HACETTEPE UNIVERSITY
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GRADUATION PROJECT REPORT
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LANDSLIDE MONITORING OVER ALKUMRU DAM RESERVOIR WITH INSAR TECHNIQUES

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ABSTRACT

Detection and monitoring of landslides in Alkumru dam reservoir is important due to the danger they pose to local people, and the maintenance and sustainable use of the infrastructure. Sentinel-1 Interferometric Synthetic Aperture Radar Interferometry (InSAR) datasets and their processing methods provide multi-time surface change information in terms of deformation and enable engineering geological analysis. In this study, we plan to analyze the deformations in large landslides by using InSAR measurements in the reservoir of Alkumru Dam and make estimations of future movements that may occur based on these analyses. The area is prone to landslides of various sizes. For this purpose, Synthetic Aperture Radar and Continental Imaging from Space (LiCSAR) products were used to apply the Small Principal Subsets (SBAS) method for deformation extraction from Sentinel-1 time series datasets. The time series analysis results were used as input for machine learning methods to predict future movements.

Key Words:Landslide, InSAR, Alkumru Dam (Türkiye), deformation analysis, Sentinel-1, LiCSAR, LiCSBAS, SBAS, SNAP

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1 PROJECT INTRODUCTION

One of the greatest challenges humanity has been facing is natural disasters, which may not be prevented. Although the types and severity of disasters vary with geography, the most frequently observed ones are earthquake, flood, erosion, fire and volcanic eruptions. According to the studies, there are approximately 45,000 deaths caused by natural disasters every year (EM-DAT, 2022; Our World in Data, 2022). The most fatal disaster events in the past were floods and droughts. Today, the number of lives lost and the amount of property damage brought on by natural disasters have significantly decreased thanks to rising public awareness of these events and technological developments.

One of the major disasters for which precautions must be taken is dam flooding, which has recently occurred in several locations and still does so sometimes while causing considerable loss of life and economic assets. Most floods in dams are based on the soil structure sliding into the filling dams from the dam reservoir. Various geodetic and remote sensing-based studies have been carried out in order to observe these movements in reservoirs.

1.1 Problem Definition and Motivation

In this project, we attempt to monitor landslides around the reservoir of 'Alkumru Dam' located in Taşbalta, Siirt (in the Southeastern Anatolia) using interferometric synthetic aperture radar (InSAR) technique with Sentinel-1 synthetic aperture radar (SAR) data. Sentinel-1 data acquired in ascending and descending orbits were processed with the Sentinel Application Platform (SNAP) open source software tool (Snap, 2022).

In the project, it was aimed to prepare a model that can predict future landslides by processing the recent changes in terrain level in the study area. With this model, it is aimed to monitor the potential landslide movements in advance and to ensure that the necessary precautions are taken based on the data of the past.

Motivation of the project is to reduce the damage caused by potential dam floods by taking the necessary precautions together with the method aimed to improve the events such as the 2018 Karabük flood and 2021 Bartın flood (Figure 1), which has recently occurred.

Figure 1 Bartın Dam Flood

1.2 Goals and Objectives

The main goal of this project is to develop a method to monitor landslide movements based on SAR data. Using this method, it may be possible to develop landslide monitoring models for potential future events by looking at past and current data on slope movement.

Based on this objective, the project stages involve:

- Obtaining data and software from the open platforms
- Verifying data quality and usability for project purposes
- Pre-processing the data as a first for data integration
- Time series data analysis for detecting the deformations
- Prediction of the future slope movements based on past observations
- Development of a web-based platform for data sharing and presentation

1.3 Methodology

First of all, Alkumru dam, which is our study area, was determined and analyzed. The dam is suitable for a landslide monitoring study since landslide movements occur occasionally. In order to solve this problem, we analyzed the landslides that can occur by making temporal estimation using a machine learning method. This project we plan to reach our goal with a high temporal interval. A group member was assigned to each work package by creating a workflow chart (Gantt) for the management of this project. Thanks to the project flow chart, we can follow the work we need to do on a weekly basis. By listing our literature review, we have provided an easy-to-understand, focused and concise summary of previous work related to our project topic.

In order to better understand the study area, a DEM of the defined area was produced.

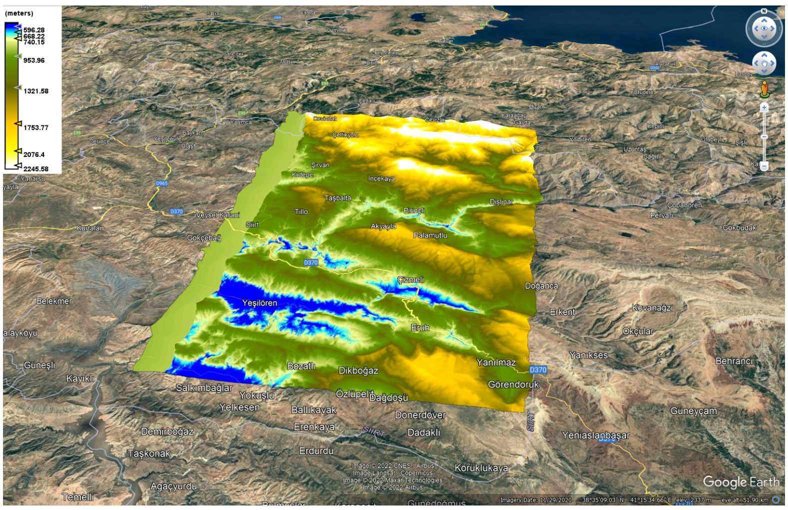

Figure 2 Digital Elevation Model

An analysis of the requirements that must be met in order to obtain a usable solution to the problem was made. Analysis of the current situation was made. Brainstorming sessions were held with the project administrator. The user and usage scenarios related to the result to be obtained from the project were determined. The major aim in the usage scenario is to get the maximum efficiency in the follow-up of the landslide in the dam by making the highest level of temporal frequency. As a requirement of this working environment, we can regularly obtain SAR data from the Alkumru Dam area. The Sentinel-1 satellite, which is minimally affected by the weather conditions that may pass through that region at regular intervals, and can operate continuously day and night, can extract the most efficient data for this working area. The system to be designed used to provide user-friendly benefits. The methodological workflow and the project stages are presented in Figure 3.

