediately and therefore traces of water or other liquid are present.

Unlike the landfill in Pernik, the landfill in Tsalapitza is surrounded by plowed and cultivated land (fig.8b, 14b).

The TCT performed on the images from the landfill in Pernik show drastic differences between July and September, and the most indicative of this are the values of the Wetness component (fig. 16 k, l). September values almost doubled in places.

For Tsalapitza, the Wetness values (fig.18f of 24/07/2022) are high only in the places that are certain to be occupied by water, including the landfill, as it is constantly flooded.

The NDGI calculated for the two territories is characterized by low change values, which indicates slight and almost insignificant changes in the territories of the selected two pairs of images on which TCT was performed, especially for Pernik (fig. 17, 19.)

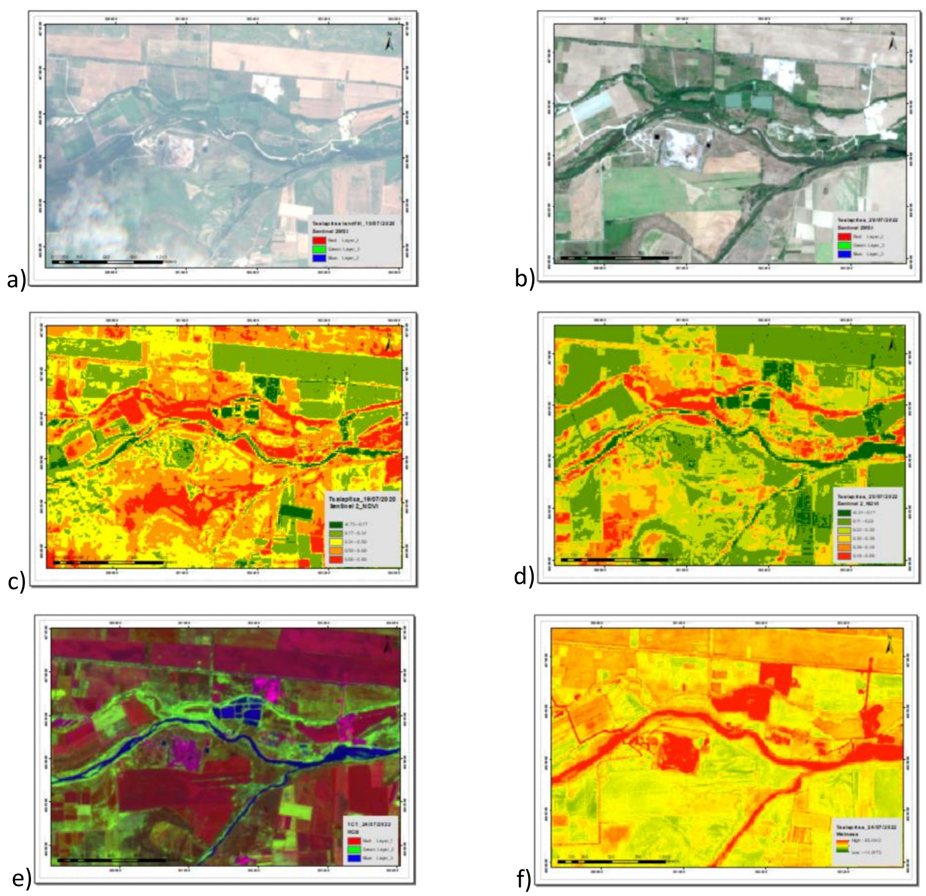


Figure 18 Optical data and indices, Sentinel 2 and Landsat 9, Tsalapiza (Plovdiv) landfill

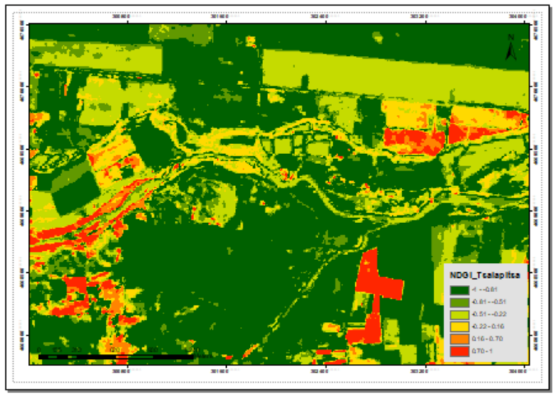
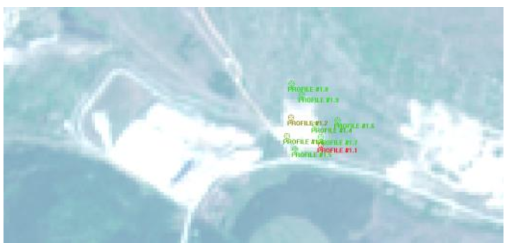
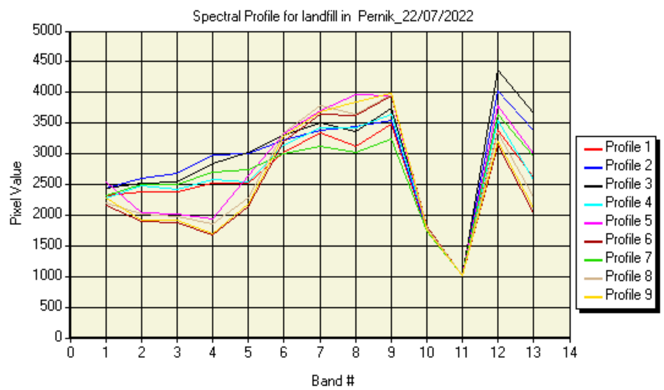
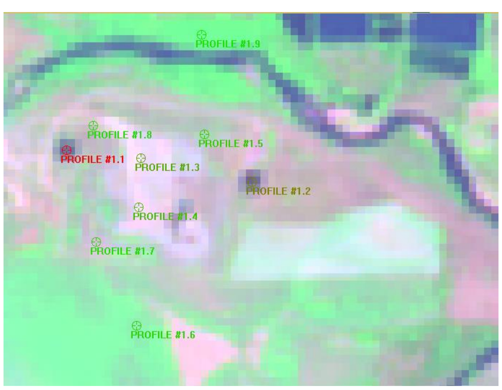


