materials proceedings

Proceeding Paper

Flood Detection in Complex Surface Mining Areas Using Satellite Data for Sustainable Management †

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† Presented at the 2nd International Conference on Raw Materials and Circular Economy "RawMat2023", Athens, Greece, 28 August–02 September 2023.

Abstract: In the context of the lignite phase-out plan in Greece, the aim of the Public Power Corporation (PPC) is sustainable mine closure and land reclamation and, at the same time, the enhancement of safe mining and post-mining activities. The main objective of this study is to provide a methodology to identify the areas in complex surface mining landscapes that are more vulnerable to flooding using remotely sensed satellite data. This is an integral part of the strategic planning of the new land uses and the design of new and improved water management strategies. In this research, the change detection method is applied using Synthetic Aperture Radar (SAR), and flood-prone zones are delineated.

Keywords: remote sensing data; Synthetic Aperture Radar (SAR); sentinel-1; Support Vector Machine (SVM); Ptolemais Basin; lignite mines; post-mining

Citation: Karalidis, K.; Louloudis, G.; Roumpos, C.; Mertiri, E.; Pavloudakis, F. Flood Detection in Complex Surface Mining Areas Using Satellite Data for Sustainable Management. *Mater. Proc.* **2023**, *15*, 1. https://doi.org/10.3390/materproc2023015001

Academic Editors: Antonios Peppas, Charalampos Vasilatos and Anthimos Xenidis

Published: 9 October 2023

1. Introduction

According to the World Health Organization (WHO), in the last ten years, floods have been the cause of 80–90% of all known natural disasters, and due to climate change, the frequency and intensity of floods are expected to increase [1]. Much literature has been published on flood detection and mapping [2,3]. Remote sensing data integrated with geographical information systems (GIS) presents a helpful tool in delineating flooding areas [4,5] and providing spatiotemporal information. Flood scenarios [6] need to be considered for accurate flood mapping, thus reducing false alarms and missed identifications.

Floods are a major threat that should be considered during the mining operation and, in the post-mining stage, in land use repurposing and reclamation strategies. The main objective of this research is to provide a methodology to detect flood events in complex mining areas using Synthetic Aperture Radar (SAR) images and remote sensing data during extreme weather events.

2. Materials and Methods

2.1. Research Area

This research focuses on the Ptolemais lignite mines in northern Greece, where the exploitation of lignite has been carried out for more than 60 years [7]. The Public Power Corporation (PPC) of Greece operates three lignite mines using open-cast mining: Mavropigi, Kardia, and South Field [8] (Figure 1). This study area is located between the Skopos, Askion, and Vermion mountains, where a complex stream network is evident. The rainwater flows into the Soulou river, which discharges into Vegoritis Lake [8].

