**Task 1**

Introduction

* The objective of the project is to determine which uncultivated lands in a specified area in Malta have the potential to be cultivated.
* Making use of sentinel imagery to obtain visual changes in agricultural land in Malta across different periods.
* Actual data is gathered from the Agriculture and Rural Payments Agency (ARPA) as datasets about which lands are cultivated and uncultivated from their inspections.
* Making use of different algorithms, both supervised and unsupervised classifiers, to compare which would obtain better results.
* Both single date and multi-temporal satellite image classification techniques are used for comparison.

Completed work

* During Summer, I carried out research on relative papers which focus on remote sensing and agricultural studies. I gathered these papers to be used for the Literature Review later.
* Weekly mentor meetings are being held to discuss how to move forward in building up my project.
* ARPA were contacted to issue me with ground truth data on which land was found to be cultivated and which was uncultivated from their on-the-spot inspections. A meeting was set with the Senior Manager where I went on their premises to discuss my project and what data they can provide me with.
* ARPA forwarded me a complete dataset as parcels from their inspections, including agricultural land all around Malta which is cultivated and that which is not.
* This data was transferred to QGIS, a geographic information system application that supports viewing, editing, and analysis of geospatial data. A google earth map layer was placed underneath, and ARPA’s dataset was placed over, dictating which lands go under the specified class. The classes were then named *Arable*, *Non-Cultivated*, and *Other*. A new study area covering a larger area was formed by drawing a polygon around the area I want to focus on for my study, that being the outskirts of Siggiewi, Qrendi and Haz-Zebbug. The remaining parcels from the dataset which fell outside of the study area were discarded.
* A time phase was decided for the study to be focused on to determine the changes throughout. Hence, cloud-free satellite imagery was downloaded from the Copernicus Hub platform: 12 satellite images from 2015-2017 and another set of 12 from 2020-2022, by alternating months.
* I followed a tutorial that carried out a Random Forest (RF) Classification based in Seville on both a single satellite image and on multiple images.
* Random Forest, a Supervised classification, was carried out on SNAP (Sentinel Application Platform), an ideal architecture for Earth Observation processing and analysis, by using both sets of imageries. A final, masked image for both sets was generated as a GeoTiff displaying the predicted cultivated and uncultivated lands along with the other features such as buildings, streets, and quarries.
* The GeoTiff images were transferred to QGIS, and a Postprocessing for the Landcover Change was done from the Semi-Automatic Classification Plugin (SCP). However, the images being masked on SNAP didn’t return the same Extent values for both images, resulting in SPC postprocessing to return an empty confusion matrix, with area in degree2 as opposed to m2. Hence, the GeoTiffs were once again masked on QGIS, resulting in both having the same Extent value and proper results after running the SPC postprocessing for land cover change, by inputting the 2015-2017 mask as the reference classification, and the 2020-2022 mask as the new classification.
* In the meantime, during the prototype process, I focused on writing up my Literature Review, making use of the papers I found during the Summer and afterwards. A comparison was done to see which algorithms perform best to give better results. The literature review was split into different sections discussing the different types of algorithms possible to be carried out for the purpose of my study and how they work. The first part of the literature review focuses on the changes in Malta’s agriculture throughout the years. The first study was published in 2006 by Markou et al., followed by another study by NSO in 2016 which covers the period between 2005 and 2013, a Farm Structure Survey carried out in 2016 by the European Commission in 2021, and the latest Census of Agriculture 2020 by NSO in 2022.

