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ASSESSMENT OF THE EUROPEAN GROUND MOTION SERVICE ORTHO PRODUCTS FOR LANDFILL SYSTEMATIC OBSERVATION

Iulia DANA NEGULA[1, 2*], Cristian MOISE[1, 2*], Florina DEDIU[1, 2], Mihaela GHEORGHE[3], Georgeta TUDOR[4], Umut Güneş SEFERCIK[5]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania
[2]Romanian Space Agency, 21-25 Mendeleev Street, District 1, Bucharest, Romania
[3]GMV Innovating Solutions, 246C Calea Floreasca, District 1, Bucharest, Romania
[4]National Institute for Research and Development in Environmental Protection, 294 Splaiul Independenței, District 6, Bucharest, Romania
[5]Gebze Technical University, 41400 Gebze/Kocaeli, Turkey

Corresponding author email: iulia.dana@fifim.ro
*These authors contributed equally to this work and share first authorship.

Abstract

The European Ground Motion Service (EGMS) is a new, open and freely available addition to the pan-European component of the core Copernicus Land Management Service (CLMS). The service offers very accurate and consistent information regarding the ground motion velocity that might be correlated with a wide range of circumstances, such as landslides, subsidence, volcanic activity and many others. The products (i.e., basic, calibrated and ortho) delivered by EGMS were generated based on Sentinel-1 time-series acquired between 2016 and 2020, using advanced Differential Synthetic Aperture Radar Interferometry (A-DInSAR) techniques. The present study addresses the suitability of the EGMS ortho products for the monitoring of 15 solid waste landfills located across the territory of Romania. The vertical displacements extracted for each selected landfill were analysed and correlated with the available background information (e.g., exploitation duration, the quantity of waste disposal per year, etc.). The study proved that EGMS might be an important tool for waste management since it enables the continued monitoring of the landfill settlement process.

***Key words**: Advanced Differential Synthetic Aperture Radar Interferometry (A-DInSAR), European Ground Motion Service (EGMS), landfill monitoring, landfill settlement, Sentinel-1.*

INTRODUCTION

Landfills have complex structures that enable the storage of waste without contaminating the environment. Landfills have several layers that prevent the leachate to reach groundwater. Soil is frequently added to cover the waste for odour reduction and keep the trash inside the disposal site. Landfill settlement represents a process in which the ground or surface of a landfill lowers over time. The magnitude and duration of this process is influenced by various factors such as the volume of the stored waste as well as the mechanisms that are developing in the lower layers of the structure (Chabuk et al., 2018). According to He et al. (2021), the settlement process usually takes place over a period of 20 to 30 years and may reach 50% of the initial landfill depth, therefore continuous monitoring is of high importance for effective waste management that results in reduced impact on the environment (Virsta et al., 2020).

The monitoring of landfills can be successfully performed based on satellite data, especially when a synergistic use of different data types and methods is employed (Papale et al., 2023). The use of synthetic aperture radar (SAR) and interferometric techniques is also demonstrated by several studies (Du et al., 2021; Zhang et al., 2021; Tabish et al., 2022). EGMS provides products generated based on Advanced Differential SAR Interferometry (A-DInSAR) techniques (Crosetto et al., 2020). These are based on time series of SAR images, examples including Persistent Scatterers Interferometry (PS-InSAR) and Small Baseline Subset Interferometry (SBAS-InSAR). The present study aims to assess the suitability of the EGMS products for landfill systematic observation, using 15 test sites located in Romania.

MATERIALS AND METHODS

EGMS functions within the Land Management Service (CLMS) of the Copernicus Programme and provides accurate information about the ground and infrastructure displacements, expressed in mm/year for each identified stable point named persistent scatterer. The service is covering the territory of the European countries that are committed to Copernicus Programme and the United Kingdom (Kotzerke, 2022).

The information provided by EGMS is derived based on multitemporal series of Sentinel-1 data acquired between Feb 2015 and Dec 2021, using Persistent and Distributed Scatterers (Crosetto et al., 2020). EGMS offers three types of open and free products, namely: Basic (relative displacements measured on the Line-of-Sight, derived from ascending and descending orbits, having 20 x 5 m spatial resolution), Calibrated (also derived from combined ascending and descending orbits, with absolute displacements measured on the Line-of-Sight, at 20 m x 5 m spatial resolution) and Ortho (reference geodetic model, horizontal/east -west and vertical/up-down displacements, 100 m spatial resolution, data derived from both ascending and descending orbits). In case of the latter product, the north-south component of motion is compensated using calibration based on Global Navigation Satellite System (GNSS) data. Due to the SAR acquisition geometry, the detection of motion on this direction is less sensitive (Kotzerke, 2022).