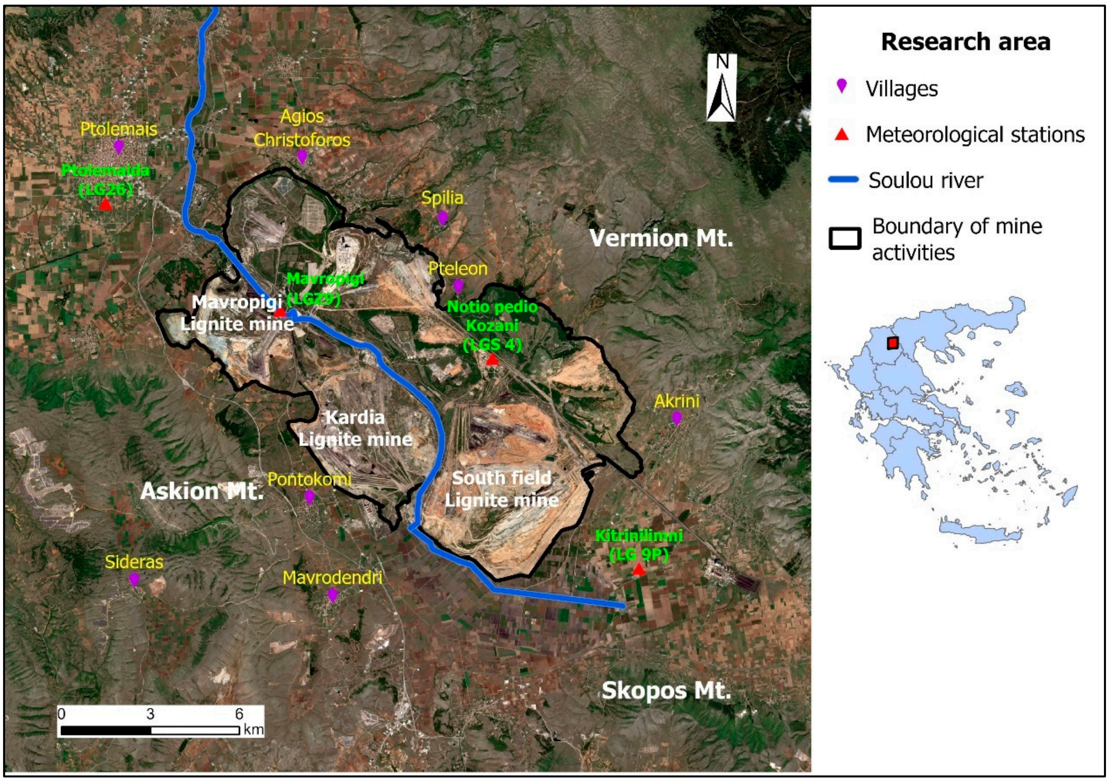

Figure 1. Location of the Ptolemais lignite mines and meteorological stations in the geographical space.

2.2. Methods

To identify the floods in the mining area of Ptolemais, two dates were selected after extreme weather events using meteorological data from the National Observatory of Athens (https://www.meteo.gr/Gmap.cfm (accessed on 24 April 2023)). Heavy rainfall events are recorded between 7 September 2016 and 9 September 2016 (49.4 mm maximum daily precipitation) and between 20 August 2022 and 24 August 2022 (27.6 mm maximum daily precipitation). This research employs Ground Range Detected (GRD) products from Sentinel-1 SAR images using the interferometric wide swath (IW) mode and a combination of vertical (V) and horizontal (H) wave polarizations (Table 1). Both pre-flood and post-flood images were selected to distinguish the permanent water bodies and the flooding regions.

Table 1. Available sentinel-1 data for the pre- and post-flooding events.

Acquisition Date	Mode	Orbit	Pixel Size	Polarization
27 May 2016 (pre-flood)	IW	Ascending	10×10	VV-VH
12 September 2016 (post-flood)	IW	Ascending	10×10	VV-VH
1 June 2022 (pre-flood)	IW	Ascending	10×10	VV-VH
24 August 2022 (post-flood)	IW	Ascending	10×10	VV-VH

Data generated from the Copernicus open access hub (https://scihub.copernicus.eu/ (accessed on 20 March 2023)).

The procedure proposed is divided into two main steps: (1) the pre-processing of the data using the Sentinel Application Platform (SNAP) and (2) the post-processing where the Support Vector Machine (SVM) algorithm [9] was deployed to identify the flood areas (Figure 2). Firstly, the orbit files adapt the orbit, the velocity, and the position of the satellite. After that, the thermal noise was removed in cross-polarization [3], and the invalid backscatter and low intensity were removed from the edges of the images. The images were then calibrated to obtain the radiometrically calibrated backscatter at each pixel. Following that, speckle filtering [4,10] is applied using the Intensity Driven Adaptive Neighborhood (IDAN) filter to lessen the granular disturbances or speckles in the images brought on by the interference of signals from several scatterers. Subsequently, terrain correction was applied to reduce terrain effects in sloped regions as well as obtain valid geolocation. Then, the images adapted to this study area are converted into decibels (dB). The last pre-processing step was to merge the water bodies to distinguish the permanent water bodies (non-flood) and the flooding areas (flood) (Figure 3). The ArcGIS software was used to collect the samples for the classification, perform the SVM classification, and validate the results.