Work to be done

* Using PyCharm, an integrated development environment used in computer programming, specifically for the Python programming language (Wikipedia, 2022), a K-means classification will be applied to two of the downloaded satellite images, one from each set of periods.
* First, the necessary libraries are to be installed and imported, mainly the library ‘EarthPy’, which is a python package that makes it easier to plot and work with spatial raster and vector data using open-source tools (Earth Lab, 2021). I would need to get the band names, hence the method os.listdir() is to be used from the imported library ‘os’, which gets the list of all files and directories in the specified directory, in my case all the bands of the two images.
* The study area is to be saved as a .geojson file as it represents simple geographic features and their nonspatial attributes, and also it would be able to support the polygon geometry type. The Region of Interest Geometry will then be read, and all bands will be returned after clipping all raster files.
* A Principal Component Analysis (PCA), a commonly used unsupervised machine learning algorithm, will be carried out to lower the dimensionality of the datasets, hence improving interpretability while minimizing data loss. It accomplishes this by generating new uncorrelated variables that optimize variance in a sequential manner (Jolliffe & Cadima, 2016). The number of components should be taken into consideration which corresponds to the number of classes I have as my datasets, which are 3.
* The bands should then be visualized after implementing the PCA technique. Finally, the k-means clustering algorithm will be carried out with the same number of components and data extracted from the PCA, to be able to visualize the predicted labels.
* If need be, I would make use of further algorithms for the evaluation phase, to be able to analyze results in different approaches and compare which would be most suited for my study.
* For the write-up part, I would need to write the methodology section, discussing what system of methods were used for my study and how I went about obtaining the results. By looking at other relatable studies and comparing their methodologies I would see which studies comply best with my purpose.
* Finally, I would focus on writing up the conclusion, introduction, and abstract sections of the paper:
  + The conclusion of the paper would focus on re-examining the initial hypothesis and note objectives that were met and those that were not met based on specific findings in the data. Strengths and flaws will also be identified after critically evaluating the work carried out, along with insights into the most essential results that were crucial to the aims' success. Lastly, future research recommendations will also be mentioned in this section.
  + A brief overview of the research topic will be written in the introduction, along with the purpose and objectives of the research, the research questions and hypotheses and an outline of the research which would include a brief explanation of what will be covered in each chapter of the publication.
  + Finally, the write-up will be closed off with the Abstract section found right at the beginning of the paper which will be an overview discussing the problem's definition, the research question(s) and methodology, the results, conclusions, and any limitations encountered, along with any suggestions for further investigation.

Conclusion

By submitting this research paper, I aspire for this study to facilitate future studies and anyone who would be making use of remote sensing in agriculture, specifically in Malta, and to further develop on the technology to ultimately obtain the desired purpose of this study. Collaborating with ARPA has given this study great credit and credibility and I anticipate for them to utilize my work for their future projects and research.

Research:

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**Task 2**

Being a relatively new area of study, findings and research are still scarce, and the number of sources focusing on remote sensing in agriculture was limited. Particularly taking into consideration that my study focuses on Malta, where no other forms of related studies were found. The majority of the studies found are based on large map areas as compared to my study area which is quite small, using specific methods and approaches which might not be ideal for my purpose, and this might lead to inconsistent results than that of the found studies. Even though the concept map is in a spider mapping format, which is typically the easiest type of concept map to make and interpret, it might be visually intimidating or chaotic when used to investigate a particular subject. It might also seem like a vague concept map due to being limited with keywords.

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**Task 3**

Quantitative studies:

Tong et al. (2020) undertook the study of mapping fallow fields across the Sahel using Sentinel-2. The purpose of this study is expected to distinguish between actively cropped fields and fallowed fields within agricultural lands whilst improving our understanding of crop-fallow rotation dynamics by mapping cropped and fallow land patches across the entire Sahel at a 10m spatial resolution. Sentinel-2 satellite imagery was used to disentangle the named agricultural land, facilitated with Google Earth Engine for big data handling. The first 10 m resolution Sahelian fallow field map was created for the baseline year 2017, by developing a remote sensing-driven approach for producing reference data for mapping over broad regions.

Abdi (2019) conducted a study on the efficiency of machine learning algorithms in classifying land cover and land use in a boreal region using Sentinel-2 data. The intent of this study was to compare and examine in terms of classification the performance of four non-parametric algorithms: Support vector machines, random forests, extreme gradient boosting, and deep learning. A complex mixed-use landscape in south-central Sweden with eight land-cover and land-use classifications was chosen as the research region. Sentinel-2 multi-temporal sceneries including spring, summer, fall, and winter conditions were employed to classify the satellite pictures. Each LCLU class received 1477 samples, which were separated into training (70%) and assessment (30%) subsets using stratified random sampling. The accuracy of the algorithm was measured using metrics generated from an error matrix, but the total accuracy was utilized to determine the algorithm hierarchy.

He and Zhao (2019) attempted a study of using Temporal Convolution Networks (TCN) to detect anomalies in time series. The purpose of this study was to utilize TCN to forecast patterns in several time steps after training it on normal sequences. A multivariate Gaussian distribution is used to model prediction errors and produce point anomaly scores. In addition, the performance of a multi-scale feature mixing approach is improved. On three real-world datasets, the method's validity is validated.

