Mapping fast fashion landfills: remote sensing and GIS approach to analyze textile waste

Elia Stoyanova[1], Viktor Vitov[2]

[1] University of Architecture, Civil Engineering and Geodesy (UACEG), Faculty of Geodesy, Department of Photogrammetry and Cartography, Sofia, Bulgaria – stoyanova.elia@gmail.com
[2] University of Mining and Geology "St. Ivan Rilski", Faculty of Geology and Exploration, Department of Engineering Geoecology, Sofia, Bulgaria – vvitov@abv.bg

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Abstract

The rise of fast fashion has led to a surge in textile waste, with discarded clothing often ending up in unregulated landfills, posing significant environmental and social challenges. This has become a pressing global concern, as textile waste contributes significantly to pollution and land degradation. The study area covers an illegal clothing dump located near Iquique, Atacama Desert, Republic of Chile. This research focuses on mapping and analysing fast fashion landfill using remote sensing and Geographic Information Systems (GIS) to uncover the spatial and temporal dynamics of textile waste accumulation. By leveraging satellite imagery and spectral analysis, we identified the spatial extent and the "development" of the illegal clothing dump for the period from November 2016 to November 2024, highlighting their environmental footprint. Spectral analysis techniques were applied to distinguish textile waste from other materials using their unique spectral signatures. Temporal analysis further revealed trends in landfill growth, offering insights into the dynamics of textile waste accumulation.
This study emphasizes the utilization of open-source tools and freely accessible data to ensure reproducibility and accessibility. The adoption of open data and open-source software underpins the research's commitment to fostering transparency, reproducibility, and iterative improvements. By leveraging these resources, the study facilitates reusability and innovation in addressing similar environmental challenges. By demonstrating the utility of remote sensing and GIS as scalable, cost-effective tools for monitoring illegal waste sites, this study provides a framework for addressing similar challenges globally. This research also highlights the critical role of interdisciplinary approaches in tackling the complex environmental challenges.

1. Introduction

The rapid expansion of the fast fashion industry has led to a significant rise in textile waste, much of which ends up in landfills across the globe. The environmental consequences of these landfills are severe, contributing to soil and water contamination, greenhouse gas emissions, and long-term ecological degradation. Despite growing awareness of the issue, a lack of comprehensive data on the location, scale, and impact of fast fashion landfills presents a challenge for policymakers and environmentalists alike.

In recent years, advancements in geospatial technology have provided new tools for analysing and monitoring environmental concerns. Remote sensing and Geographic Information Systems (GIS) offer powerful methods to identify and map textile waste accumulation sites, assess their impact, and track changes over time. Using satellite imagery and spatial analysis techniques can help to better understand the global footprint of fast fashion.

This paper examines the use of remote sensing and GIS to identify and analyse fast fashion landfills, offering insights into the spatial extent and progression of illegal clothing dumping (Iquique, Atacama Desert, Republic of Chile) over an eight-year period (November, 2016 - November, 2024). By leveraging geospatial technology, this study seeks to bridge gaps in existing research, providing a data-driven foundation for more effective waste management strategies. Additionally, it underscores the critical role of geospatial analysis in tackling textile waste while highlighting the pressing need for sustainable practices within the fashion industry.

2. Main problem

In our contemporary world convenience has become the new norm. Life has become fast-paced and almost every aspect of our being can be delivered with a simple click. It has never been so simple – you like a product and you obtain it. But it comes with a hidden toll – the cost of production, transport of the goods, labor and material longevity. Thus, a major problem concerning what happens after the use of the product emerges.

This paper focuses on the impact of so called „Fast Fashion''. The term was first introduced in around the 1990s. An article in the New York Times referenced the process of designing a garment to being shipped in stores in just 2 weeks. The drawbacks that this type of manufacturing create several environmental and sustainability issues.

