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SPECTRAL MAPPING OF WASTE DISPOSAL SITES NEAR IHTIMAN

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Abstract

The presented study provides a spatial-temporal analysis of the development of a municipal waste landfill located near the town of Ihtiman, focusing on the processes and factors that led to the emergence and expansion of an unregulated landfill after the recultivation of the main landfill. This article is a continuation of a 2020 study that analyzed the main municipal waste landfill. At this stage, the focus is broadened to track the subsequent processes and changes that occurred after recultivation, including the emergence and development of illegal landfills.

Introduction

At the beginning of the 21st century, waste management remains one of the most serious challenges to sustainable development. Despite scientific and technological progress and the existence of regulatory mechanisms, there is a global trend towards increased waste generation, which puts pressure on both the environment and the institutional capacity to manage it effectively. The organization and management of municipal waste is the direct responsibility of local authorities, which should provide the necessary infrastructure for the collection, transport, treatment, and final disposal of household waste. However, a number of developed and developing countries are experiencing serious difficulties in maintaining landfills in a sustainable condition. The main challenges stem from inefficient management, often due to social, institutional, and technical constraints, including a lack of coordination between the responsible authorities, insufficient financial support, and outdated technological solutions. According to global estimates, the amount of waste generated has doubled over the last decade, and forecasts indicate that it will reach 2.5 billion tons per year by 2025. This negative trend is the result of the combined impact of accelerated urban development and increased consumption by the population [1].

The growing availability of open and spatial data sets has significantly improved opportunities for timely and informed decision-making, not only in the business sector and decentralized administrations, but also in municipalities and local communities. This trend is particularly important in the context of the pronounced shortage of highly qualified specialists.

Financial constraints and limited institutional capacity in smaller settlements have necessitated the adoption of research approaches that could be implemented by a relatively small number of well-trained professionals. Given the wide availability of valuable administrative data, such as open and spatial data sets, satellite information from the Copernicus and Landsat programs, and data from continuous environmental monitoring provided by the Ministry of Environment and Water, it is imperative that these resources be used systematically to generate significant economic benefits and added value [2].

Unregulated landfills for household and construction waste pose a significant environmental and social challenge. Illegal waste accumulation is increasingly observed in various spatial contexts, including peripheral neighborhoods, suburban areas, and even central public spaces. Although population growth and urban expansion contribute to this phenomenon, the main factors for the formation and persistence of such illegal waste dumps remain inadequate monitoring and enforcement mechanisms [3].

Study area

The landfill for municipal waste in Ihtiman is a former municipal facility located in the area of “Swamp”, near the road to the village of Muhovo and the “Trakia” highway. The facility ceased operations in October 2016 due to non-compliance with the current waste management regulations [4, 5].

In the period prior to its final closure, a number of problems were reported, including the occurrence of combustion processes and the risk of contamination of environmental components, which necessitated control activities and the implementation of preventive measures to limit unauthorized activities. In 2018, the Regional Inspectorate for Environment and Water – Sofia carried out an inspection, which did not find any exceedances of the permissible standards for air pollution, but additional instructions were issued for enhanced monitoring and control [4, 6].

The process of closing and recultivating the landfill was carried out in stages, with the municipality of Ihtiman conducting public procurement procedures and market consultations. The technical recultivation of the site was finally completed in 2020 [6].