The EGMS products are quality controlled (Kotzerke, 2022) and validated (Crosetto et al., 2021). For each product, mean velocity standard deviation is 0.7 mm/year (Kotzerke, 2022).

The EGMS products can be used in a large number of applications, such as the study of geohazards (e.g., subsidence, volcanic activity, earthquakes, landslides, etc.), civil engineering and infrastructure (e.g., buildings, roads, ports, railways, tunnels, bridges, airports, etc.), energy and natural resources (e.g., oil and gas, power plants, wind farms, power lines, dams, mining, etc.) and cultural heritage (Kotzerke, 2022). In addition, other applications, such as landfill monitoring, are acknowledged as being suitable for benefiting from the products provided by this service (EGMS, 2023). For the present study, the EGMS Ortho product (Jan 2016 - Dec 2021, vertical displacements) covering the territory of Romania (Figure 1) was used.

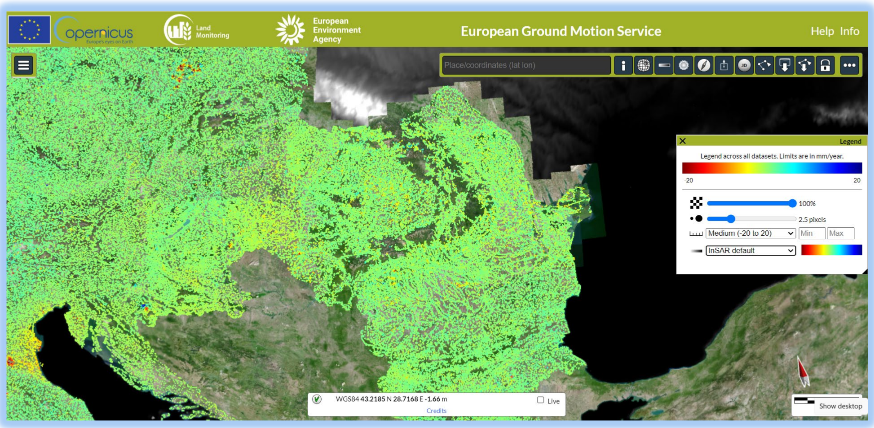

Figure 1. EGMS Explorer view (centre of the picture: dataset covering Romania)

Data regarding the studied waste disposal areas were provided by the National Institute for Research and Development in Environmental Protection. These data consist of: date when the landfill became operative, closure date, landfill structure (e.g., total number of cells, number of operational cells, number of projected cells), status (usually at the level of 2021), history and evolution, quantity of waste stored (in tons/year) and any other useful information (quality of the surrounding construction works, such as roads, dams; known issues regarding the leachate, the condition of the geotextile layer, etc.).

The selected landfills are illustrated in Figure 2.