The significant impacts of the textile industry are related to:

- Climate
- Freshwater use
- Chemical pollution
- Biodiversity
- Social issues

2.1 Climate

According to the Quantis International 2018 report, the combined apparel and footwear industry generated between 5 and 10 % of global pollution impacts in 2016. The graph below displays the amount of million metric tons carbon dioxide equivalent (CO_2eq) generated in 2016.

	%	MILLION METRIC TONS CO_2eq
Apparel	6.7%	3,290
Footwear	1.4%	700
Total apparel & footwear impacts	**8.1%**	**3,990**
Compared to:		
Total global CO_2eq impacts	100%	49,300

Figure 1. Total apparel & footwear industries’ impacts compared to total global impacts in 2016 [Quantis. 2018]

There are 7 different stages in garment cycle:

1. Fiber production
2. Yarn Preparation
3. Fabric Preparation
4. Dyeing and Finishing
5. Assembly
6. Distribution
7. Disposal

The Quantis International 2018 report found that the three main drivers of the industry’s global pollution impacts are dyeing and finishing (36%), yarn preparation (28%) and fiber production (15%). According to the UN Framework Convention on Climate Change, emissions from textile manufacturing alone are projected to skyrocket by 60% by 2030.

2.2 Freshwater use

The environmental impact of fast fashion involves exhaustion of non-renewable sources, use of enormous amounts of energy and water and greenhouse gases.
Textile dyeing is the second largest polluter of water globally since the water leftover from the dyeing process is often dumped into ditches, streams or rivers. It takes around 7570 liters of water to make a typical pair of jeans and 757 liters to produce one cotton shirt.

2.3 Chemical pollution

The use of synthetic fibers like polyester, nylon and acrylic take hundreds of years to biodegrade. A 2017 report from the International Union for Conservation of Nature (IUCN) estimated that 35% of all microplastics – tiny pieces of non-biodegradable plastic – found in the ocean come from the laundering of synthetic textiles like polyester. The production of leather requires large amounts of feed, land, water and fossil fuels to raise livestock, while the tanning process is among the most toxic in all of the fashion supply chain because the chemicals used to tan leather- including mineral salts, formaldehyde, coal-tar derivatives and various oils and dyes- is not biodegradable and contaminates water sources.

2.4 Biodiversity and Social issues

Due to the location of the landfill the fauna and flora is limited in the specific region and the impact on them is minimal. More substantial is the Social factor – every second, the equivalent of one garbage truck of textiles is landfilled or burned. This practice leads to wasteful land utilization, soil contamination from microplastics and using poor regions with lax government control to be used as dumping sites without regulations.

3. Study area and dataset

3.1 Study area

As mentioned, the study covers an illegal clothing dump located near Iquique, Atacama Desert, Republic of Chile (Fig. 2).

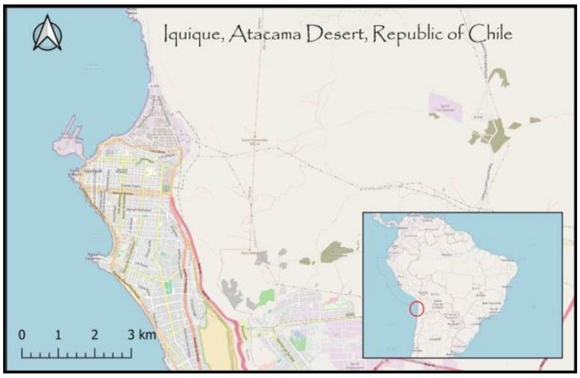

Figure 2. Area of interest: Iquique, Republic of Chile

The illegal clothing dump near Iquique in Chile was selected as an object of interest due to its significant environmental, social, and economic implications. The Atacama Desert, one of the driest places on Earth, is particularly vulnerable to pollution, and the discarded textiles, mostly made from synthetic materials, degrade very slowly, contributing to microplastic contamination and land degradation.

The vast scale of the dump makes it easily visible from space, a key advantage for satellite monitoring. Remote sensing techniques are used to analyze the growth and spread of the dump over time, providing valuable information on its development. In addition, the Iquique Free Trade Zone (Zona Franca de Iquique, ZOFRI) imports a large amount of second-hand clothing each year, playing a crucial role in the global textile waste stream. A satellite image from Google Earth from June 13, 2004 shows that the illegal and indiscriminate dumping of clothes began more than 20 years ago (Fig. 3).