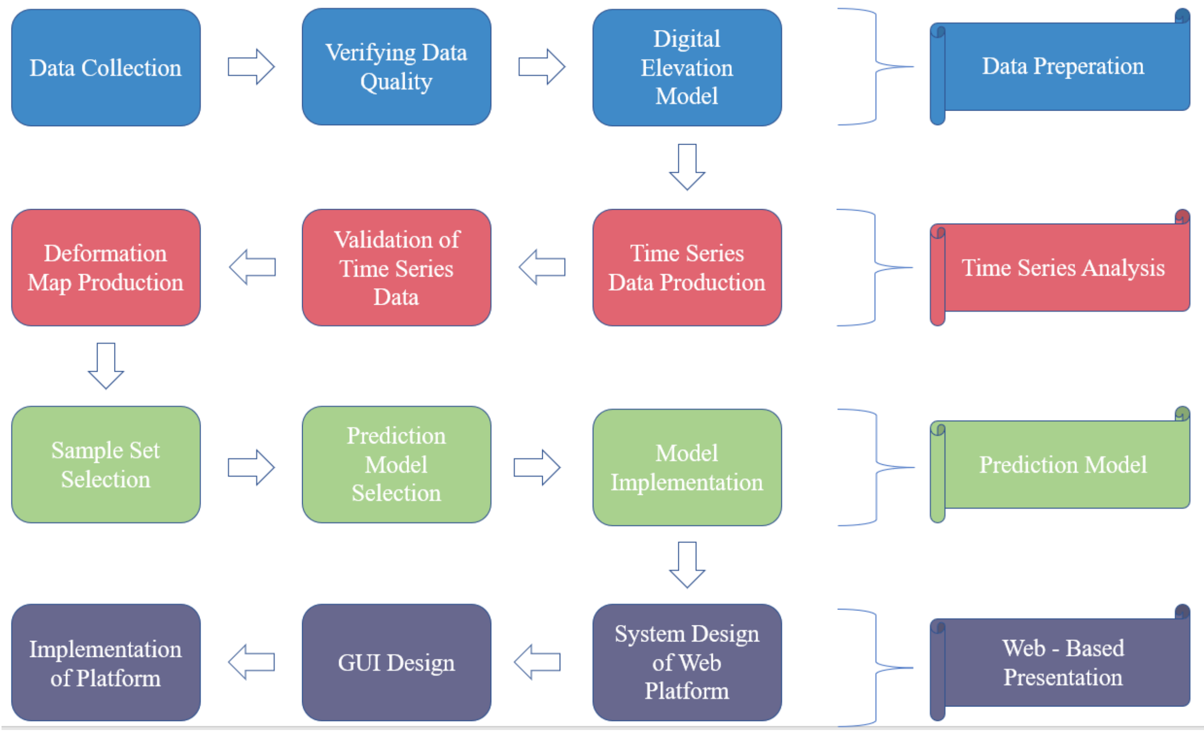

Figure 3 Project workflow

Obtaining information about the analysis is possible with Sentinel-1 Synthetic Aperture Radar Interferometry (InSAR) data sets, which provide multi-time surface change information in terms of deformation, and their processing techniques.

To achieve this, deformation extraction from Sentinel-1 time series datasets are performed using the Small-Baseline Subsets (SBAS) method (Tavus et al., 2022) using the Looking into Continents from Space with Synthetic Aperture Radar (LiCSAR) products (Tavus et al., 2022).

1.3.1 Sentinel-1 Sensor Characteristics

The first SAR satellite in the Copernicus Program satellite constellation operated by the European Space Agency is called Sentinel-1. The Copernicus program distributes Sentinel-1 products in accordance with its free and open data policy. The Sentinel-1A and Sentinel-1B satellite constellation that makes up this mission orbits in the same orbital plane. They are equipped with a C-band synthetic-aperture radar that can collect data day or night, in any weather. The orbit repeats every 12 days and completes 175 orbits in that time. However, as of August 3rd, 2022, Sentinel 1B mission failed and does not provide data anymore.

1.3.2 Sentinel Application Platform (SNAP)

Since the SNAP software architecture is ideal for processing and analyzing Earth Observation data, SNAP helped us process the SAR image during this project.

DEM production was carried out with the SNAP program and KMZ with Google Earth Pro. It was opened in the format and checked on the ground, and it was concluded that it was a correct DEM.

The single look complex images were downloaded by the Alaska Satellite Facility (ASF).

1.4 Structure of the Report

This report covers the problem definition, abstract, table of contents, basic methodological explanations, methodological workflow, sensor and data characteristics, information about Sentinel Application Platform (SNAP), DEM product, Landslide monitoring and assessment methods, studies around the world and Türkiye, requirement analysis, use case analysis and scenarios, responsibility in usage scenarios, actors, multitemporal data analysis, non-functional requirements, usability, reliability, performance, sustainability, implementation and interoperability requirements, standards and compliance,environmental protection, packaging, legal requirements, preliminary design of the proposed solution product system, project planning and management, implementation and tests, discussion, conclusion, references, appendices part.

2 BACKGROUND

2.1 Landslide Monitoring and Assessment Methods

There are several methods to assess and to monitor surface deformations caused by landslides. These methods can be based on engineering studies such as precipitation amount in the landslide area, terrestrial laser scans, Global Navigation Satellite System (GNSS) observations, and SAR satellites time series.

The GNSS is a widely used method for landslide monitoring. This is because GNSS is real-time, provides a high degree of automation, and can be used in all weather conditions. In addition, GNSS positioning technology has become one of the most effective methods for three-dimensional landslide monitoring. However, the data collection method with GNSS receivers provide sparsely distributed data.

Terrestrial laser scanning (TLS) methods can be used to assess landslide deformation. The deformation of the landslide area can be observed from a digital terrain model (DTM) obtained from a TLS. However, this approach is costly both in time and economically.

Deformation in some landslide areas may be caused by fluctuations in the water level of the region. In addition, precipitation is also effective. Comparisons of slip masses can be made due to the slope structure and precipitation events.

As the rain water descends to lower layers, it increases the underground water level and thus the hydrodynamic pressure, causing landslide deformation. Studies on slope instability can be carried out by looking at the seismic data and the amount of moisture in the soil after precipitation.

Using SAR data, landslide deformation can be observed. Thanks to the InSAR methods, an interferogram is obtained by using the phase information of two SAR data belonging to the same region. Since this method provides the opportunity to measure the third dimension of the targets, it is generally used to make the topography of the earth 3D or to observe the spatial changes that occur in a certain region. Multi-time surface change information is required for landslide deformation. Based on this information, deformation mapping can be made using time series datasets of SAR data.

2.2 Studies Around the World and Türkiye

Most of the landslides in dam reservoirs studied worldwide (about 90% of 390 reservoirs) are related to landslides triggered by rainfall/snowmelt or earthquakes. Some regional studies have been carried out to collect and classify data on existing and historical landslides in dam reservoirs in different parts of the world. The failure of dams caused by landslides has often resulted in devastating floods that have caused loss of life, housing and infrastructure downstream.

The largest documented landslide dam in the world is the 200-300 m high Raikhot landslide dam in Pakistan, which flooded a 65 km long lake on the Indus River and collapsed in 1841.

The grain size distribution of the debris material that makes up a dam affects the overall strength of the landslide dam, erosion processes that can cause failures through overlap or piping.

In Türkiye, however, the studies on landslides in dam reservoirs are rather rare and research on this subject is limited. There is still a significant lack of detailed case studies on landslide dams and related reservoirs in Türkiye.

In order to reveal and understand the landslide process in Türkiye, the 'Türkiye Landslide Inventory Maps' project was carried out between 1997 and 2007 by the General Directorate of Mineral Research and Exploration. In accordance with the purpose of this project, landslides were mapped on 1/25.000 scale maps with detailed aerial-photo interpretation and field studies. According to the landslide inventory maps of Türkiye, there are 16 reservoirs with permanent landslide dams of significant size in Türkiye. The most important landslide dam reservoirs are located in the northeastern part of Türkiye. The reason for this clustering is both orographic precipitation and high relief of the Pontides.

In a study conducted in the Tortum valley located in this region (Tortum landslide), it was mentioned to reveal the characteristics, age and causal factors of the Tortum landslide, to reveal the geomorphometric parameters and grain size distribution of the landslide dam, and the environmental effects of the landslide dam lake. To estimate the age of the Tortum landslide, radiocarbon dating was performed on wood chips extracted from alluvial fans at the foot of the landslide. The volumes of the landslide mass, landslide dam and associated lake were estimated based on a reconstruction of the original topography of the slip and lake area. In the mentioned study, the characterization of the landslide dam was carried out using the photogrammetric technique. Photographs of 4 square meters were taken from clean vertical windows of the outcrop area and a digital image processing technique was used to evaluate grain size up to 4 mm.