Figure 19 NDGI (Normalized Differential Greenness Index), Tsalapiza (Plovdiv) landfill



a) Sentinel 2MSI, 22/07/2022, bands 4, 3, 2; Pernik landfill





b) Sentinel 2MSI, 24/07/2022; bands:12,8a,4; Tsalapiza (Plovdiv) landfill

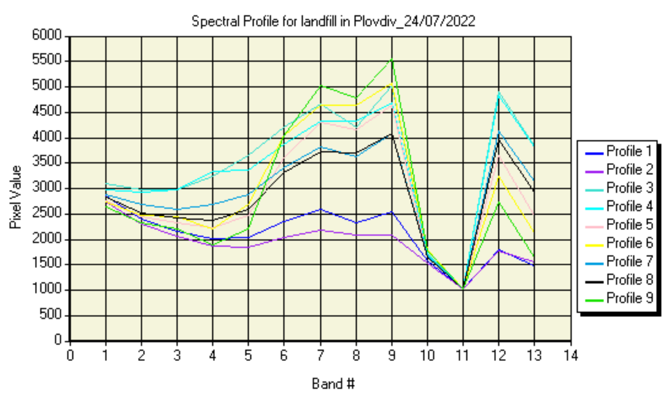


Figure 20 a, b Spectral reflectance characteristics, Pernik landfill and Tsalapiza (Plovdiv) landfill

The spectral profiles of the two objects from the hybrid model are extremely similar. The spectral curves from the Pernik landfill (fig. 20 a) are from objects that are from the site itself and represent plastic garbage, plastic bags and car tires (profile 7) in the southeastern part of the landfill (fig. 20 a), profile 9 is of plastic bags (north-eastern part).

The spectral profiles from the landfill in Tsalapitza (fig. 20 b) also include spectral reflectance curves of water (profile 1, 2) in blue and purple, and vegetation (profile 6 and 9) in yellow and green.

Vegetation profiles are clearly visible, as the curves in band 8a (in the graph is band 9) have the highest curve due to the presence of chlorophyll. The spectral reflecance curves of water are from the two water pools on the territory of the site with garbage. The rest of the profiles resemble the profiles from the landfill in Pernik.
And since field spectral profiles were also made by mobile spectrometer (fig. 9, 10), they were compared with those from the optical images. Field profiles are actually from small local dumps, but in the visible range they have similar spectral reflectance characteristics.
Saturation determines the brightness and intensity of the color, and for the selected objects these values are high and vary from 35 to 52%.
Characteristic of the regions is the presence of high values of color temperature, which means values above 3500 K, and it is a guarantee that the source of light is the Sun.
Hue as one of the main properties (called color appearance parameters) of color is also characterized by high values for objects and is from 38 to 40 deg.