Figure 3. The beginning of the landfill, 2004 © Google Earth

GIS technology allows for precise mapping of affected areas, helping to identify patterns of illegal dumping and informing waste management policies. The clear skies and minimal vegetation of the Atacama Desert provide an ideal environment for continuous satellite monitoring, allowing changes to be tracked throughout the years.

The study examines a period of more than eight years, spanning from November 2016 to November 2024, offering an exploration of changes and patterns over time. Figure 4 shows a photo from 2021, showing a small portion of the discarded clothing in the illegal landfill.

Figure 4. Aerial view of discarded used clothes in the Atacama Desert, September 2021 © Martin Bernetti/Getty Images

3.2 Dataset

This study utilizes images from Sentinel-2, which are freely available through the European Space Agency (ESA) as part of the Copernicus program. All imagery used in the research was sourced from the Copernicus Browser.

Level-2A Sentinel-2 products were selected as they met the criteria for surveying the target area. These optical multispectral images offer medium spatial resolution, with a revisit frequency of just a few days, ensuring consistent data acquisition. Additionally, they cover the necessary electromagnetic spectrum ranges, making them suitable for the study's objectives. As per the Sentinel-2 tiling grid system, the Iquique region is located within tile number 19KCT.

A total of 25 multispectral images from Sentinel-2 were analyzed to monitor changes in the illegal dump over time. The study focused on images of the same area captured at different periods, covering the timeframe from November 2016 to November 2024. For each year, three images were selected—one from March, July, and November—to ensure a comprehensive temporal assessment. Detailed information about the selected images is provided in Table 1.

Table 1. Information about Sentinel-2 images

№	Mission	Image type	Date	Tile Number
1	Sentinel-2A	S2MSI2A	November 23, 2016	19KCT
2	Sentinel-2A	S2MSI2A	March 13, 2017	19KCT
3	Sentinel-2A	S2MSI2A	July 31, 2017	19KCT
4	Sentinel-2A	S2MSI2A	November 18, 2017	19KCT
5	Sentinel-2B	S2MSI2A	March 13, 2018	19KCT
6	Sentinel-2A	S2MSI2A	July 16, 2018	19KCT
7	Sentinel-2B	S2MSI2A	November 8, 2018	19KCT
8	Sentinel-2B	S2MSI2A	March 18, 2019	19KCT
9	Sentinel-2B	S2MSI2A	July 26, 2019	19KCT
10	Sentinel-2B	S2MSI2A	November 3, 2019	19KCT
11	Sentinel-2B	S2MSI2A	March 22, 2020	19KCT
12	Sentinel-2A	S2MSI2A	July 15, 2020	19KCT
13	Sentinel-2B	S2MSI2A	November 17, 2020	19KCT
14	Sentinel-2B	S2MSI2A	March 17, 2021	19KCT
15	Sentinel-2A	S2MSI2A	July 10, 2021	19KCT
16	Sentinel-2A	S2MSI2A	November 17, 2021	19KCT
17	Sentinel-2B	S2MSI2A	March 22, 2022	19KCT
18	Sentinel-2A	S2MSI2A	July 25, 2022	19KCT
19	Sentinel-2A	S2MSI2A	November 12, 2022	19KCT
20	Sentinel-2B	S2MSI2A	March 17, 2023	19KCT
21	Sentinel-2A	S2MSI2A	July 30, 2023	19KCT
22	Sentinel-2A	S2MSI2A	November 27, 2023	19KCT
23	Sentinel-2B	S2MSI2A	March 11, 2024	19KCT
24	Sentinel-2A	S2MSI2A	July 14, 2024	19KCT
25	Sentinel-2A	S2MSI2A	November 11, 2024	19KCT

4. Methods

4.1 Workflow

A structured workflow is essential for studies involving remote sensing and GIS in the analysis of textile landfills, ensuring accuracy, consistency, and reliability in data collection, processing, and interpretation. Given the complexity of satellite imagery and geospatial analysis, a well-defined approach is necessary to produce meaningful and reproducible results. It also fosters collaboration among team members by providing a shared understanding of the methodology.