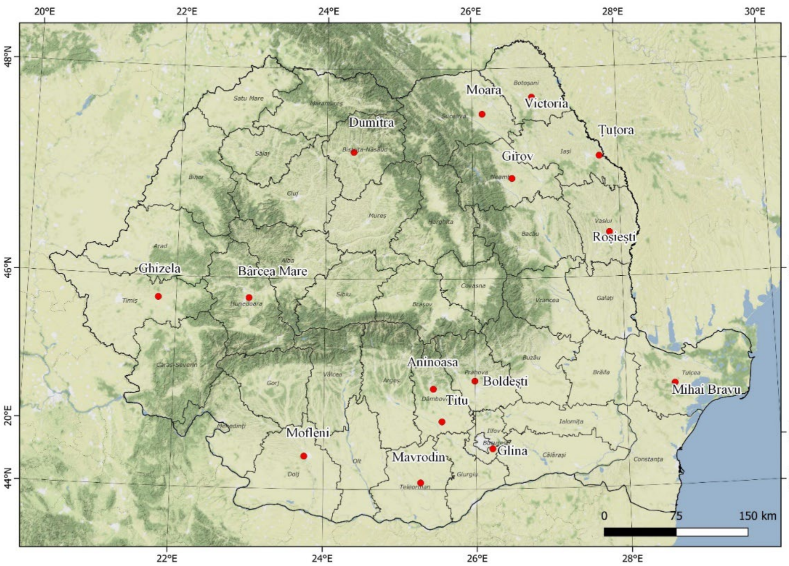

Figure 2. Location of the selected landfills within the territory of Romania

The methodology is presented in Figure 3 and it consists of 5 main phases. In the first phase, the EGMS dataset was downloaded from the CLMS site (https://egms.land.copernicus.eu/). Regions of interest were defined in order to obtain a complete coverage of the Romanian territory. The dataset was downloaded in .CSV format at grid level. Next, the .CSV format was converted into the OGC (Open Geospatial Consortium) GeoPackage format for further processing in QGIS, an open-source Geographic Information System (GIS). For each landfill, a selection of relevant persistent scatterers was performed. The information regarding the boundaries of the landfills was not available, hence the choice of suitable persistent scatterers was made manually using very high-resolution satellite data. In the following phase, the data were analysed in order to determine the evolution of each landfill in what concerns the detection of the settlement process (a negative subsidence trend, with high displacement values, reveals the lowering of the landfill over time). Firstly, the extracted EGMS data required preparation, meaning that the displacement values (in mm/year) available for all the persistent scatterers located within a landfill were averaged for each acquisition date; next, the mean values obtained before were averaged at quarter level; hence, for each landfill 24 displacement values were computed for the 6-year monitoring window. Since the average values are not entirely revealing the amplitude of subsidence, 3 persistent scatterers displaying the most significant displacement rates were selected for each test site. For these points, the actual displacement values measured at the beginning of each quarter were analysed. Hence, the displacement trend was investigated also using 24 values, for each selected persistent scatterer. In the last phase, the results were evaluated based on the available information. For example, the start and closure dates are essential knowledge in this context, as well as the information regarding the number of landfill cells and their status (currently operational or non-operational, covered or not covered, the quantity of waste disposal stored each year etc.) during the observation period.

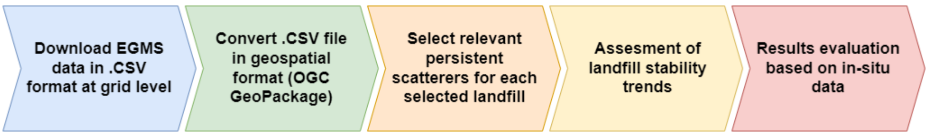

Figure 3. Workflow for the identification of potential landfill settlement process

RESULTS AND DISCUSSION

The overall mean displacement velocity (in mm/year) was computed for each landfill (Figure 4), based on the EGMS dataset covering a time interval of 6 years (January 2016 - December 2021). EGMS enables a detailed analysis of the displacement process by providing vertical shift rates every 6 days, thus resulting more than 360 records for each persistent scatterer (Figure 5).

Next, the most significant displacement values were investigated (Figures 6-8). Overall, the results indicate that Glina landfill presents the most significant negative displacement rates that might be associated with the evolution of the settlement process. A clear negative trend is also observed for Victoria, Aninoasa, Titu, Ghizela, and Mofleni; the negative trend in less pronounced for Dumitra and Mavrodin landfills. On the contrary, Bârcea Mare is the only solid waste landfill showing positive displacement velocities that suggest an uplift process. Landfill stability or slight negative displacement rates are specific to Roșiești, Boldești, Girov, Moara, Țuțora and Mihai Bravu disposal sites. Further, a more detailed analysis in presented.