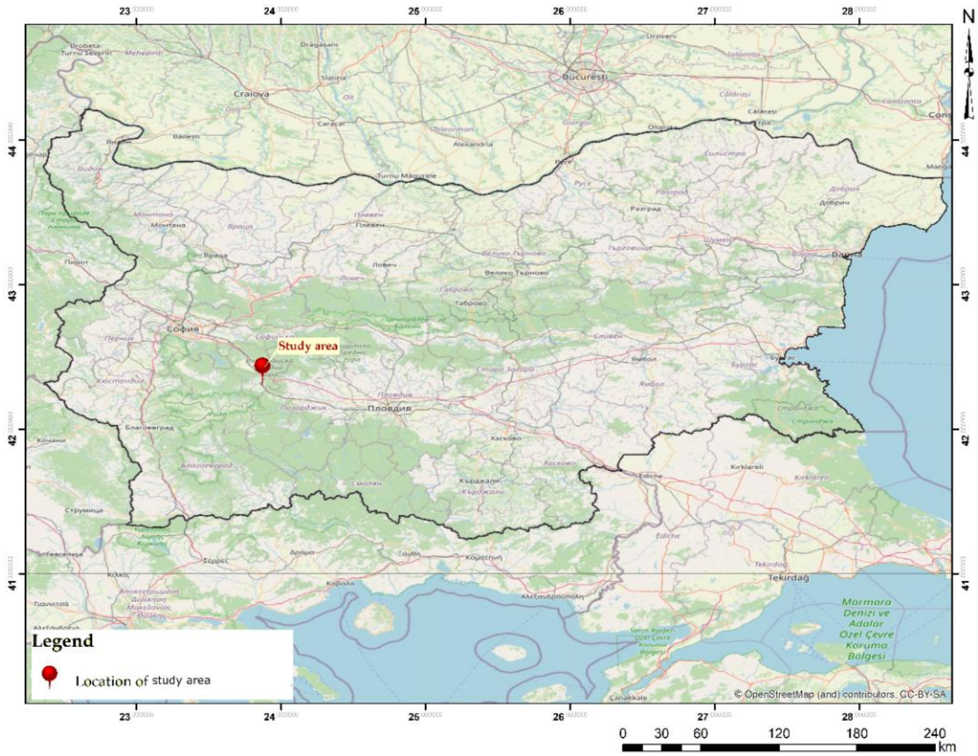


Fig. 1. Map of the area of interest

Materials and Methods

The satellite data used in this study were obtained from the European Space Agency (ESA) Sentinel-2B and Sentinel-3B missions and from the Landsat 8 and 9 OLI/TIRS sensors operated by the National Aeronautics and Space Administration (NASA) (Table 1). Sentinel satellite images are freely available through the Copernicus Data Space Ecosystem, and all Landsat 8 and 9 products are available free of charge through the Earth Resources Observation and Science (EROS) Center of the US Geological Survey (USGS) [7–10].

The selection of images was limited to scenes captured during cloudless weather over the study area to ensure data quality and reliability of the analysis. The capture dates of the satellite images used to monitor the study sites, along with the corresponding sensors, are presented in Table 1.

Table 1. Satellite data

Satellite	Date
Sentinel-2B	30.08.2020
Sentinel-2B	10.08.2025
Sentinel-3B LST	23.07.2023
Sentinel-3B LST	08.11.2023
Sentinel-3B LST	30.12.2023
Sentinel-3B LST	27.09.2024
Sentinel-3B LST	13.08.2025
Landsat 8 OLI / TIR	11.07.2016
Landsat 9 OLI / TIR	04.072022
Landsat 9 OLI / TIR	27.07.2022
Landsat 9 OLI / TIR	23.07.2023
Landsat 9 OLI / TIR	08.11.2023
Landsat 9 OLI / TIR	27.09.2024
Landsat 9 OLI / TIR	13.08.2025

Two optical indices were used in this study: Normalized Difference Greenness Index (NDGI) and Modified Soil-Adjusted Vegetation Index (MSAVI2).

MSAVI2 is an adapted version of the soil-adjusted vegetation index (SAVI). It was developed to reduce NDVI inaccuracies in areas with exposed soil surfaces [11]:

$$(1) \qquad \mathrm{MSAVI2} = \frac{\left(2*NIR+1-\sqrt{(2*NIR+1)^2}-8^*(NIR-RED)\right)}{2}$$

The quasi-synchronous assessment using LST data from two satellite platforms, combined with vegetation and greenness indicators, provided a more comprehensive characterization of surface conditions and improved spatiotemporal stability. Verification and validation of the satellite images were performed using the Tessellated Cap Transformation (TCT) model in combination with the Normalized Difference Greenness Index (NDGI). The analyses focused on pre-selected test areas covering waste disposal sites outlined by high-resolution optical images.