Remote sensing studies rely on satellite images captured at different time periods, making standardized data selection and preprocessing crucial for maintaining consistency. Steps such as subsetting and resampling help minimize errors and ensure comparability across different datasets. Additionally, a structured workflow streamlines image processing, enabling more efficient handling of large datasets. A systematic approach also enhances temporal and spatial analysis, allowing researchers to assess changes in landfill size and composition under uniform conditions. For the purposes of the study, the workflow presented in Figure 5 was used.

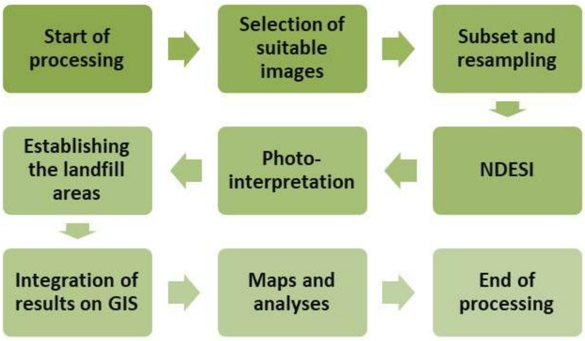

Figure 5. Study workflow

4.2 Initial processing

As detailed in Table 1, 25 multispectral optical satellite images were acquired and processed for the purposes of this study. The selection criteria for these images included both the acquisition date and the percentage of cloud cover present at the time of capture.

A subset of the original remote sensing dataset, defined by geographic coordinates, was extracted to delineate the study area. This reduced processing time and enabled focused analysis of the area of interest. The subset retained all original metadata, including sensor information, acquisition parameters, and spatial reference system, ensuring data integrity. This approach optimized computing resources, reduced processing time, and facilitated the extraction of relevant information for analysing the illegal landfill.

Resampling of remote sensing products involves modifying the sampling rate by adjusting pixel size, transforming the original image grid into a new spatial resolution. This process standardizes pixel dimensions, enabling the comparison of images or bands with different resolutions. The Nearest Neighbour resampling method was applied, assigning the value of the closest source pixel to the corresponding element in the resampled image. Band 2 (B2) was chosen as the reference due to its high 10 m resolution, with all other bands resampled accordingly.

4.3 Spectral analysis

Spectral analysis is a powerful tool for mapping fast fashion landfills, enabling the detection, classification, and monitoring of textile waste using remote sensing and GIS. Given the environmental impact of discarded textiles, this approach provides critical insights into the landfill expansion over time. Leveraging spectral data enables a more effective response to the growing issue of textile pollution, supporting global sustainability efforts.

One of the key advantages of spectral analysis is its ability to differentiate textile waste from natural land cover. Textile materials exhibit distinct spectral signatures compared to surfaces like soil, vegetation, sand, and water (Fig. 6). Synthetic fabrics (e.g., polyester, nylon) and organic textiles (e.g., cotton, wool) reflect light differently across the visible, near-infrared (NIR), and shortwave infrared (SWIR) bands, making it possible to map textile waste effectively.

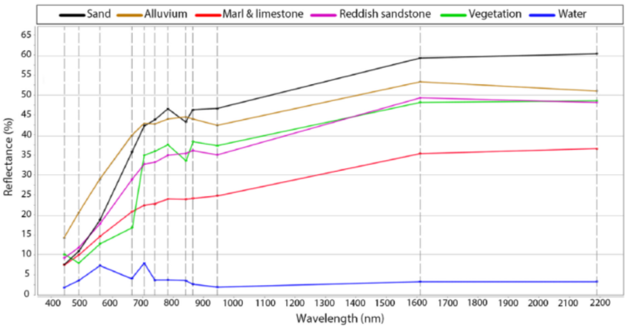

Figure 6. Reflectance curves of different surfaces [Marz. et al.]