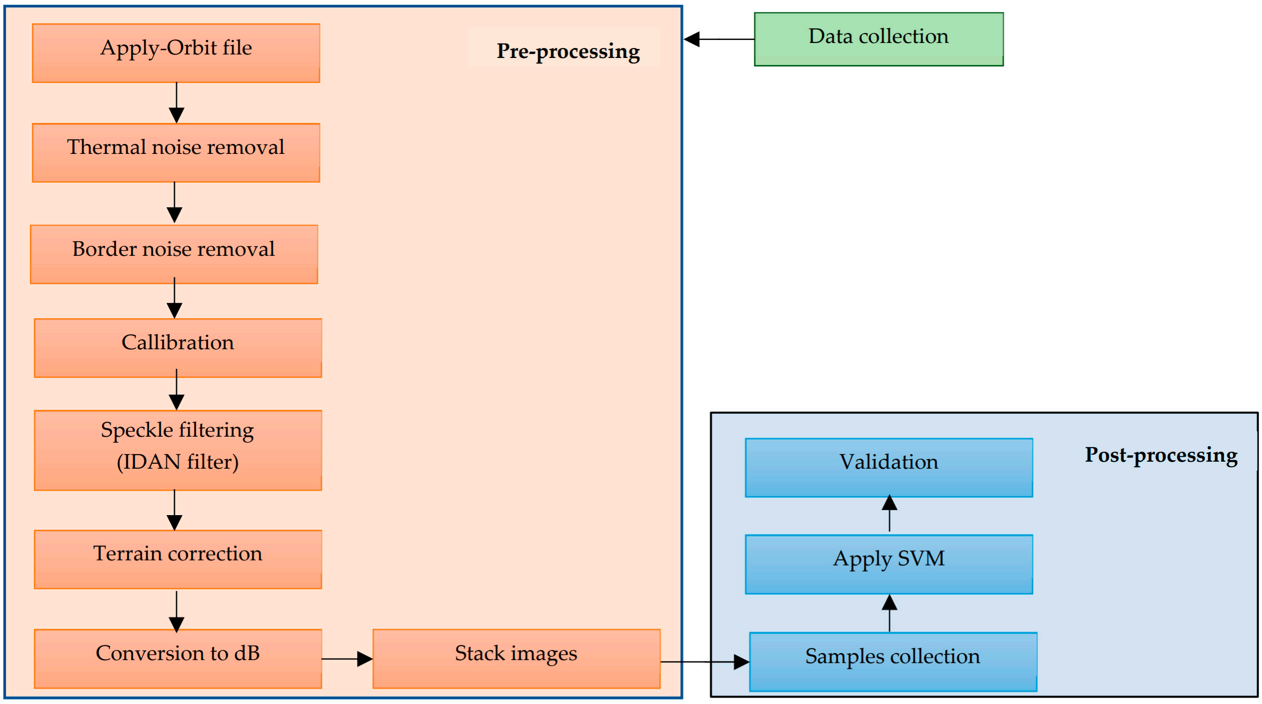

Figure 2. Flowchart of the applied methodology.