All Sentinel-2 MSI bands are used for TCT calculation, Kauth and Thomas (1976) [12], Crist and Cicone (1984) [13]:

Brightness (Br), Greenness (Gr), Wetness(W)

(2) $\mathrm{nW} = (\mathrm{W} - \mathrm{E}\{\mathrm{W}\})/\mathrm{St.Dev}(\mathrm{W})$

(3) $\mathrm{nBR} = (\mathrm{BR} - \mathrm{E}\{\mathrm{BR}\})/\mathrm{St.Dev}(\mathrm{BR})$

(4) $(\mathrm{nGR}=(\mathrm{GR}-\mathrm{E}\{\mathrm{GR}\}))/(\mathrm{St.Dev}(\mathrm{GR}))$

Derived from the Greenness component of TCT-applied Sentinel-2 imagery, NDGI quantifies vegetation state variations over time. With values ranging from +1 to -1, it serves as an indicator of vegetation development [14]:

(5) $\mathrm{NDGI} = \frac{\mathrm{GR_n(t_2)} - \mathrm{GR_n(t_1)}}{|\mathrm{GR_n(t_2)}| + |\mathrm{GR_n(t_1)}|}$

To achieve the main objective of the study, temperature changes associated with thermal emissions from landfills were monitored over different time periods. For this purpose, satellite data from Landsat missions 8 – 9 were used, calculated from thermal infrared data by applying the following formula:

(6) $\mathrm{T}_{[K]} = \mathrm{a} * ln^{-1} (\frac{b}{c*Q+d} + 1)$

where **a**,**b**,**c**,**d** are the constants for the different types of Landsat images;
T is the pixel temperature (K);
Q is the spectral brightness coefficient of the surface in the thermal bands of Landsat (4–9). After the georeferencing procedure of the thermal images, rectangular sections are cut out in each image, covering the area around the geographic coordinates. The time series {Q1, Q2, . . . , Qn} of the images in the thermal channel of each waste disposal site is extracted. The data from the image is converted into the surface temperature {T1, T2, . . . , Tn} using the transformation:

(7) $\mathrm{T}_{[°\mathrm{C}]} = \mathrm{a} * ln^{-1} (\frac{b}{c*Q+d} + 1) - 273.15,$

where

a is the K_2 = Thermal conversion constant for the band (K2_CONSTANT_BAND_n from the metadata);
b is K_1 = Thermal conversion constant for the band (K1_CONSTANT_BAND_n from the metadata);
c is M_l = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata);
d is L_λ = Spectral radiance $(W/(m2 * sr * \mu m))$;
Q = L1 pixel value in DN;
T = TOA (Top of Atmosphere) Brightness Temperature [10].

The other data used are from Sentinel-3A and Sentinel-3B (Table 1), and the SLSTR thermal bands used to extract SST (the three infrared channels S7, S8, and S9 at 3.74 µm, 10.85 µm, and 12 µm) are also used to extract LST in SLSTR Level 2 products. The algorithms for extracting LST using split-window radiation are sufficiently sophisticated to achieve an accuracy of 1 K, especially at night when there is no differential heating of the surface [15].

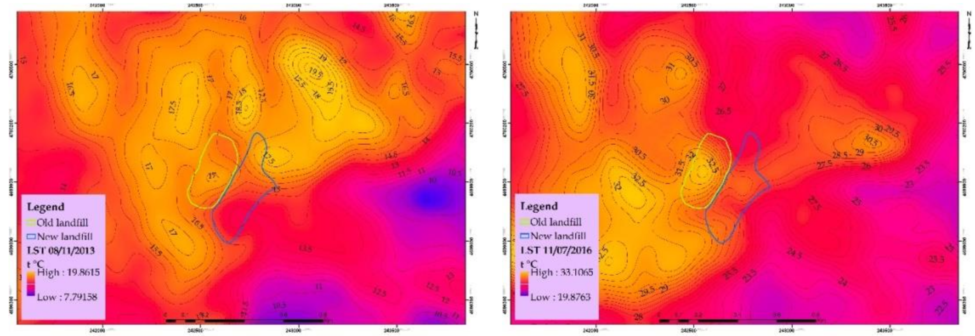
Results and Discussions

Fig. 2 shows images from Google Earth, where the old landfill is marked with a green polygon and the new landfill with a blue polygon. Fig. 2a shows an image from September 23, 2020, and Fig. 2b shows an image from 2021, when the recultivation process began, according to data from the municipality of Ihtiman.