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**Task 4**

Research Design:

For my study, I collected a specific dataset of ground truth data from the Agriculture and Rural Payments Agency (ARPA), which send out inspectors to go on survey inspections to gather which agricultural land is being used and cultivated and which is not. They provided me with this data in agreement with the purpose of my study to be able to conduct my research on whether using Sentinel imagery and machine learning could provide the means of identifying the potential of uncultivated land to be cultivated. This data consists of three parcels representing the land surface variables and are declared as No-Minimum (NMM) agricultural activity which consists of land where no ploughing takes place; the declaration is confirmed, and another observed as bare soil; the declaration is not correct. The other cases represent the Arable land class, which also includes no ploughing and bare soil classes. I have added another class called ‘Other’ to represent the variables for roads, quarries, and buildings.

My study takes a quantitative approach since the overall used research strategies focus on experimenting with the different algorithms and datasets accordingly, and the specific methods employed in conducting these strategies are based on collecting data quantitatively from instruments rather than observing a setting. Therefore, a more objective approach to the findings of the research is considered. A quantitative method consists of data being derived using technical means, which in my case include the sentinel imagery platform, computing algorithms and the software to compute such algorithms together with the datasets.

The Sentinel Hub EO Browser’s Agriculture theme comes with 9 land variables: True Color, False Color, NDVI, EVI, Barren Soil, NDMI, Moisture Stress, Agriculture and SAVI. By examining the relationship among the variables used, the resulting outcomes would produce insight into the accuracy of the methods and algorithms used, of whether the potential of uncultivated land to be cultivated can be determined. There is a deficiency in past research when it comes to agricultural remote sensing based in Malta, and no specific studies were carried out related to my study purpose. Many of the found studies focus on retrieving the accuracy of certain algorithms, which were suitable for me to assess which algorithms to use.

For my study, there was no need to gather information from participants or respondents, hence no questionnaire or survey instrument was needed.

Research Methods:

The methods carried out for this study started off with exploring useful purposes for utilizing remote sensing in Malta. A look at the agricultural state on the island was taken into consideration, and a noticeable amount of uncultivated land has been spotted, which led to wondering how and if such lands had the potential to be cultivated, given that Malta is rather limited with resources and with rapid population growth, agriculture land is becoming strained (FOEMalta, 2020). By applying the remote sensing technology, I can perceive the possibility of improving on this matter by making use of Sentinel imagery obtained from Copernicus Hub with the Sentinel-2 mission, based on a constellation of two satellites orbiting 180o apart. This satellite acquires optical imagery at a high spatial resolution over land and coastal waters, allowing repeated surveys every 5 days at the equator and every 2-3 days at middle latitudes. There are 13 Sentinel-2 bands at different resolutions ranging from 10 to 60m, mainly 10m resolution for Blue (Band 2), Green (Band 3) and Red (Band 4). An element of remote sensing analysis used for this study focuses on land cover classification. I went for this **method** since remotely sensed images give a rudimentary portrayal of land cover diversity on the Earth's surface, as various land cover characteristics reflect radiation in different ways (Aplin, 2004). Land cover classes, which in my instance would be agricultural, may be used to classify these land-based properties.

Another **method** was deciding on narrowing my study on a study area at the limits of Siggiewi, Qrendi and Haz-Zebbug, as according to the 2020 Census for Agriculture, the distribution of agricultural holdings by locality has a higher quota around that area, which would aid my study by having a bigger dataset for better accuracy once I run the necessary algorithms and machine learning techniques.