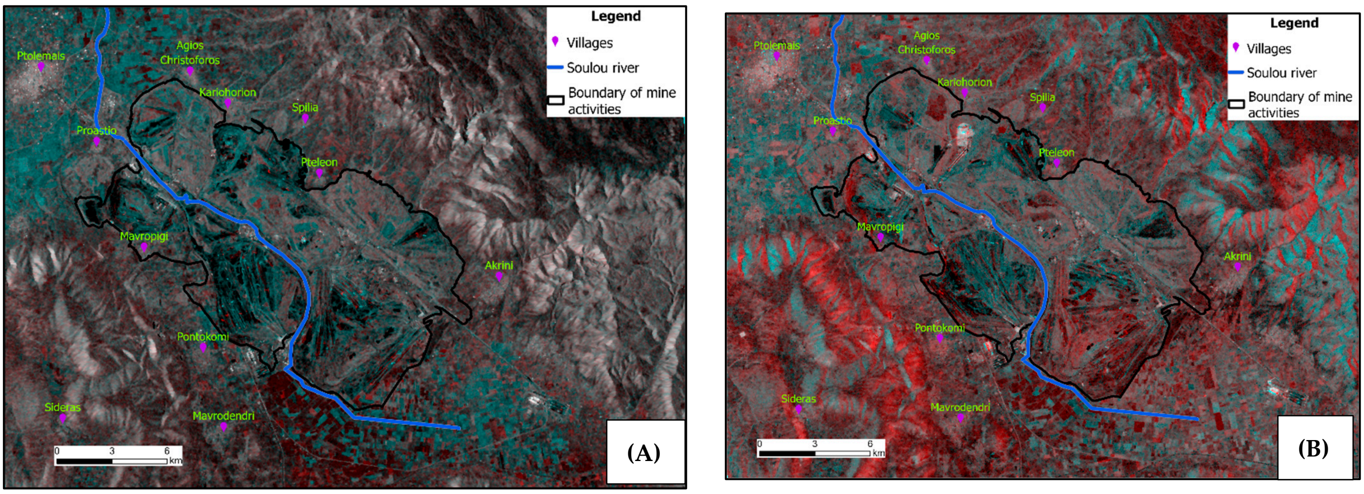

Figure 3. Stack sentinel-1 images (**A**) on 12 September 2016; (**B**) on 24 August 2022. Dark red highlights flooded areas, while light red reveals image shadow disparities.

3. Results and Discussion

The classification results are shown in Figure 4. It is apparent that most of the flooded areas are outside the boundaries of the mine activities and mainly in the agricultural area (south and southwest of the boundary) near Mavrodendri village, close to the Soulou river. Furthermore, flooded areas can be seen scattered inside the boundaries of mine activities in Mavropigi, Kardia, and South field lignite mines, where most of these areas are mine sumps. On the contrary, the agricultural fields near the city of Ptolemais were slightly affected by high precipitation levels, appearing to be more resilient to extreme weather events. Comparing the two different time periods, in 2022, flooded areas can also be seen southeast near Akrini village and north near Agios Christoforos village, where crop fields appear. Finally, agricultural fields that were resilient in 2016 and will continue unaffected by high rainfall levels in 2022 are evident.