a) *b)*

Fig. 2. a) Image from Google Earth from 23.09.2012;
b) Image from Google Earth from 20.09.2020

With regard to surface temperature (LST), data from Landsat 8 for 08.11.2013 were found (Fig. 3a). The figure shows an increase in surface temperature from the old municipal waste landfill (outlined in green), with a temperature of 17° C within the boundaries of the landfill, which is higher than the rest of the surface (+12°C – +14°C). In the northeastern part of the landfill, there is also a photovoltaic park, which further affects the surface temperature in the area. Several heat islands can be observed north of the landfill and the photovoltaic park.



a) *b)*

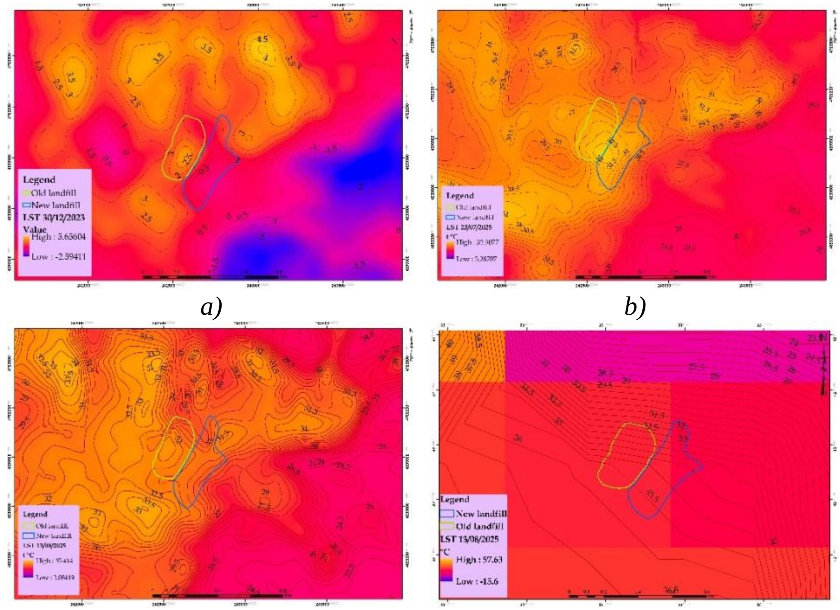
Fig. 3. a) LST Landsat 8 from 08.11.2013;
b) LST Landsat 8 from 11.07.2016

South of the landfill (newly formed after 2020), no increase in surface temperature is observed. Fig. 3b shows the LST from July 11, 2016, where a heat island is located, again within the boundaries of the old landfill. The maximum temperature in the center of the landfill is +32°C, and several additional heat islands are observed to the west of the landfill itself.

a) *b)*

Fig. 4. a) Image from Google Earth from 13.03.2023;
b) Image from Google Earth from 11.01.2025

Fig. 4 again shows images from Google Earth for a clearer visualization of the studied area in the visible spectrum. Fig. 4a shows an image from March 13, 2023, which shows that the old household waste landfill has been reclaimed. However, a new unregulated landfill is forming within the boundaries of the blue polygon. Fig. 4b shows an image from January 11, 2025, which reveals that the waste has already spread throughout the newly formed unregulated landfill.