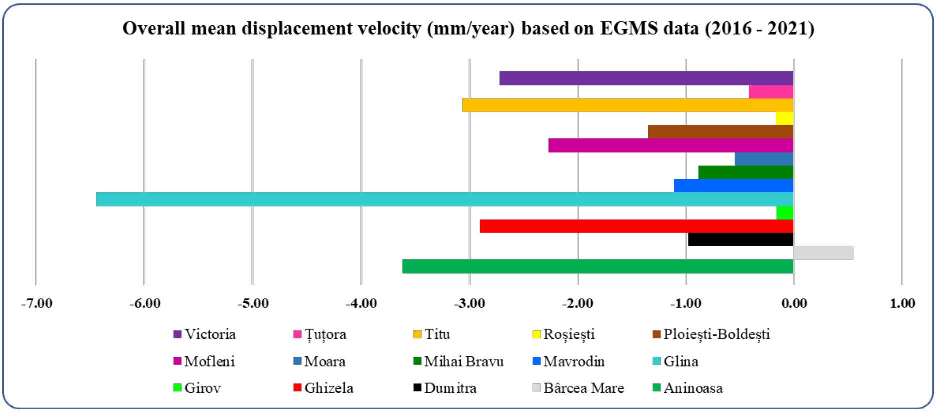

Figure 4. EGMS-derived overall mean displacement rate

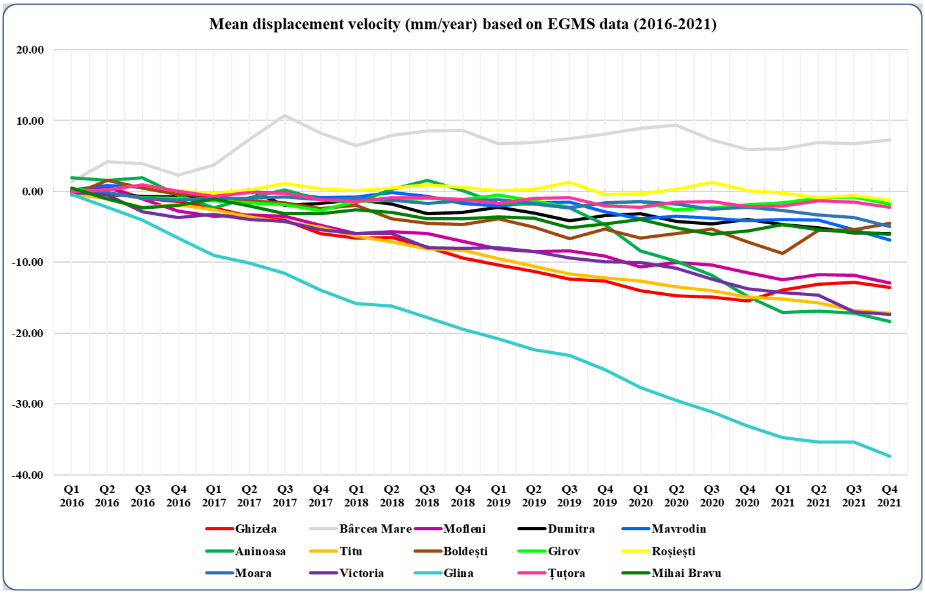

Figure 5. EGMS-derived displacement rate for each quarter of the investigated time frame - all landfills

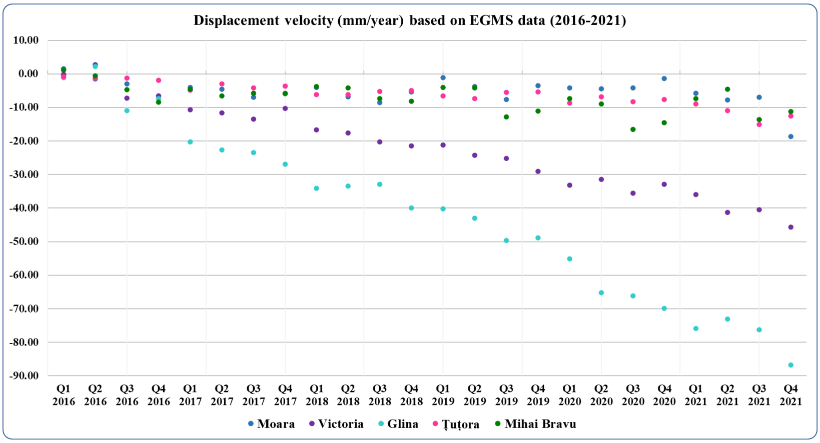

Figure 6. EGMS-derived displacement rate for each quarter of the investigated time frame - batch 1

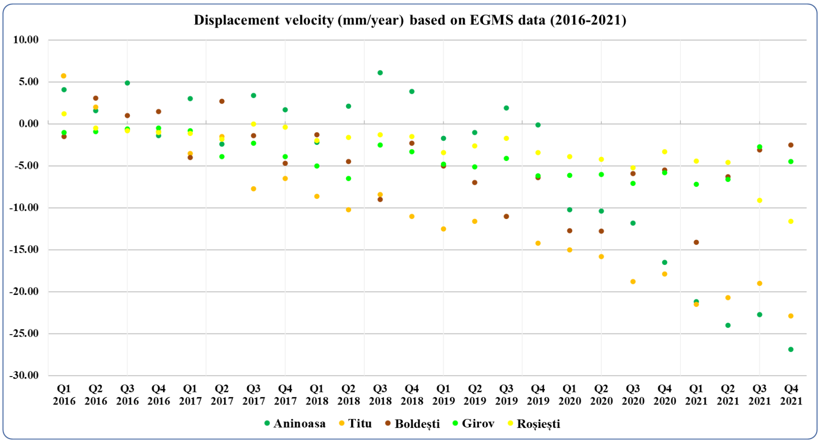

Figure 7. EGMS-derived displacement rate for each quarter of the investigated time frame - batch 2