3 REQUIREMENT ANALYSIS

There is a landslide problem in Alkumru dam. Various ideas have been proposed and evaluated for solving this problem. Although the size of the field is large, the area needs weekly monitoring. Since the field is very large for UAV-based monitoring and we cannot observe small deformations from optical data, Sentinel-1 satellite data from open source ASF (Alaska Satellite Facility) is used here. As a result, a deformation map as output that we obtained with time series analysis obtained.

A high-capacity workstation with large storage space and Linux operating system is used as a working environment. Linux is an operating system that is being developed jointly by many people and that can run on many platforms, especially IBM-PC compatible personal computers, and with free licenses.

Python programming language is planned to be used for the implementations.

The main requirements and constraints of the project are;

- Approximately weekly monitoring is required
- Considering the size of landslides (a maximum of 285,540,000 m^2), a sampling distance with a minimum of 100 m is preferred.
- Many areas are inaccessible for terrestrial surveying
- A positional accuracy of at least 10 cm is required as deformation monitoring rate
- Estimation on future movements is required (ca. for the next 6 months – 1 year)
- A user-friendly web interface for the assessment of movements and predictions is required for the use of geoscientists and the managers.

3.1 Use Case Analysis and Scenarios

There are many different methods to monitor landslides in a dam reservoir. Time series of SAR data were used in this project. This data is available from Sentinel-1 satellites. This satellite produces data every 6 days (until 3 August 2022, 12 days since then) and the data is freely available by ESA. Multi-time surface change information is needed to produce a deformation map. This indicates that a large number of data sets are needed. Therefore, free data usage is an important advantage.

Surface change analysis is performed using Sentinel-1 time series data sets. A deformation map is then generated from this data, where the user can clearly see the change. This map should be in a way that the user can understand.

In the project, the input is the SAR data and the output is the deformation map. This map must have a certain temporal and spatial resolution. In addition, time symbolizes a dimension and this deformation map is accepted as 4-dimensional. After the necessary analyzes are made from the SAR data, the deformation map is presented to the user in a web-based interface.

3.1.1 Actors

The actors of the project are us geomatics engineers, who are primarily proficient in using SAR data, creating web-based interfaces and analyzing time series datasets. User-side actors can be geoscientists and civil engineers who want to analyze the area.

3.1.2 Multitemporal Data Analysis

Users of the system can perform temporal analysis of historical data.
They can make comments about the future of landslides by making 3D analyzes on the deformation map produced. In the future, they can work to prevent landslides in these areas.It draws the polygon of the area where the deformation is requested from the web interface and determines its coordinates.

The necessary scenarios for performing these analyzes are as follows:

- The user opens the web interface.
- It draws the polygon of the area where the deformation is requested from the web interface and determines its coordinates.
- It sends this information to our company.

3.2 Non-Functional Requirements

3.2.1 Usability Requirements

Product of this Project is a time series analysis report. In order to use the product, users need an Internet connection for connecting from a computer, phone, tablet etc. The data presented on the web.

3.2.2 Reliability Requirements

For the reliability of this project, the same processes must be repeated for each work area for the reuse of the product. The project continues to be used as long as Sentinel-1 data are available to the public and are free.
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3.2.3 Performance Requirements

The performance of the system to be produced depends on the data processing speed and spatial accuracy. The processing speed of data varies depending on the amount of data, data transfer rate, bandwidth and data traffic. Amount of data is the value of a data in bits or bytes.

The data transfer rate is the number of bits or bytes that pass in one second during the transmission of data in a network or internet environment between two points.

The term bandwidth is used to express the capacity of a data communication environment or communication channel. Bandwidth is the measurement of the amount of data in data communication sources in bits per second or bytes per second.

The current data flow on the band is defined as data traffic. To put it another way; It is the traffic created by the data passing through the band.

The positional accuracy of the detected deformations are at cm level.

3.2.4 Sustainability Requirements

The sustainability of the project depends on the continuity of the data from the Sentinel-1 satellite. As long as the Sentinel-1 data remains public and free, the project continues to be used.

3.2.5 Implementation Requirements

We rely on open data and software tools for the implementation due to budget limitations and expertise of the project personnel.

3.2.6 Interoperability Requirements

The presentation system considered the geospatial standards of OGC (OGC, 2022). The satellite data assimilation and processing system are standalone systems.

3.2.7 Standards and Compliance

The presentation report considers the geospatial standards of OGC (OGC, 2022).

3.2.8 Environmental Protection Requirements

In this study, we use remote sensing methods. Hence there is no need for requirements for environmental protection

3.2.9 Packaging Requirements

The output of the study is a report. Therefore there is any packaging requirements for this project.

3.2.10 Legal Requirements

We use public and free Sentinel-1 data for this study. There is no need for legal requirements.

4 DESIGN OF THE PROPOSED SOLUTION

The three stages of realizing our problem are: find the deformation itself, make a prediction about the future, presenting it correctly to the user.

Can the user download the data within the framework of the plan arranged before starting the design? Can the user download data according to the given instruction? or how much can be done by giving instructions to the user? It is necessary to answer some important questions such as: Within the framework of these discussed questions, two different system design ideas were considered.

It is designed with the idea that it is carried out by a company that performs deformation measurements analysis using SAR data and used in line with the needs of various institutions.

As a service-oriented company, we perform processes using SAR data of the desired region with the LiCSBAS application in the Linux operating system, produce deformation maps in this process, produce and map the prediction of the deformation in the near future with the machine learning from these maps, compare and report our analysis by superimposing it on the DEM map with the deformation prediction map. We present our report together with our map data.

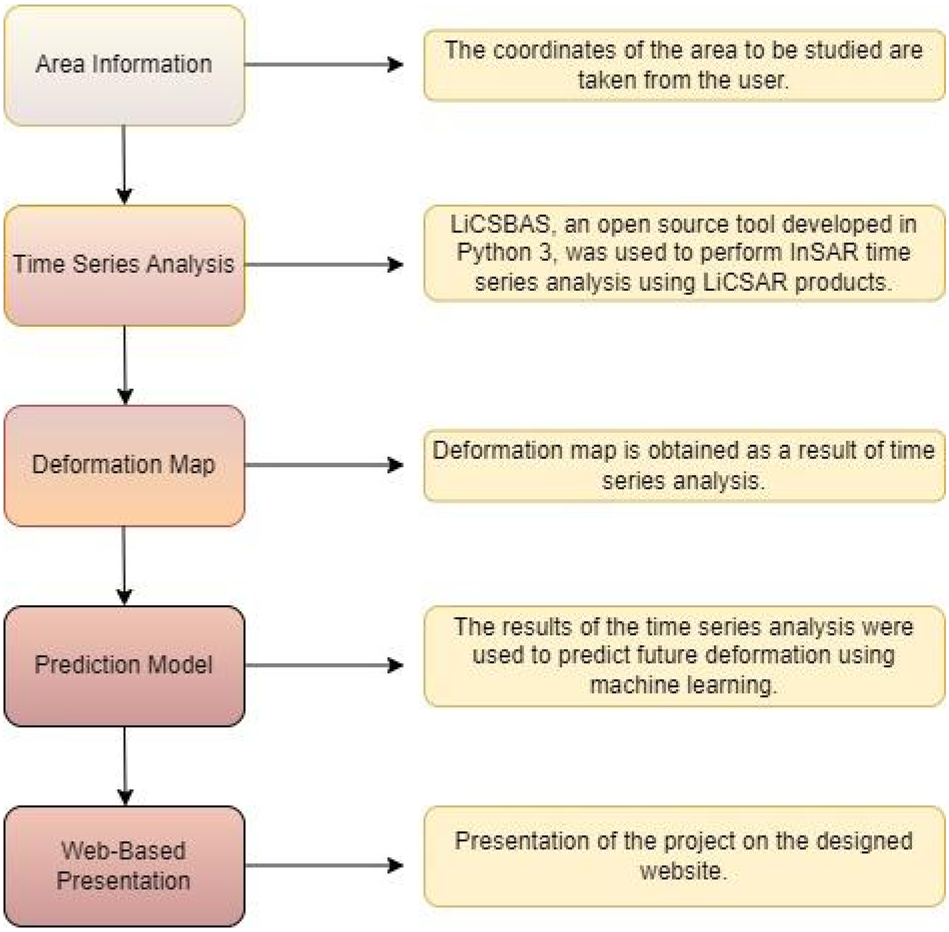

Figure 4 Proposed solution

Alternative Design :

The user requires knowledge of the deformation of an area. The designed interface for the user opens.