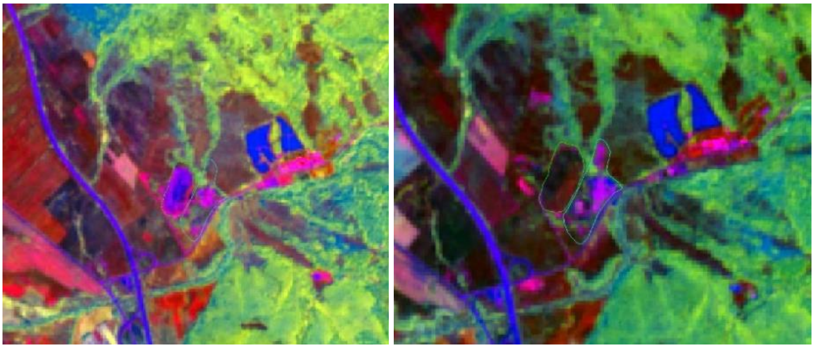


a) *b)*

c) *d)*

Fig. 5. a) LST Landsat 9 from 30.12.2023; b) LST from 23.07.2025,
c) LST Landsat 9 from 13.08.2025; d) LST from Sentinel-3 from 13.08.2025

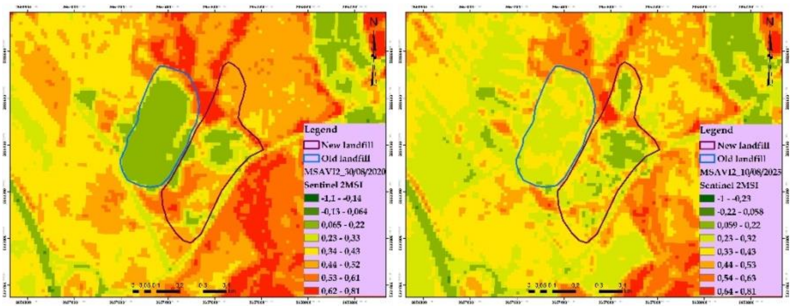
Fig. 5a–c shows surface temperature data from Landsat 9. To verify the results, LST from Sentinel was also used, with a spatial resolution of 1 km, while Landsat has a spatial resolution of 30 m. Fig. 5a shows data from December 30, 2025, where the local island that has formed again is within the boundaries of the old (already recultivated) landfill. The temperature reaches +3°C, while for comparison, within the boundaries of the new island, it is +0.5°C. For the rest of the surface, it varies from -1.5°C to +0.5°C. Fig. 5b shows the LST values for July 23, 2025. Here, a large heat island has formed, which is within the boundaries of both the old (reclaimed landfill) and the unregulated landfill. The surface temperature reaches +32.5°C, exerting a strong influence on the northwest. The formation of local heat islands is the result of the combined effect of the deposited waste and the photovoltaic panels, which change the albedo and heat balance of the surface located east of the landfill. The same can be observed in Fig. 5c and Fig. 5d, which are from the same date – 13.08.2025, but from different satellite platforms. The data from Landsat 9 again show the spread of local islands due to the combination of the nearby photovoltaic park and the reclaimed landfill, in combination with the unregulated one. Based on the data obtained from Landsat and Sentinel-3, it can be clearly concluded that the studied objects have a strong impact on the surrounding area, which is located to the northwest.



a) b)

Fig. 6. a) TCT from 30.08.2020; b) TCT from 30.08.2025

TCT is the surest method of identifying municipal landfills, as they are colored in a color that is out of character for the other components – soil, vegetation, moisture. Fig. 6a shows the TCT model as of August 30, 2020, which shows purple coloration entirely within the old municipal landfill and purple coloration in the northeastern portion of the unregulated landfill. For 2025, the model indicates that the waste that is again colored purple is entirely within the boundaries of the unregulated landfill (Fig. 6b).



a) b)

Fig. 7. a) MSAVI2 from 30.08.2020; b) MSAVI2 from 10.08.2025

The Modified Soil-Adjusted Vegetation Index (MSAVI2) is an enhanced version of the Soil-Adjusted Vegetation Index (SAVI), designed to account for soil brightness effects more effectively. The index is calculated using reflectance values from the near-infrared and red spectral bands, which are commonly available in satellite imagery. MSAVI2 is particularly sensitive to variations in vegetation density and provides a more accurate representation of green vegetation cover compared to other widely used indices, such as the Normalized Difference Vegetation Index (NDVI) [16].