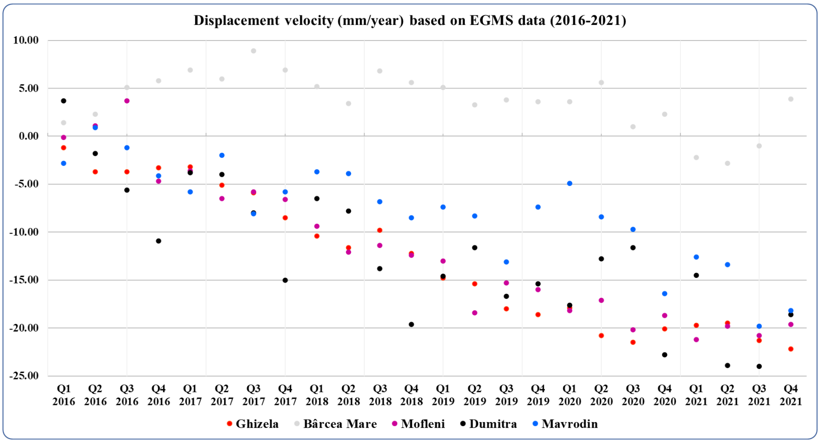

Figure 8. EGMS-derived displacement rate for each quarter of the investigated time frame - batch 3

Batch 1 of the selected sites (Figure 6) contains 3 rather stable landfills, namely Moara, Țuțora and Mihai Bravu. Moara is an ecological waste disposal site that is operational starting with July 2019. At the level of 2021, the landfill was receiving waste collected from the entire Suceava County, the first cell having a projected lifetime of 10 years. A subsidence process is not clearly observable within the EGMS dataset, primarily because the exploitation time frame and the EGMS time coverage are overlapping for a rather short interval (i.e., July 2019 - December 2021). Having a similar evolution, Țuțora is also an ecological landfill that will be composed of 4 main cells, covering a 30-year time span. The first cell is in service since 2012 and it is receiving all the waste that accumulates within the Iași County. Starting with 2013, the landfill stored more than 125,000 tons/year, reaching almost 181,000 tons/year in 2019. Even though some technical and maintenance issues have been present (i.e., with leachate and geotextile layer) and the disposal site is in use for a rather large number of years, a clear subsidence process was not detected based on the EGMS data. With regard to the Mihai Bravu landfill, it is functional since 2020, hence the analysis period is of only 2 years. Similar to the previous examples, a subsidence process is not observable yet for this waste disposal site.

Victoria landfill (Botoșani County) is in use since September 2016. Starting with the first quarter of 2018, a subsidence process is noticeable (Figure 6), with subsidence rates reaching almost -50 mm/year at the end of 2021, based on the several persistent scatterers (Figure 9) that are present within the waste disposal site.

The Glina landfill (Ilfov County) was officially operational from 2008 until 2017. However, the site was used for waste disposal since 1977, when large quantities of construction debris generated by the 7.2 magnitude earthquake were stored there. For this landfill, the EGMS contains the greatest number of persistent scatterers and the most significant displacement values (Figure 10). The analysis shows that the settlement process started even before the closing of the landfill and continued on a steady basis until the end of the monitoring window. In the latest observation years, for some persistent scatterers, the vertical displacements reached almost -90 mm/year, hence the amplitude of the landfill settlement process is considerable. Figure 11 illustrates the surrounding area of Glina landfill, where the mean displacement velocities of the persistent scatterers located within a buffer of 1,000 m to 2,000 m around the landfill are approximately 6 times lower than the mean values corresponding to the landfill.

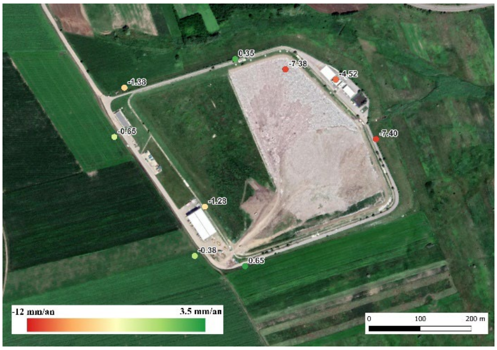

Figure 9. Overall mean displacement velocities (2016-2021) for the persistent scatterers of the Victoria landfill

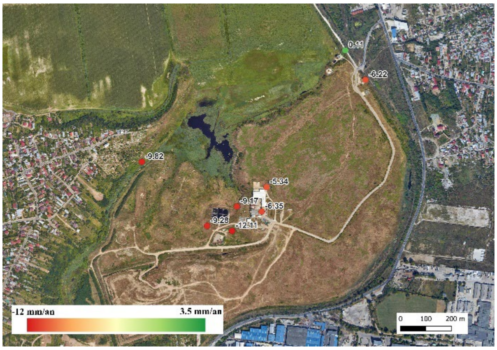

Figure 10. Overall mean displacement velocities (2016-2021) for the persistent scatterers of the Glina landfill