Textile waste possesses distinct spectral characteristics that differentiate it from the surrounding environment, making it possible to analyse and classify using remote sensing techniques. In the context of this study, the illegal landfill is situated in a desert region, where the predominant land cover consists of sand. Due to the significant spectral contrast between textile waste and the sandy terrain, it is essential to apply an appropriate spectral index to enhance the distinction between these materials.

To achieve this, the Normalized Difference Enhanced Sand Index (NDESI) [Marz. et al.] was employed as a key analytical tool. This index is specifically designed to enhance the detection of sandy surfaces, making it particularly effective for distinguishing non-sand materials, such as textile waste, from the surrounding environment. By leveraging the spectral properties of sand and textile waste in different wavelengths, NDESI (Equation 1) facilitates more accurate classification and mapping of landfill sites within arid landscapes.

$$\mathrm{NDESI} = \frac{(\mathrm{B4}-\mathrm{B2})}{(\mathrm{B4}+\mathrm{B2})} - \frac{(\mathrm{B12}-\mathrm{B11})}{(\mathrm{B12}+\mathrm{B11})}, \quad (1)$$

where:
B2 = Blue band in Sentinel-2 image
B4 = Red band in Sentinel-2 image
B11 = SWIR band in Sentinel-2 image
B12 = SWIR band in Sentinel-2 image

Figure 7 provides a visual representation of the application of the index in the mapping of the landfill, demonstrating its effectiveness in distinguishing textile waste from the surrounding environment. To facilitate more effective photo interpretation, the image in natural colours (RGB) is presented on the left, while the image with the applied NDESI index is displayed on the right.

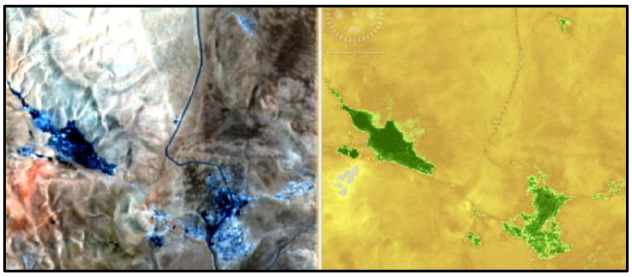

Figure 7. NDESI result (November 23, 2016)

4.4 Establishing the landfill areas

The most critical aspect of this study is the accurate identification of areas containing textile waste within the illegal landfill. To achieve this, it is necessary to establish a threshold for the values obtained when calculating the spectral NDESI index.

Marzouki and Dridri (2022) propose a formula that incorporates a specific coefficient along with the minimum and maximum values of the NDESI image, ultimately providing an accurate threshold for sand. However, their approach is designed for distinguishing various types and classes of sand. In contrast, our study requires the determination of a single value that effectively differentiates sand from textile waste.

To accomplish this, a statistical analysis was conducted on the pixels resulting from the application of the NDESI index. Several polygons were delineated and overlaid on the RGB image, marking areas containing sand and textile waste. These polygons were categorized into two distinct classes (Vector Data Containers): one representing sand and the other representing the landfill.

Based on the spatial distribution of these polygons and the corresponding NDESI index values, the statistical graph shown in Figure 8 was generated. This graph presents a dataset illustrating the pixel values associated with the two defined object classes. The results indicate that, in this study, NDESI values exceeding 0.30 correspond to sand, while more than 95% of the pixels associated with textile waste exhibit values below 0.25. Consequently, a threshold value of 0.25 was established, below which the presence of textile waste is assumed, thereby enabling the identification of landfill areas.