Then click on the select area button.

When clicked it takes the user to COMET-LiCS.

The desired area is roughly selected in COMET-LiCS.

Finally, Coordinate information is requested to cut the area.

After these processes, the necessary steps are taken by our company without asking anything to the user.

As a result, the deformation map is shown to the user and the user can click anywhere to see the deformation.

In this way, various option ideas were considered and evaluated. Since the steps to be performed on the web base have a serious temporal process. By sending the area where the deformation will be followed by the user, in return, download the deformation in shape file or similar formats and send the analysis report as txt. format is thought to be available.

5 PROJECT PLANNING AND MANAGEMENT

Four people work together on this project. The part of the project that these four people were responsible for was determined at the beginning of the term before starting the project. Each person provides the management and work sharing of the department they are responsible for. Thus, while the tasks are carried out in a sequential manner, confusion is avoided in writing the report about who do the research on which subject or in which part.The following gantt chart lists the tasks to be done and deliverables throughout the year.

ALKUMRU LANDSLIDE DEFORMATION BY GEOERA

TASK	ASSIGNED TO	PROGRESS	START	END
A1: Workflow implementation	HBD/ENK			
Data collection (D1: data)	AL	100%	10.24.22	10.30.22
Software implementation (installation, training) (D2: Running code)	DH	100%	10.24.22	11.30.22
Verifying data quality and usability for project purposes based on pre-processing results (D3: preprocessed data)	ENK	100%	10.31.22	11.5.22
A2: Deformation map production	AL/DH			
Time series data production (D4: Time series data)	HBD	25%	12.1.22	12.15.22
Validation of time series (with optical data, expert opinion) (D5: Validation report)	ENK	0%	12.15.22	12.19.22
Deformation map production (D6: Deformation maps)	DH	0%	12.20.22	1.3.23
Final exam week		100%	1.4.23	1.29.23
A3: Prediction model for future movements	ENK/AL			
Selection of observation samples for modeling (D7: Sample set)	AL	0%	1.30.23	2.5.23
Selection of prediction model (D8: model report)	DH	0%	2.6.23	2.12.23
Model implementation (Python, Matlab, ...) (D9: running code)	HBD	0%	2.13.23	2.26.23
A4: Web-based presentation system	DH/HBD			
System design of the web-based platform (D10: system architecture diagra	ENK	0%	10.24.22	3.13.23
GUI design (D11: designed GUI)	HBD	0%	3.14.23	3.31.23
Implementation of the platform (D12: operational platform)	AL	0%	4.1.23	4.30.23

Figure 5 Gantt Chart

As seen in the Gantt chart, the project involves 4 milestones. A 3-stage task was determined prior to each milestone and the study was carried out accordingly. The determined tasks were created in harmony with the design ideas.

A leader from within the group has been designated for each milestone. This leader is responsible for the work sharing and management of that part. There is another co-leader besides the leader. Because in cases where the leader cannot fulfill his duty (such as sick leave), the co-leader saved the situation. The leaders assigned the other group members to the 3-stage tasks determined for their department. Of course, in every situation and generally at every stage, group members are in cooperation and sharing knowledge.
In the "assigned to" section of the Gantt chart, the initials of the names and surnames of the persons in charge are included. According to this representing the names are below:

- HBD: Hikmet Barış Demir
- AL: Ayşe Levent
- ENK: Eda Nur Kabay
- DH: Deniz Hisarkaya.

We held a meeting with our supervisor every week on Monday. In these meetings, we shared what we have done and how far we have progressed. Linux software and a powerful computer were needed for the deformation map, which was planned to be one of the outputs of the project. That's why our supervisor set up a computer for us in the photogrammetry lab. We carry out our studies, information sharing and problems with our supervisor every Monday and also the group members in the photogrammetry lab. We also meet once or twice for the rest of the week and continued our work.

6 IMPLEMENTATION AND TESTS

6.1 Implementation of Solution

We mentioned two alternatives in the proposed solution section. Here we decided to use the first alternative. In other words, we designed our project as a company and we ask the user for the coordinates of the area whose deformation he wants to monitor. Area knowledge is required when starting our application. We said we will get it from the user. We get information from the user from the communication section of the website we designed. The image about how to do it is in the appendices section[2]. And the we downloaded the SAR data using the received coordinate data and the requested date range.

The Sentinel-1 satellite provides abundant and useful Synthetic Aperture Radar (SAR) data with the potential to reveal global earth surface deformation at high spatial and temporal resolutions. However, it is difficult for most users to take full advantage of the large amount of correlated data, especially in large areas. To overcome this challenge, we used LiCSBAS, an open-source SAR interferometry (InSAR) time series analysis package integrated with the automated Sentinel-1 InSAR processor (LiCSAR). LiCSBAS uses LiCSAR products that are freely available. In this way, we saved processing time and disk space while getting the results of InSAR time series analysis. In the LiCSBAS processing scheme, interferograms with many tripping errors were automatically completed with loop closure. We got reliable time series and velocities. To achieve this, deformation extraction from Sentinel-1 time series datasets are performed using the Small-Baseline Subsets (SBAS) method using the with Synthetic Aperture Radar (LiCSAR) products. The LiCSBAS and LiCSAR products have made it easy for us to make more use of the globally available and abundant SAR datasets. The LiCSBAS tutorial we use is in the appendices[3]. At the end of the tutorial, we got an hdf5 file named cum.h5 that contains cum and dates information.

Additionally, the LiCSBAS method allows us to produce a deformation map. This map has been converted to GeoTIFF format, which enhances its usability in applications like QGIS and Google Earth. The user can then see a clearer expression of the deformation zone. By adding a legend to this map, it is possible to show how much the soil has slipped or accumulated.