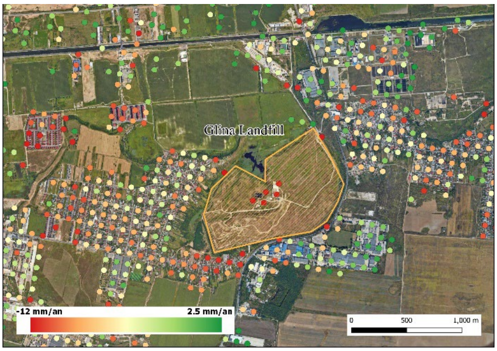

Figure 11. Displacement map (2016-2021) for the surrounding area of Glina landfill

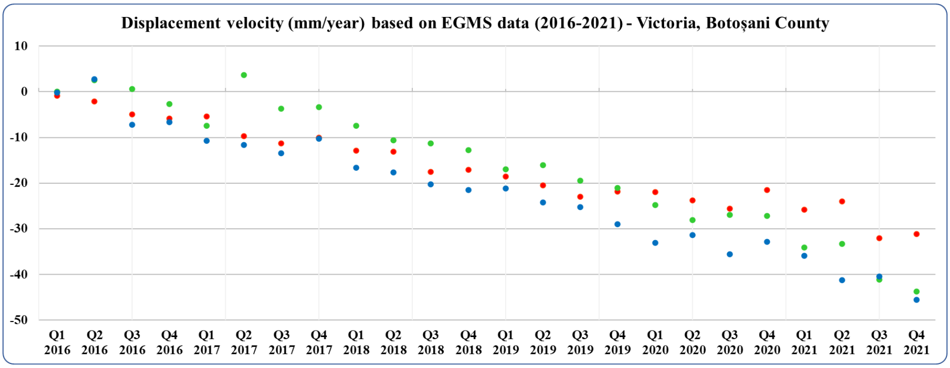

Figure 12. Persistent scatterers displaying the most significant displacement rates (2016-2021) - Victoria

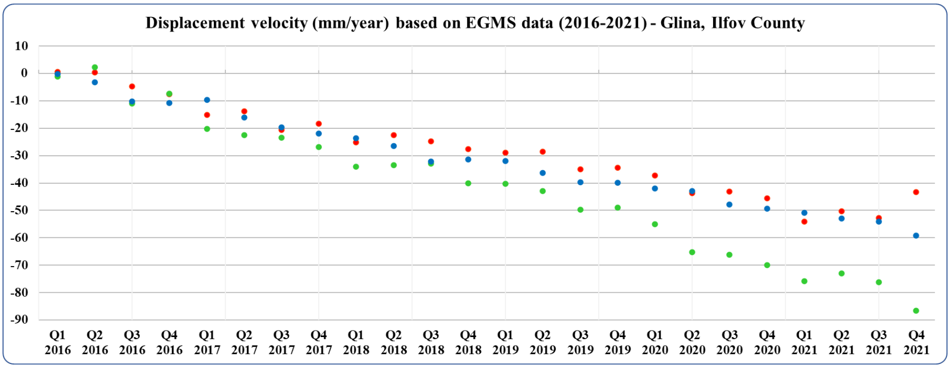

Figure 13. Persistent scatterers displaying the most significant displacement rates (2016-2021) - Glina

Figures 12 and 13 present the evolution of the 3 persistent scatterers that present the most significant displacement values for Victoria and Glina, respectively. The subsidence trend is definite in both cases, for the points considered. The second batch of the selected test sites (Figure 7) includes two landfills that are stable, namely Girov and Roșiești. The first one (Girov) is located in Neamț County and it is operational since 2015. The landfill is designed to have a lifespan of 21 years, while the first of the 3 projected cells will be functional for 5 years. The second landfill (Roșiești) represents the only landfill of Vaslui County, being functional since 2018 and storing more than 70,000 tons in 2019. Further, the Boldești landfill (located in Boldești -Scăieni, near Ploiești, Prahova County) became operational in 2001 and it is still currently in use. In this case, although the operational framework is considerably long (approximately 20 years), a pronounced landfill settlement process was not detected based on EGMS data. Some possible explanations include: (1) the settlement process ended before the monitoring window started, thus indicating a relatively stable area; (2) the quality and number of persistent scatterers are not satisfactory (Figure 14).

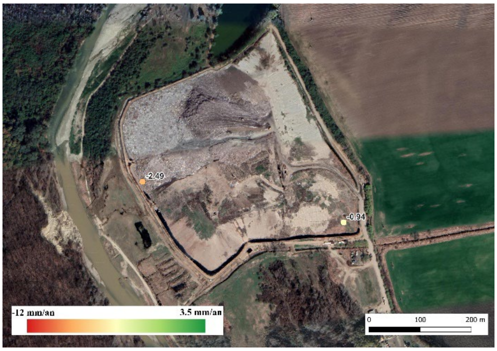

Figure 14. Overall mean displacement velocities (2016-2021) for the persistent scatterers of the Boldești landfill

Titu and Aninoasa landfills are both located in Dâmbovița County. These waste disposal sites present a similar displacement trend, although in

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case of the latter the values are slightly higher (Figure 7). The Titu landfill (Figure 15) is in service since 2010; the first cell functioned until 2018, whereas the second one was operational between 2018 and November 2019. Almost the same trend is impacting a small part of the near-by city of Titu (i.e., the area located in a buffer of 1,000-2,000 m around the landfill). In this case, the displacement rates are equalling almost 60% of the numeric values corresponding to the waste disposal site (Figure 16).