Chart

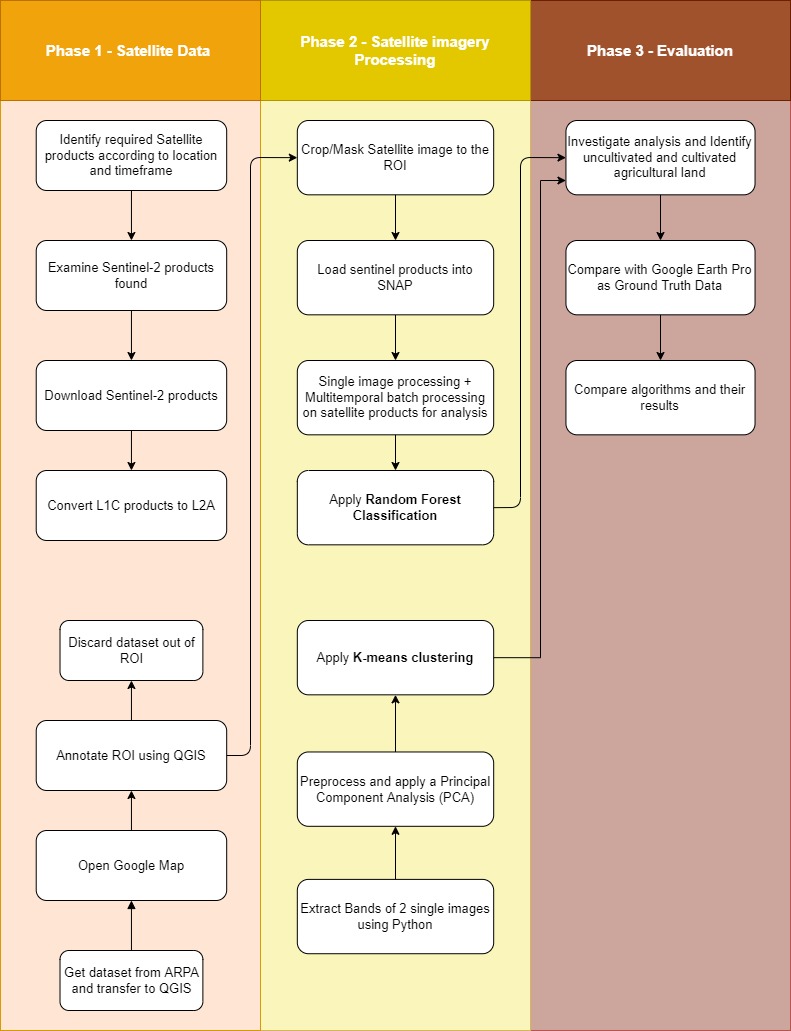
Description automatically generated

Figure Source: Census for Agriculture, 2020

The desired sentinel products were downloaded which cover 2 sets of different periods, one of 2015 – 2017 and another of 2020-2022. The reason behind this **method** was to differentiate the obtained results from both sets and observe the land changes that have occurred after running the different algorithms.

The approach of obtaining results consists of two main machine learning algorithms: Random Forest Classification and K-means clustering. These **methods** were found to be the most accurate in the research I carried out. According to Li et al. (2021), their results show that the general classification accuracy of Random Forest Classification rates the highest with a rate of 95.96% compared to two other algorithms: support vector machine (SVM), and the maximum likelihood classification (MLC), with an accuracy of 80.58% and 87.95% respectively.

Research Pipeline:



The research pipeline is divided into three phases, starting from identifying what is required to carry out the research, to implementing the necessary techniques and to eventually evaluate the resulting outcomes.

In the first phase, I focused on collecting the satellite data by researching and recognizing how this data will best suit my study. Hence, I started off with determining my study area which has a promising amount of agricultural land whilst incorporating ARPA’s dataset, indicating which land is cultivated and which is not from their ground truth data inspection. This dataset is opened in QGIS with an underlying layer of a Google Earth image to visually detect which land the parcels are representing. The study area is then established using a polygon around a substantial number of parcels for a better outcome once used with the algorithms and machine learning techniques mentioned. The next process was to eliminate the rest of the parcels which fell out of the study area. This way there would not be extra data which can interrupt the algorithms. During the prior processes, I decided on the timeframe to focus on for the necessary products to be downloaded and to be compared later from the resulting outcomes of the algorithms. I made sure that the products found are cloud and glare-free for better results and downloaded the right format as L2A, whose data is atmospherically corrected. The earlier products (2015-2016) were only available as L1C which are products resulting from using a Digital Elevation Model (DEM) to project the image in cartographic geometry. These were then corrected by being converted to L2A using the Sen2Cor processor to keep in line with having the same format for all products.

The second phase is directed at processing the downloaded satellite imagery. The initial step was to mask off data outside of the study area such that processing wouldn't be burdened with unnecessary data. Following that, products were transferred to SNAP where batch processing is performed, which includes resampling, subsetting, vector import (study area shapefile), reprojection, land masking, and writing to a new file. The same process is also done to the two single images. Afterwards, the Random Forest Classification is applied. A Python algorithm called K-means clustering is also employed. This time, only the two single images are used. The first approach was to extract the bands from each image individually, then preprocess and apply a Principal Component Analysis technique before applying the k-means.

The outcomes of both algorithms are evaluated in the third and final phase by first identifying the cultivated and uncultivated land from both results, then comparing them with ground truth data using the Google Earth Pro tool, which enables viewing of older imagery of locations to see how places have changed over time, dating back to 1984 till 2020. The algorithms’ accuracy is also assessed with that data, and their findings are then compared against each other to determine which technique is the best for my research.

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