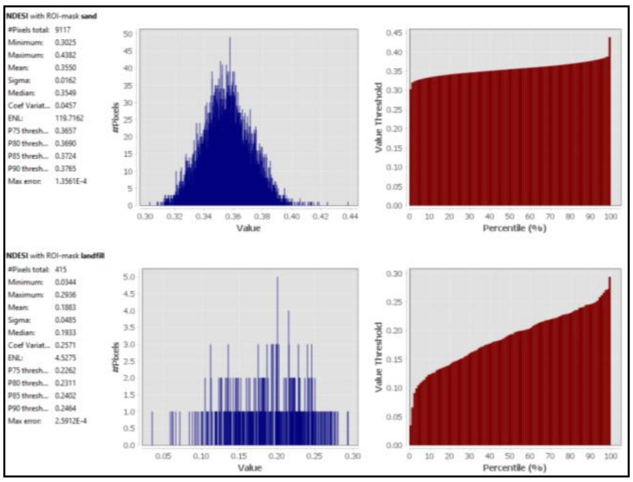

Figure 8. Pixel statistics for NDESI (sand and landfill)

The use of multispectral satellite imagery and spectral analysis enabled a comprehensive time-series analysis, facilitating the identification of patterns related to textile waste accumulation and illegal dumping activities. By monitoring spectral variations over time, the study successfully detected the expansion of the landfill resulting from newly deposited waste. Furthermore, the spatial distribution of textile waste was assessed, and the results were integrated into GIS to generate maps visualizing the extent and progression of landfill growth throughout the study period.

4.5 Integration of results in GIS

The integration of results into Geographic Information Systems (GIS) plays a pivotal role in this study. GIS serves as a powerful tool for organizing, analyzing, and visualizing remote sensing data, facilitating a comprehensive spatial assessment of textile waste accumulation and landfill expansion. By incorporating spectral indices and time-series analysis, GIS enhances the interpretation of landfill dynamics and supports data-driven decision-making in environmental management.

Beyond visualization, GIS enables spatiotemporal analysis, allowing for the tracking of changes in textile waste accumulation over time. Through the analysis of multi-temporal datasets, the study identifies growth patterns, shifts in spatial distribution, and the progression of illegal dumping activities, providing critical insights into landfill expansion trends.

5. Results and analyses

For the purposes of this study, following the implementation of the proposed workflow, the spatial distribution of the illegal landfill was mapped across 25 different dates. Based on the obtained data, the respective areas of discarded textile waste were calculated, leading to the creation of various thematic maps and comprehensive analyses.

Figure 9 illustrates the spatial distribution of the landfill at the initial and final stages of the study, specifically on November 23, 2016 (depicted in red) and November 11, 2024 (depicted in blue). The figure provides a visual representation of the development and expansion of the illegal landfill over an eight-year period.

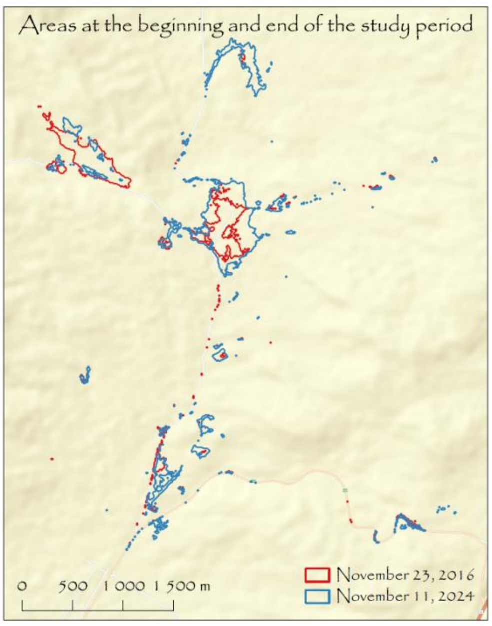

Figure 9. The landfill at the beginning and end of the study

Figure 10 presents the spatial distribution of the landfill at the points when it reached its maximum and minimum extent during the study period. Specifically, on November 3, 2019 (depicted in green), the landfill covered approximately 87.8 hectares, whereas on July 15, 2020 (depicted in purple), its area was reduced to 32.7 hectares.