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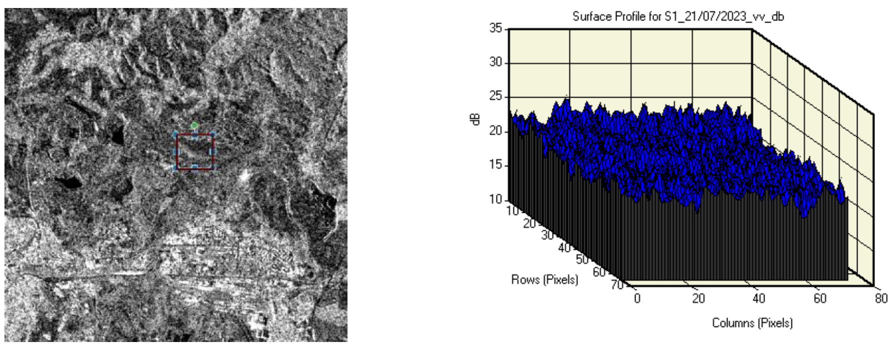
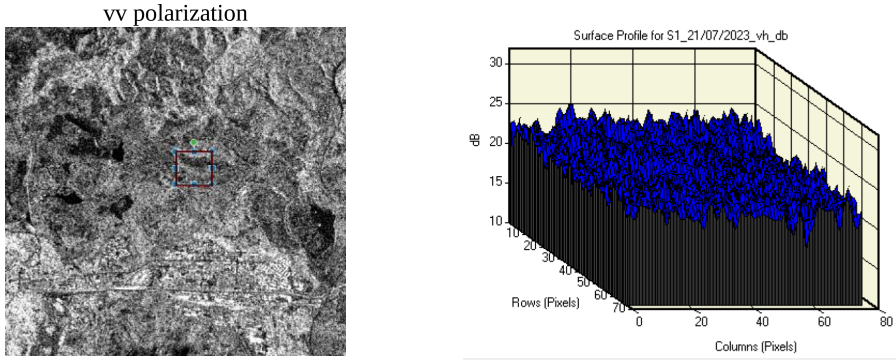


vv polarization



vh polarization

Figure 21 SAR images and Surface profiles, Pernik landfill, 21/07/2023, Sentinel 1A, dB

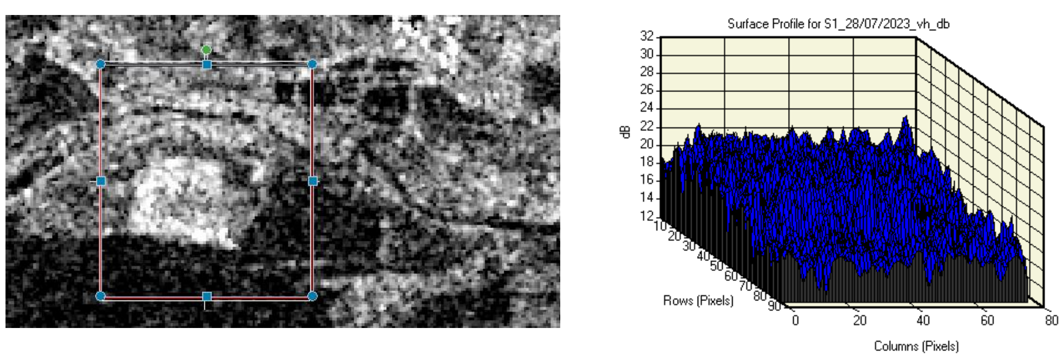


Figure 22 SAR image and Surface profiles, Tsalapiza (Plovdiv) landfill, 28/07/2023, Sentinel 1A, dB

As a sure way to validate the data, radar area profiles (figs. 21, 22) were used for each of the two landfills. The images were georeferenced and transformed in dB, as there is a clear classification for some of the objects. A very interesting fact is that the sunshine in Plovdiv (on one of the hottest days of the summer) is much higher than in Pernik, the

reflectance values should be much higher, but from the landfill in Tsalapitza they are demonstrated by -low values. Both vv and vh polarization profiles were used, but vh polarization is preferred for the purposes of the study.
It can be clearly noted that values below 18-20dB indicate a strong presence of moisture, and values lower than these for the presence of water. This is particularly characteristic of the southeastern part of the landfill (fig. 22).

5. CONCLUSION

The research enables the validation of the current state of the objects through each of the types of data of the created hybrid monitoring model. The complex approach is workable and accurate enough, as it has a variety of data and results. Data from field surveys as mobile spectrometer and thermal imager[32], satellite data from Sentinel can be clearly compared. LST gives a sufficiently good idea of the temperature anomalies and amplitudes of the considered objects. (fig. 15)[21].
Spectral reflectance curves from a mobile spectrometer for plastics and other objects are comparable to data from Sentinel 2 profiles because they can clearly be validated by drone data or by SAR data if no field survey is possible.
Contrary to the logic of the physico-geographical location of the landfill area in Tsalapitza, it turned out to have much higher moisture values. Of course, this isn't due to natural climatic factors, but to the fact that the landfill is regularly flooded with water.
Last but not least, it became clear that regardless of the location, the methodology model is applicable and provides up-to-date information for making management decisions. This was also proven by the fact that the data and approaches used were the same for both territories, in two different economic regions. The aim of the methodology is not to use long lines of statistical data, but data that can be used by experts and non-experts, scientists and administration.
The model can be of benefit to society, as it presents information and data that are devoid of a subjective factor.
The availability of field research through an innovative automatic recording weather station is an opportunity for more detailed information in the field, because the data are often interpolated. An example can be given with the averaged atmospheric pressure according to EEA data (fig. 13) and the more accurate data from AWG (table 3). This type of station is an innovation because it uses a renewable energy source such as salt water and magnesium. It can work regardless of geographical location, as it has already been tested in Antarctica in 2022.

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