Figure 15. Overall mean displacement velocities (2016-2021) for the persistent scatterers of the Titu landfill

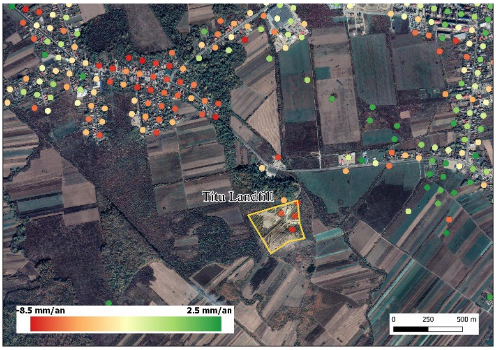

Figure 16. Displacement map (2016-2021) for the surrounding area of Titu landfill

The Aninoasa landfill is operational since 2010; first cell reached maximum capacity in 2018, while the second cell is still in service. Based on the EGMS data (Figure 17), a clear subsidence process can be identified for the first cell a few months after its closure (beginning of 2019). In addition, the surrounding areas of the landfill (including a part of Aninoasa city) also have relatively high subsidence values (Figure 18), following the same displacement trend. In this case, the persistent scatterers located in the buffer of 1,000-2,000 m around the waste disposal site have mean displacement values that are reaching almost 50% of the figures detected for the Aninoasa landfill.

Figure 17. Overall mean displacement velocities (2016-2021) for the persistent scatterers of Aninoasa landfill

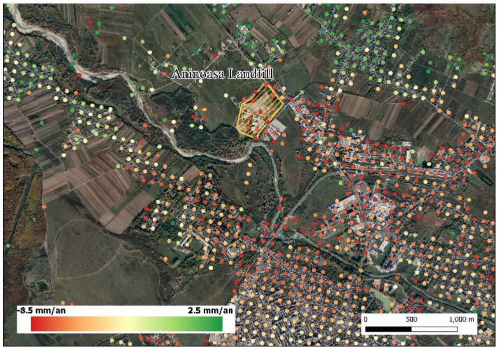

Figure 18. Displacement map (2016-2021) of the surrounding areas of Aninoasa landfill

For both Titu and Aninoasa waste disposal sites, the persistent scatterers that display the most significant subsidence values are revealing a clear subsidence process (Figures 19 and 20).
The last batch of selected sites (Figure 8) contains Dumitra (Tărpiu, Bistrița-Năsăud) and Mavrodin (Teleorman), two landfills with a similar pattern that suggests a less evident subsidence trend due to the presence of also stable persistent scatterers. The first one is operational since 2014, with cell 1 reaching full capacity at the end of 2020 and cell 2 being in service starting with 2021. Mavrodin serves as a landfill since 2013. The waste quantities decreased from almost 85,000 tons in 2014 to approximately 50,000 tons in 2019.

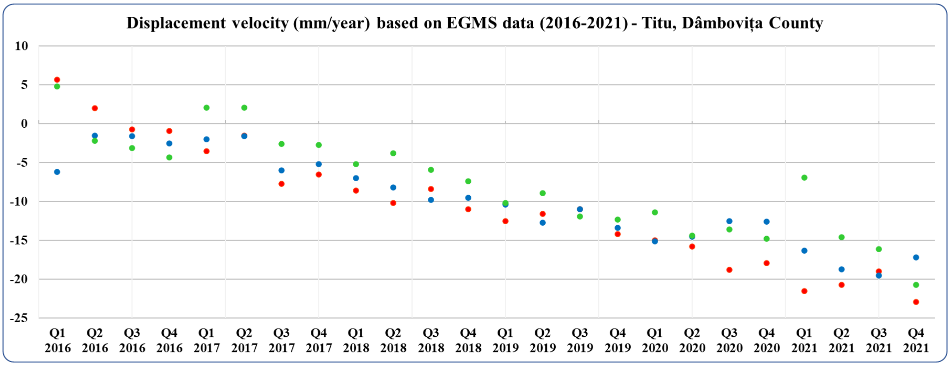

Figure 19. Persistent scatterers displaying the most significant displacement rates (2016-2021) - Titu