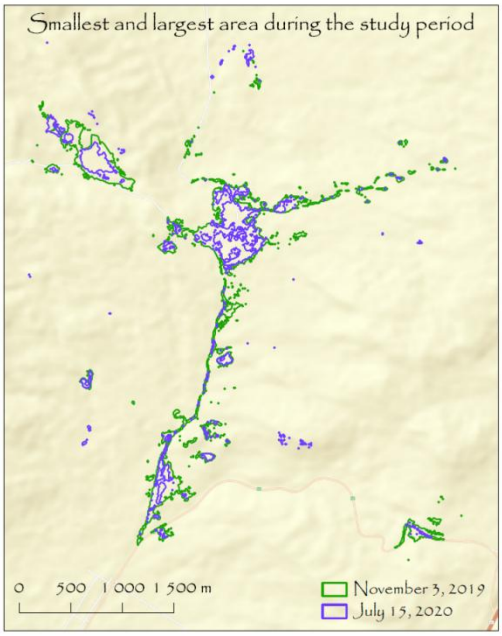

Figure 10. The landfill at its minimum and maximum extent

Figure 11 provides a detailed view of two areas within the landfill that have undergone the most significant changes. The upper section highlights an area that was already covered with waste in 2004 but experienced a substantial reduction by 2024 due to remediation efforts. In contrast, the lower section illustrates an area that began forming in 2016 and had expanded significantly by 2024.

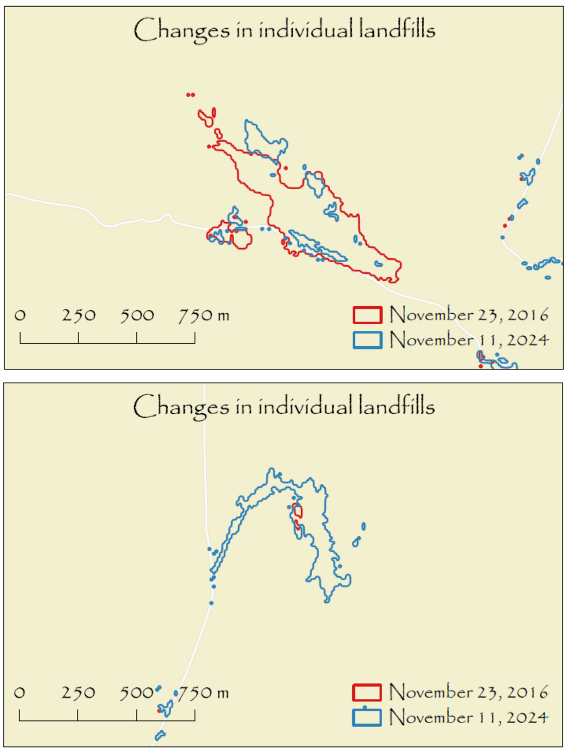

Figure 11. Changes in individual landfills

Figure 12 illustrates the spatial distribution of the landfill in November of each year throughout the study period, represented in different colours. The progression is depicted from red at the beginning of the study, transitioning through orange, yellow, and green, to blue at its conclusion. A reduction in landfill area is observed at the western end; however, in contrast, a significant expansion is evident across the remaining areas.