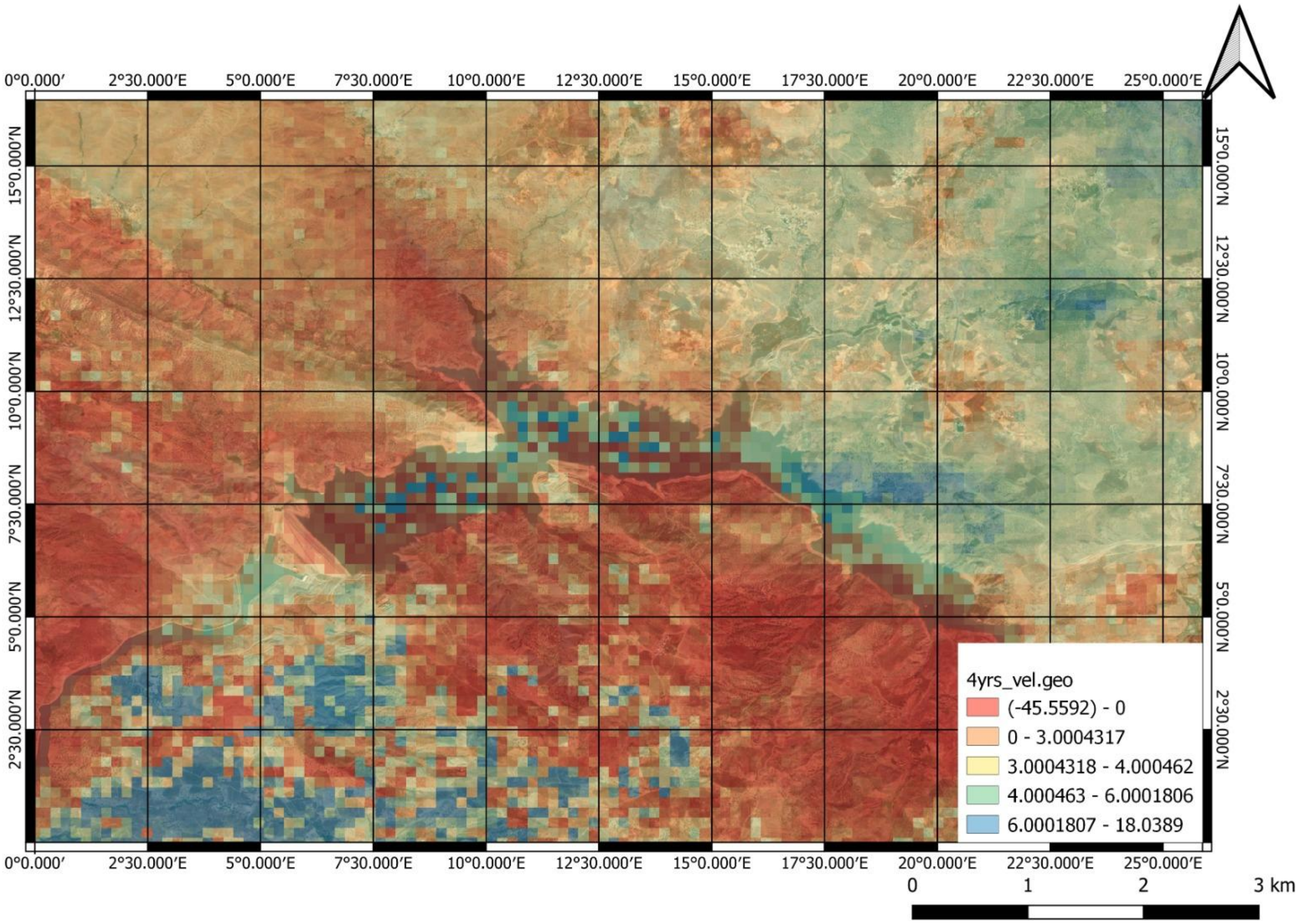

Figure 6 Deformation Map in 2D

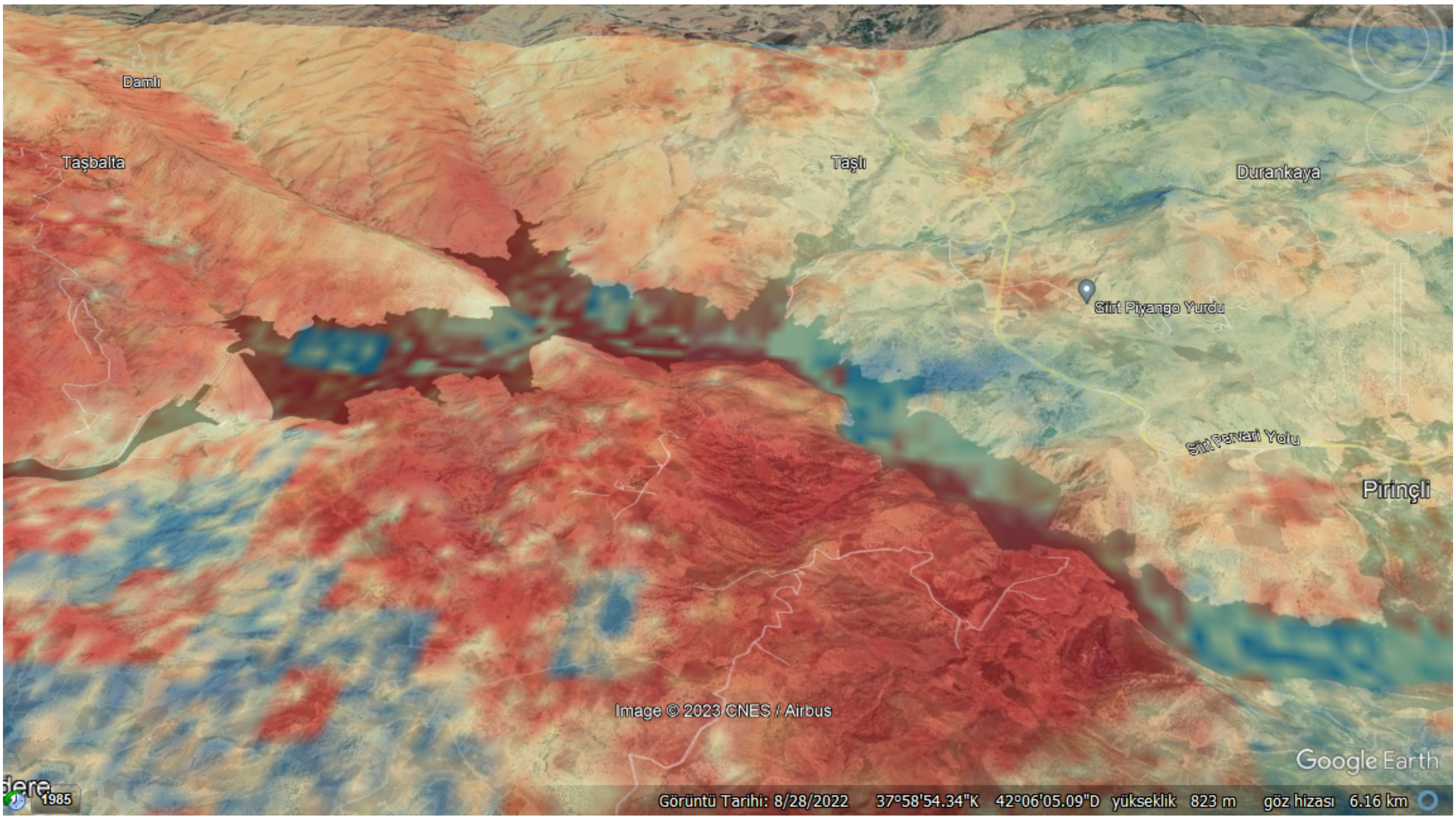

Figure 7 Deformation Map in 3D

We performed the time series analysis of these data with the methods we mentioned earlier. The results of the time series analysis were used to predict future deformation using machine learning. We used a machine learning method to predict future deformations. We used LSTM (Long Short Term Memory). LSTM networks are well suited for classifying, processing and making predictions based on time series data, as there may be delays of unknown duration between significant events in a time series. We loaded the dates and cum files in the cum.h5 file into our pyhton code. There were some "nan" values in these files. We wrote a code to fill these values with the mean of neighboring values. Now our data was completely ready to use.