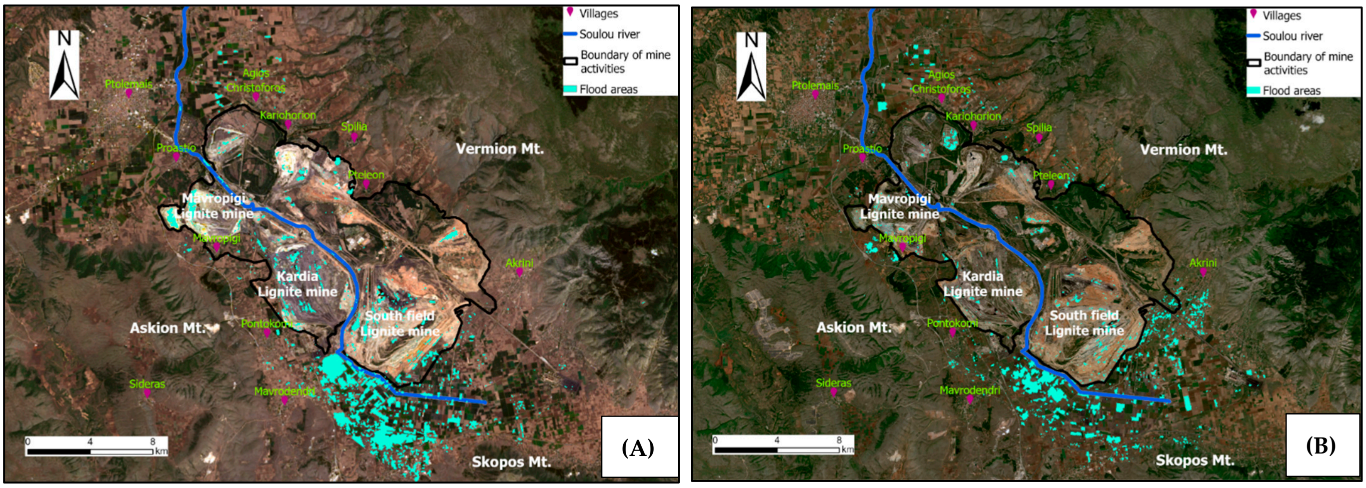

Figure 4. Flood detection using SVM classification: (**A**) on 12 September 2016; (**B**) on 24 August 2022.

To validate the results, 500 random points were generated using the create accuracy assessment points tool in ArcGIS and then assigned the ground truth values to evaluate the accuracy of the classification. The confusion matrix tool [11] was employed to visualize the accuracy of the results.

Tables 2 and 3 show the validation results, where the producer accuracy (P_Accurancy) or error of omission demonstrates how accurately the classification results depict the flood and non-flood areas, regarding the years 2016 and 2022, respectively. In addition, the errors of commission or user accuracy (U_Accuracy) show the improperly classified pixels. For 2016, 84% and 100% of the flood and non-flood areas were classified correctly, while for 2022, 85% and 99%, respectively. The U_Accuracy is in both categories above 90%, indicating that the incorrectly classified pixels are very low. Regarding the flood category, U_Accuracy is lower in 2022, while the non-flood category remains similar. Finally, the kappa statistics were produced to examine the overall assessment of the classification, indicating strong agreement between the actual values and the classification.

Table 2. Confusion Matrix of control points results for the year 2016.

ClassValue	Flood	Non-Flood	Total	U_Accuracy (%)	Kappa
Flood	32	2	34	94	0
Non-flood	6	460	466	99	0
Total	38	462	500	0	0
P_Accuracy (%)	84	100	0	98	0
Kappa	0	0	0	0	88

Table 3. Confusion Matrix of control points results for the year 2022.

ClassValue	Flood	Non-Flood	Total	U_Accuracy (%)	Kappa
Flood	22	5	27	81	0
Non-flood	4	469	473	99	0
Total	26	474	500	0	0
P_Accuracy (%)	85	99	0	98	0
Kappa	0	0	0	0	82

4. Conclusions

The area of Ptolemais lignite mines is an environment that has changed rapidly over the last few years. Today, it is characterized by the complexity of having mine exploitation areas and, at the same time, land reclamation works for rapid mine closure. Modern monitoring systems, such as remote sensing, can be sufficiently robust for assessing flooding areas.

This research employs an SVM classification on merged SAR images to detect floods and non-flood areas. The results of the analyses indicated that the areas that were flooded in 2016 are almost similar to those in 2022, while the areas that are more susceptible to flooding are agricultural areas near the Soulou river. Additionally, the flooded areas inside the boundary of mine activities are scattered mainly in the waste dump area. The findings of this study indicated the importance of remote sensing data in flood monitoring in complex mining areas, as the applied methodology provides a rapid and effective tool for flood detection. Aims for future research include delineating zones prone to flooding and evaluating flood risk.

Author Contributions: Conceptualization, K.K., G.L., C.R., E.M. and F.P.; methodology, K.K., G.L., C.R., E.M. and F.P.; software, K.K. and E.M.; validation, K.K., G.L., C.R., E.M. and F.P.; formal analysis, K.K., G.L., C.R., E.M. and F.P.; investigation, K.K., G.L., C.R. E.M. and F.P.; resources, K.K., G.L., C.R. E.M. and F.P.; data curation, K.K., G.L., C.R., E.M. and F.P.; writing—original draft preparation, K.K., G.L., C.R. and E.M.; writing—review and editing, K.K., G.L., C.R., E.M. and F.P.; visualization, K.K., G.L., C.R. and E.M.; supervision, G.L. and C.R.; project administration, G.L. and C.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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