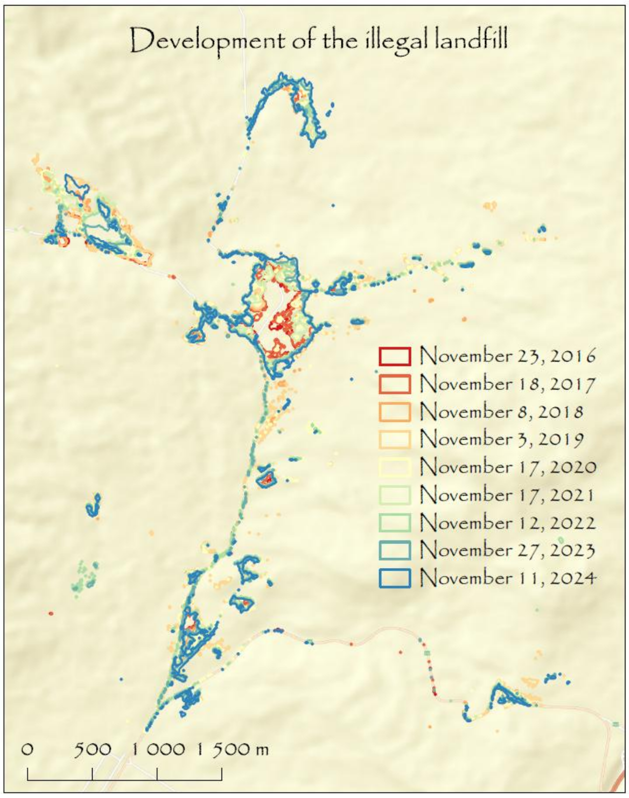

Figure 12. Eight years of expansion of the illegal landfill.

Figure 13 provides a comprehensive overview of the changes in the area of the illegal textile waste dump throughout the eight-year study period. The data reveals a clear trend of expansion, with the landfill's area consistently increasing over the years. The largest extent of the landfill during the study period occurred in November 2019. Furthermore, the analysis identifies March as the peak month for the growth of the landfill, with a notable increase in its size during this time. In contrast, a decrease in the landfill's area is observed in July, suggesting a seasonal fluctuation in the accumulation of textile waste. This pattern highlights both the ongoing expansion and the temporal variations in the development of the illegal dump.

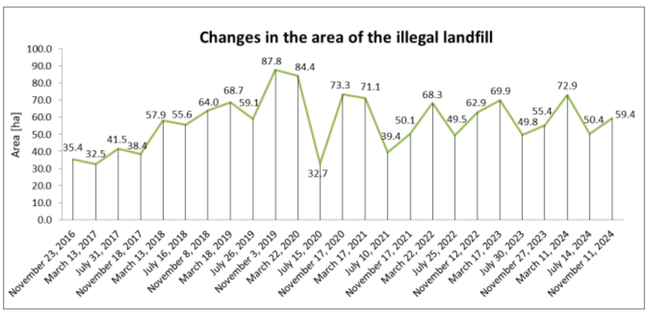

Figure 13. Development in the landfill area

6. Conclusion

Using the spatial and temporal capabilities of satellite sensors, data on the development of an illegal landfill in Iquique, Chile have been collected.

The findings confirm that, with the careful selection of remotely sensed imagery, digital processing techniques can effectively map the spatial distribution of landfills. The implementation of the proposed workflow ensures the generation of reliable, efficient, and rapid results, facilitating accurate landfill monitoring.

In conclusion, this study underscores the efficacy of utilizing remote sensing and Geographic Information Systems (GIS) for the mapping of fast fashion landfills and the analysis of textile waste, employing open-source software and freely accessible satellite imagery. The integration of these advanced technologies provides a cost-effective, scalable solution for monitoring the spatial distribution and progressive expansion of textile waste over time.

The results highlight the indispensable role of remote sensing and GIS in addressing the growing challenge of textile waste, offering a practical and adaptable framework for future research and policy development in waste management and sustainability. Furthermore, a deeper understanding of the scale and environmental impact of these illegal landfills can support the development of more effective policies, waste management systems, and recycling strategies. Ultimately, this will contribute to the well-being of both local communities and the broader global environment.

Furthermore, this study aligns with three of the United Nations Sustainable Development Goals (SDGs) outlined in the 2030 Agenda for Sustainable Development:

- Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation

Supports domestic technology development, research, and innovation in developing countries by ensuring a conducive policy environment for industrial diversification and value addition to commodities.

- Goal 12: Ensure sustainable consumption and production patterns

Contributes to the reduction of waste generation through prevention, reduction, recycling, and reuse by 2030.

- Goal 13: Take urgent action to combat climate change and its impacts

Promotes mechanisms for enhancing capacity in climate change-related planning and management, particularly in least developed countries and small island developing states, with a focus on women, youth, and marginalized communities.

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