To do LSTM we then created the training and testing data. There are 198 interferograms between 16/01/2019 and 13/01/2023. We used the time series we created from these interferograms. We then converted these interferograms to GeoTIFFs [4]. We used 158 of the interferograms that we converted to GeoTIFFs to train the model. Thanks to the lookback function in the LSTM model, we have made it possible to predict the next data according to the previous data. The parameter of this function was important to us. For example, when we give 1, he expects him to guess the remaining 40 files, but he made 39 guesses because he tried to predict the next review using the previous review. We then saved the forecast data as GeoTIFFs. However, in order to make more accurate predictions, we decided to give the lookback function a value of 8 in the last case. Therefore, there are an estimated 32 GeoTIFFs.[5] Although the number of predictions decreased, we found it appropriate because the accuracy increased.

Batch size and epoch parameters are other factors that affect prediction accuracy. As the period increases, the loss parameter decreases, but the execution time of the code increases. The "loss" parameter is the calculation of the error difference between the values obtained after each training and the actual values.
Batch size is the packet size of the data added to the training. The larger the batch size, the more accurate the gradient value calculation. [6].

6.2 Tests

We used 4-year data to estimate the deformation of the region. We said that there are a total of 198 interferograms in these four years of data. We used 158 of them to train the LSTM model. The remaining 40 data were entered into the model as test data. What we wanted from the model was to learn 8 test data and ask it to produce a prediction data. In this way, we had 32 predictions as it produced 1 prediction in every 8 test data, respectively. This number will vary according to the value we give to the lookback function. We said that we are saving GeoTIFFs from the "cum.h5" file. Now we have saved our predictions as GeoTIFF. Thus, we would be able to examine the difference between the two data.

6.3 Web Based Presentation

As we mentioned in the proposed solution section, we designed a website where we can get information from the user and publish our projects. It was a good system to simply reach us and see the projects.You can access the general view of our website from the appendices section [7].First of all, we have our homepage on this site. Here you can get general information about us and what we do. In the communication tab, we have a communication button as we mentioned before. On the Projects page, we display the project we produced on an interactive map. For this part, geoserver, which implements web map services (wms) standards, is used.

7 DISCUSSION

According to the method and data we use, our solution has some advantages and disadvantages.

First, we preferred SAR data over optical data and UAV data. Because it is necessary to go to the region to collect UAV data and it is very costly in terms of cost. On the other hand, optical data are insufficient to detect the desired tiny deformations. In this sense, SAR data can be collected at no expense and without traveling to the area. Our information came from the COMET-LICS open source portal.

Additionally, SAR was preferable for us because the area's deformation is observed on a weekly basis. As a result, we can get data quickly.

Unfortunately, Sentinel 1B, which we got data from on Sentinel 1A and 1B satellites, has not been in operation since August 3, 2022. Data collection thus switched from every 6 days to every 12 days.This is also a disadvantage of SAR to us.

We stated that Linux is the operating system that we utilize. One of the explanations is that there is an application called "Package Manager" that manages all software and updates and makes it simple for us to install software. Linux doesn't require additional drivers, which is another factor. Linux is more secure than the Windows operating system since it doesn't require an antivirus application to run.

We as a company have the expense and lost time associated with the staff's specialized training or expertise.Additionally, the business must pay a salary for 12 months even if certain jobs only continue for a month as long as it has its own workers. If they decide to hire us, the company will pay us based on how long the work took (in hours or days, for example).

In the section where we make future predictions, we use machine learning. Here, the LiCSBAS technique phase and our learning phase both took longer than we expected. The amount of data we can handle in the region whose deformation we are analyzing is reduced as a result.

In the section where we make predictions for the future, we use machine learning. Here, our LiCSBAS technical phase took longer than we expected. For this reason, we could not pass the machine learning phase in the expected time.

We used the LSTM model in the machine learning part. LSTM networks are well suited for classification, processing and predictions based on time series data. In this sense, it has been the most advantageous machine learning method for us.

We first saved the data we will use in the machine learning phase as a .csv file. However, we did not get the desired result in this way. We trained our model using the "cum" and "imdates" data in the "cum.h5" file and saved the outputs as GeoTIFF. Thus, we have obtained the results visually.

8 CONCLUSION

In this study, we analyzed the landslide activities in the Alkumru dam lake in the Southeastern Anatolia Region of Turkey, using Sentinel-1 datasets, and analyzed the increasing and decreasing LiCSAR products available to the public on the COMET-LICS website. We worked on 4-year data between 16/01/2019 and 13/01/2023. For the deformation analysis, we used the SBAS method in the LiCSBAS application. We got the time series. We then used the LSTM method to predict the future from our data. We compared the estimated geoTIFFs we obtained with the available data. We examined the difference between them. The reason we chose this methodology is to obtain the deformations with centimeter precision.

We have obtained the deformation map of the 4-year change. We examined this map in both 2D and 3D. According to the results we obtained from LSTM, we observed that there was not much change. We have obtained acceptable estimation results.

The aim of the study is to demonstrate the feasibility and usability of the datasets and technique for high temporal scale and high spatial resolution landslide assessment and monitoring activities which are crucial for the maintenance of dams.

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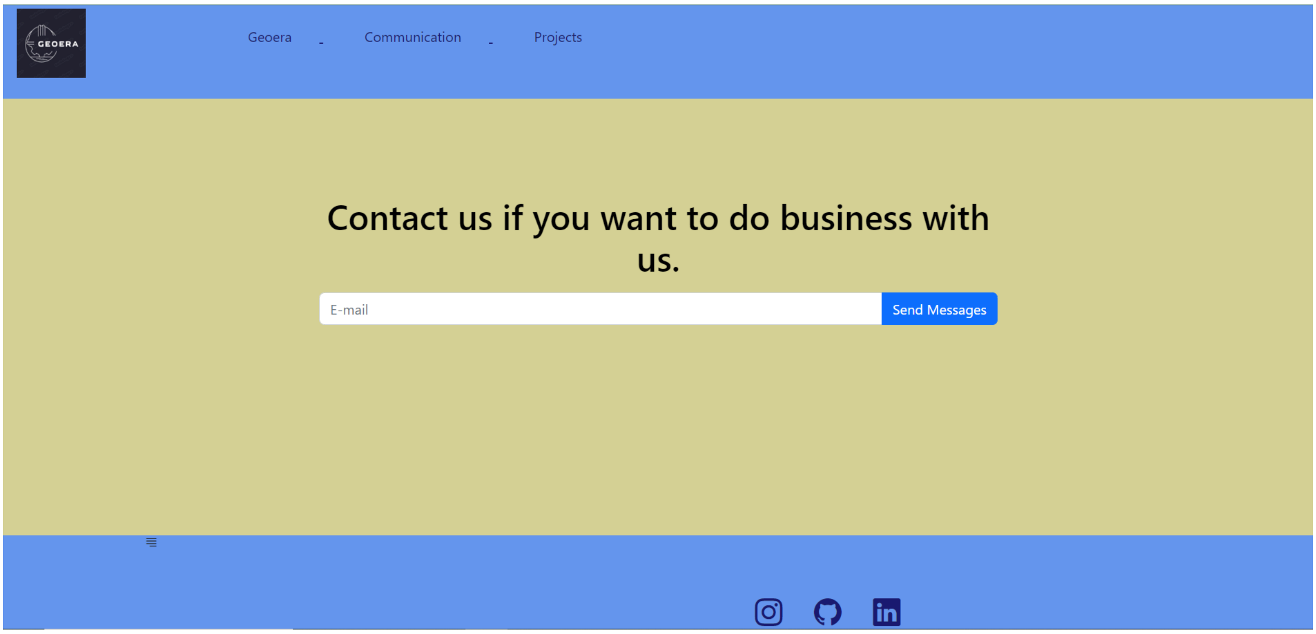
APPENDICES