MSAVI2 is widely applied in agricultural, forestry, and ecological studies, as well as in land cover mapping and classification. It is commonly derived from satellite imagery acquired by sensors such as Landsat, MODIS, and Sentinel-2. In this study, MSAVI2 was calculated using Sentinel-2 data. The index provides valuable information on vegetation distribution and density [17], which can be used to monitor land cover dynamics, assess the impacts of land-use change, and support informed decision-making in land and natural resource management [18].

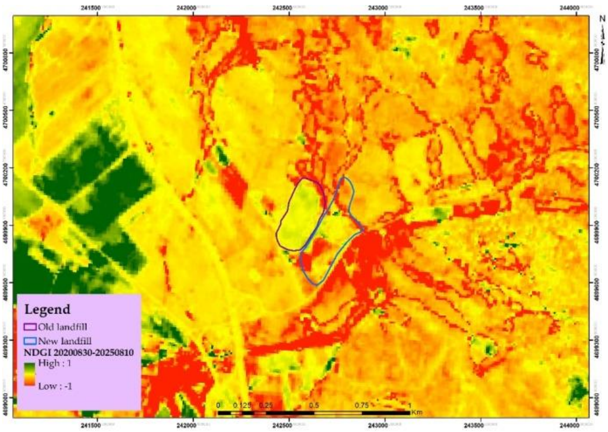


Fig. 8. NDGI 30.08.2020–10.08.2025

In general, the NDGI index shows insignificant changes in vegetation cover in the area of the waste disposal site during the period 2020–2025. The observed patterns indicate localized but clearly pronounced changes in vegetation dynamics, probably related to surface disturbances and waste disposal processes.

Furthermore, images from the Tasseled Cap Transformation (TCT) (Fig. 6b) reveal significant variations in surface moisture, represented by light blue tones, which may be associated with the presence of infiltrate and altered soil conditions characteristic of waste disposal sites.

Conclusion

Some of the key reasons for the need for regular and interim monitoring of municipal waste landfills are as follows:

- Monitoring the spread of harmful substances – hazardous materials such as heavy metals, chemicals, and electronic waste are increasingly finding their way into landfills, posing a danger if not controlled in time.
- Preventing soil and water pollution – improper waste treatment can lead to the release of toxic substances that can seep into the soil. Over time, these toxins contaminate groundwater and surface water, which are sources of drinking water, agricultural needs, and ecosystems. Regular monitoring of landfills can prevent such contamination.

- Control over the spread of heat islands and biochemical processes that can cause long-term damage to soil and surrounding water sources – Biochemical processes occurring within landfills generate methane and carbon dioxide, which are greenhouse gases and contribute to climate change. A local microclimate often forms around landfills, which differs from the rest of the surface. Methane, for example, is the main cause of spontaneous combustion in landfills. Monitoring these emissions is necessary in order to control air pollution.
- Improving waste management through informed and timely decisions based on up-to-date remote and field data.

It has been proven that land surface temperature (LST) is an important climate indicator and provides valuable information about the processes of thermal radiation from municipal waste landfills. It is these processes that contribute to the formation of localized microclimatic zones, which can lead to a number of adverse environmental and climatic consequences both in the immediate vicinity of landfills and over wider areas. Such changes may include an increase in local temperatures, changes in soil and air moisture, and a negative impact on biodiversity and agricultural productivity in neighboring areas.

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СПЕКТРАЛНО КАРТИРАНЕ НА ДЕПА ЗА БИТОВИ ОТПАДЪЦИ В БЛИЗОСТ ДО ИХТИМАН

А. Данчева, Т. Спасова, А. Стоянов

Резюме

В представеното изследване е извършен пространствено-времеви анализ на развитието на депо за битови отпадъци, разположено в близост до град Ихтиман, като акцентът е поставен върху процесите и факторите, обусловили възникването и разрастването на нерегламентирано сметище след рекултивацията на основното депо. Настоящата статия представлява продължение на изследване, проведено през 2020 г., в рамките на което е анализирано основното депо за битови отпадъци. В настоящия етап фокусът се разширява с цел проследяване на последващите процеси и промени, настъпили след рекултивацията, включително появата и развитието на нерегламентирани депонирания.