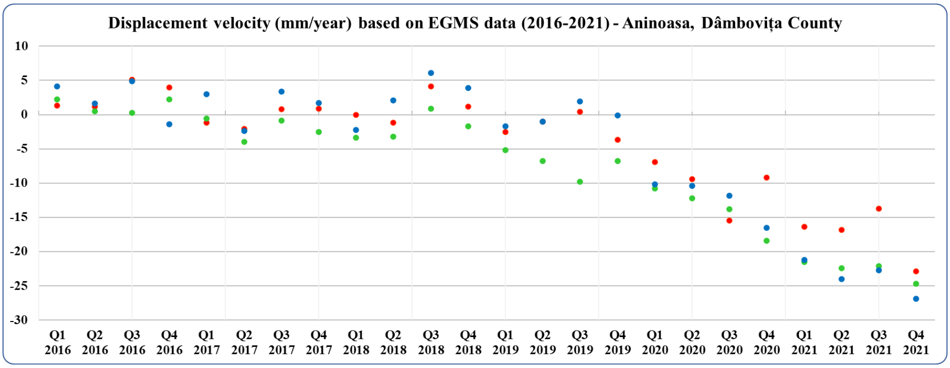

Figure 20. Persistent scatterers displaying the most significant displacement rates (2016-2021) - Aninoasa

Bârcea Mare (located in Hunedoara County) is a landfill that is in use since 2017. Only the first cell is built, the second one will be functional starting with 2028. Based on the analysis of the EGMS data, this landfill presents positive displacement values that are specific to land uplift, with mean values in the range of 5-10 mm/year. The mean displacement values were computed based on only 4 persistent scatterers identified within the test site, hence the landfill necessitates systematic monitoring for a longer time frame due to the atypical values measured. However, a possible explanation might be that the landfill does not have any closed cells within the monitoring interval, therefore the proper identification of persistent scatterers in the multitemporal series of satellite data could have been hindered.

Ghizela and Mofleni landfills (Figure 8) have a similar displacement evolution. Ghizela (Timiș County) is operational since 2012; its first cell functioned until November 2019; currently, the second cell is in service. The volumes deposited during 2019 were significantly higher than the ones stored between 2014 and 2018. A clear negative displacement trend is observed starting with the third quarter of 2018. In what concerns Mofleni landfill, it is operational starting with 2006 and collects waste from the entire Dolj County. Between 1970 and 2005, a non-compliant waste disposal site functioned in the same place. At the level of 2021, the first cell of the Mofleni landfill was closed, cells 2, 3, 4 and 5 were temporarily covered and cell 6 was operational. In this case, subsidence is observed starting with the end of 2017, reaching more significant displacement values at the end of the monitoring window. The 3 persistent scatterers that exhibit the most considerable subsidence values have values in the range of -15 mm/year ± -20 mm/year, in December 2021 (Figure 21). Their progression in time is comparable.

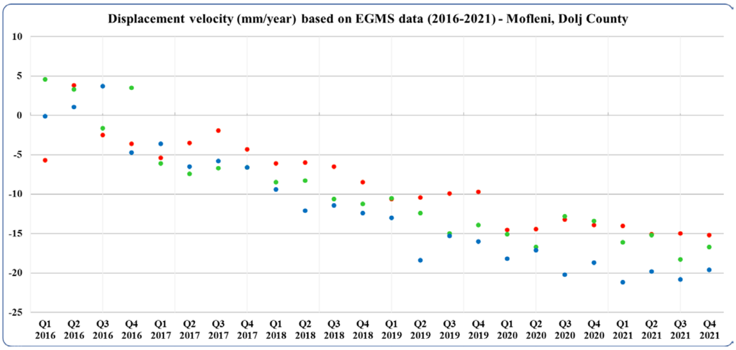

Figure 21. Persistent scatterers displaying the most significant displacement rates (2016-2021) - Mofleni

CONCLUSIONS

The analysis revealed that EGMS dataset offers good results in the identification of subsidence, considering that for 8 out of the 15 investigated landfills, the phenomenon could be identified and accurately monitored within the specific time frame. The rest of the monitored landfills present trends that relatively indicate stability. However, it should be kept in mind that a proper monitoring interval for the landfill settlement process is much longer. Therefore, the EGMS dataset might represent an important tool for landfill management since it enables both the detection and long-term, systematic monitoring of land subsidence, that could be correlated with the landfill settlement process. This aspect is of particular importance for environmental risk assessment. In addition, the EGMS dataset provides insights also about the surrounding areas, over large regions, hence the estimation of the landfill impact or the detection of other potential threats may be accomplished as well.

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