[1]. https://www.starhaber.tv/bartin-da-sel-felaketi-sonrasi-sehir-boyle-goruntulendi-h2040.html

[2]. Communication



[3]. https://www.google.com/search?q=licsbas+tutorial&rlz=1C1NDCM_trTR842TR842&oq=licsbas&aqs=chrome.2.69i57j35i39j35i19i39i512i650j0i19i512j0i19i30j69i60.4571j0j7&sourceid=chrome&ie=UTF-8

[4]. Converting the interferograms to GeoTIFFs

cumgeotif.py > ...

```python
import os
import h5py
import numpy as np
from osgeo import gdal, osr
from datetime import datetime

filename = r'C:\Users\alkumru\Desktop\cumgeotif\cum.h5'
output_folder = r'C:\Users\alkumru\Desktop\cumgeotif\geotifs'  # Çıktı klasörü

# HDF5 dosyasını aç
f = h5py.File(filename, 'r')

# Girdi verilerini al
imdates = f['imdates'][:]
data = f['cum'][:]

# Verileri tarihe göre sırala
sorted_indices = np.argsort(imdates)
sorted_dates = imdates[sorted_indices]
sorted_dates = [datetime.strptime(str(date), "%Y%m%d").date() for date in sorted_dates]  # Tarihleri dönüştür
sorted_data = data[sorted_indices]

# Projeksiyon bilgisini ayarla
output_epsg = 3857
output_srs = osr.SpatialReference()
output_srs.ImportFromEPSG(output_epsg)
output_projection = output_srs.ExportToWkt()

```

```python
# Her bir tarih için geotif dosyası oluştur
for i, date in enumerate(sorted_dates):
    # Tarih formatını düzenleme işlemini burada yapabilirsiniz
    # Örnek olarak 'YYYYMMDD' formatında bir tarih oluşturulabilir
    formatted_date = date.strftime("%Y%m%d")

    # Geotif dosya adı
    output_filename = os.path.join(output_folder, f'cum_{formatted_date}.tif')

    # Verileri geotif olarak kaydetme işlemi burada yapılabilir
    driver = gdal.GetDriverByName("GTiff")
    cols, rows = sorted_data[i].shape
    out_dataset = driver.Create(output_filename, rows, cols, 1, gdal.GDT_UInt16)

    # Veriye projeksiyon bilgisini ekleme
    out_dataset.SetProjection(output_projection)

    # Veriye coğrafi dönüşüm bilgisini ekleme
    geotransform = (0, 1, 0, 0, 0, 1)  # Örnek bir coğrafi dönüşüm
    out_dataset.SetGeoTransform(geotransform)

    # Veriyi geotif dosyasına yazma
    out_band = out_dataset.GetRasterBand(1)
    out_band.WriteArray(sorted_data[i])

    out_band.FlushCache()
    out_dataset = None

# HDF5 dosyasını kapat
f.close()
```

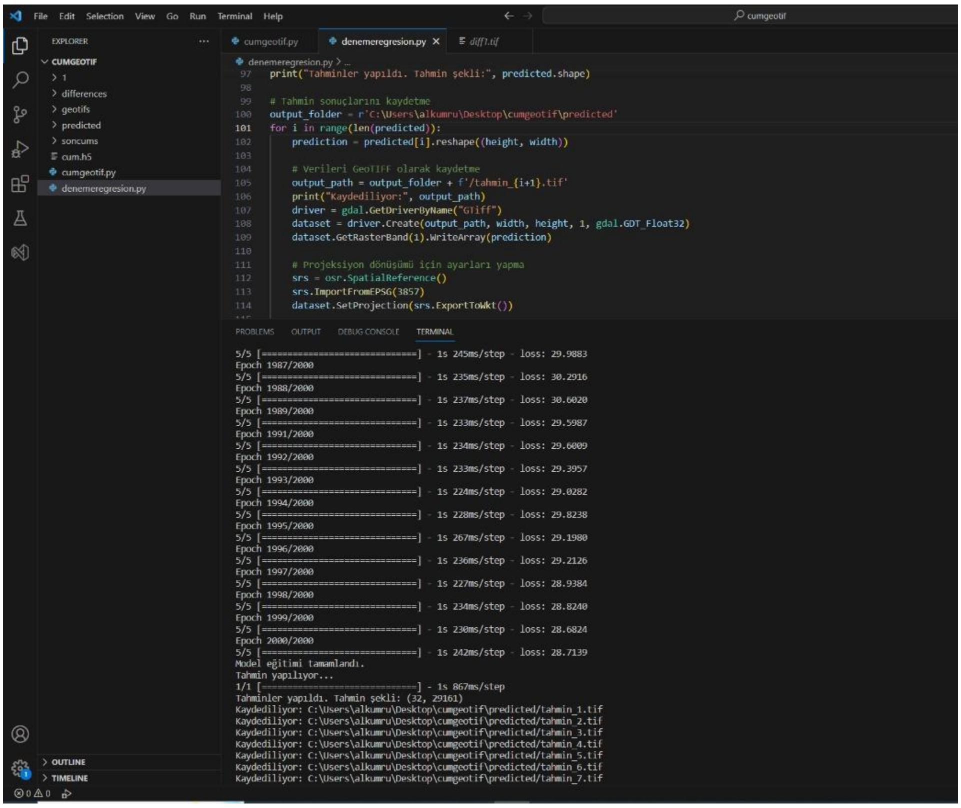
[5]. LSTM codes

```python
import h5py
import numpy as np
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import MinMaxScaler
from keras.models import Sequential
from keras.layers import LSTM, Dense
from osgeo import gdal
from osgeo import osr

# HDF5 dosyasını yükleme
filename = r'C:\Users\alkumru\Desktop\cumgeotif\cum.h5'
f = h5py.File(filename, 'r')

# Girdi verilerini al
imdates = f['imdates'][:]
data = f['cum'][:]

# Veri şeklini düzenleme
num_samples, height, width = data.shape
data = data.reshape(num_samples, height * width)
print("Veri şekli (num_samples, height, width):", data.shape)

# 'nan' değerleri 0 ile değiştirme
data = np.nan_to_num(data, nan=0.0)

# 'nan' değerleri komşu değerlerin ortalamasıyla doldurma
for i in range(num_samples):
    zero_indices = data[i] == 0
    non_zero_indices = np.logical_not(zero_indices)
    zero_count = np.sum(zero_indices)

    if zero_count > 0:
        # Komşu değerlerin ortalamasını hesaplama
        neighbor_values = np.zeros_like(data[i])
        for j in range(height * width):
            if zero_indices[j]:
                # Üst, alt, sol, sağ piksellerin değerlerini topla
                neighbors = []
                if j - width >= 0:
                    neighbors.append(data[i][j - width])  # üst piksel
                if j + width < height * width:
                    neighbors.append(data[i][j + width])  # alt piksel
                if j % width != 0:
                    neighbors.append(data[i][j - 1])  # sol piksel
                if (j + 1) % width != 0:
                    neighbors.append(data[i][j + 1])  # sağ piksel

                neighbor_values[j] = np.mean(neighbors)

        # 0 değerlerini komşu değerlerin ortalamasıyla doldurma
        data[i][zero_indices] = neighbor_values[zero_indices]

```

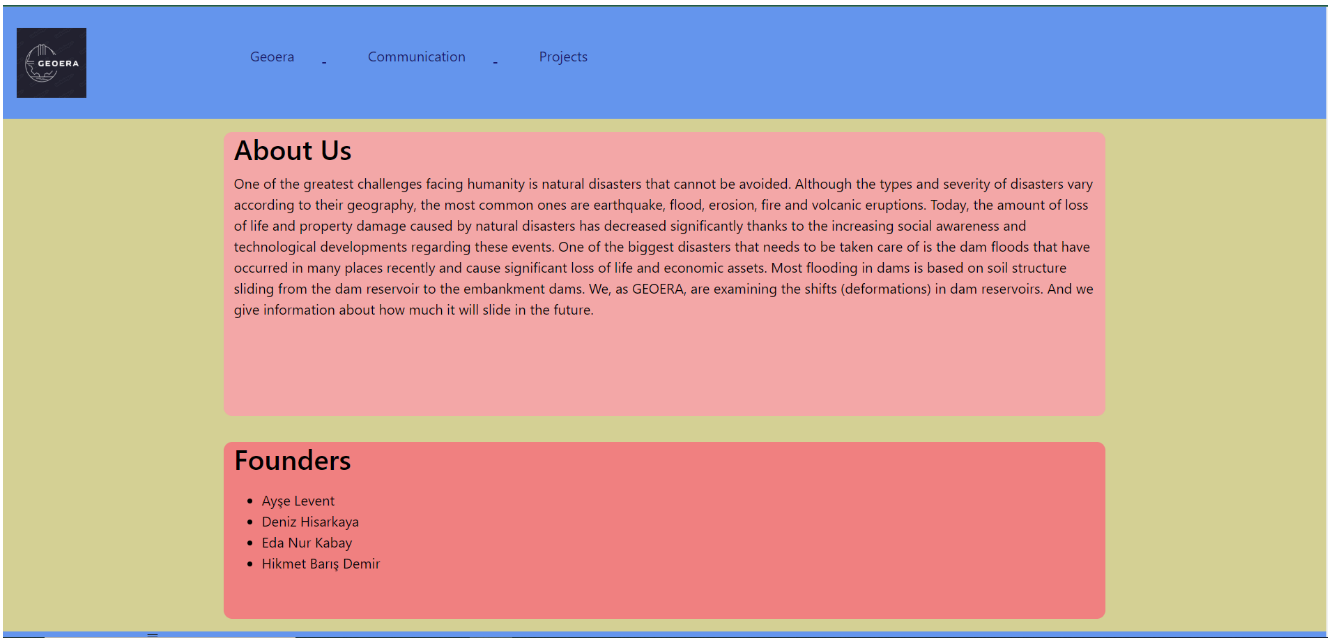
```python

# Eğitim ve test veri setlerini oluşturma
train_size = 158  # İlk 158 veri örneği eğitim verisi olarak kullanılır
train_data = data_scaled[:train_size]
test_data = data_scaled[train_size:]
print("Eğitim veri seti şekli:", train_data.shape)
print("Test veri seti şekli:", test_data.shape)

# Girdi ve çıktı verilerini oluşturma
lookback = 8  # Tahmin için kullanılacak önceki gözlemler sayısı
X_train, y_train = [], []
for i in range(lookback, len(train_data)):
    X_train.append(train_data[i - lookback:i])
    y_train.append(train_data[i])
X_train, y_train = np.array(X_train), np.array(y_train)
print("Eğitim verisi X şekli:", X_train.shape)
print("Eğitim verisi y şekli:", y_train.shape)

X_test, y_test = [], []
for i in range(lookback, len(test_data)):
    X_test.append(test_data[i - lookback:i])
    y_test.append(test_data[i])
X_test, y_test = np.array(X_test), np.array(y_test)
print("Test verisi X şekli:", X_test.shape)
print("Test verisi y şekli:", y_test.shape)

# LSTM modelini oluşturma
model = Sequential()
model.add(LSTM(units=50, return_sequences=True, input_shape=(lookback, height * width)))
model.add(LSTM(units=50))
model.add(Dense(units=height * width))
model.compile(optimizer='adam', loss='mean_squared_error')

# Modeli eğitme
print("Model eğitimi başlıyor...")
model.fit(X_train, y_train, epochs=2000, batch_size=32)
print("Model eğitimi tamamlandı.")

# Modelin tahmin yapması
print("Tahmin yapılıyor...")
predicted = model.predict(X_test)
print("Tahminler yapıldı. Tahmin şekli:", predicted.shape)

# Tahmin sonuçlarını kaydetme
output_folder = r'C:\Users\alkumru\Desktop\cumgeotif\predicted'
for i in range(len(predicted)):
    prediction = predicted[i].reshape((height, width))
```

```python
# Tahmin sonuçlarını kaydetme
output_folder = r'C:\Users\alkumru\Desktop\cumgeotif\predicted'
for i in range(len(predicted)):
    prediction = predicted[i].reshape((height, width))

    # Verileri GeoTIFF olarak kaydetme
    output_path = output_folder + f'/tahmin_{i+1}.tif'
    print("Kaydediliyor:", output_path)
    driver = gdal.GetDriverByName("GTiff")
    dataset = driver.Create(output_path, width, height, 1, gdal.GDT_UInt16)
    dataset.GetRasterBand(1).WriteArray(prediction)

    # Projeksiyon dönüşümü için ayarları yapma
    srs = osr.SpatialReference()
    srs.ImportFromEPSG(3857)
    dataset.SetProjection(srs.ExportToWkt())

     # Veriye coğrafi dönüşüm bilgisini ekleme
    geotransform = (0, 1, 0, 0, 0, 1)  # Örnek bir coğrafi dönüşüm
    dataset.SetGeoTransform(geotransform)


    dataset.FlushCache()
    dataset = None

# HDF5 dosyasını kapatma
f.close()
```

[6]. LSTM parameters results



[7]. The website:



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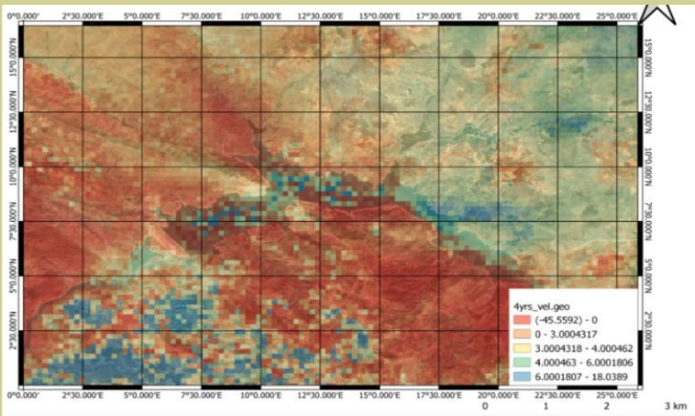

Alkumru Dam Reservoir

In this study demonstrates the feasibility and usability of datasets and technique for high temporal scale and high spatial resolution landslide assessment and monitoring activities that are crucial for the maintenance of dams. . The 2-dimensional deformation map of Alkumru Dam Reservoir, produced from 4 years of data between 16/01/2019 and 13/01/2023, is as above.

In this study demonstrates the feasibility and usability of datasets and technique for high temporal scale and high spatial resolution landslide assessment and monitoring activities that are crucial for the maintenance of dams. . The 2-dimensional deformation map of Alkumru Dam Reservoir, produced from 4 years of data between 16/01/2019 and 13/01/2023, is as above.