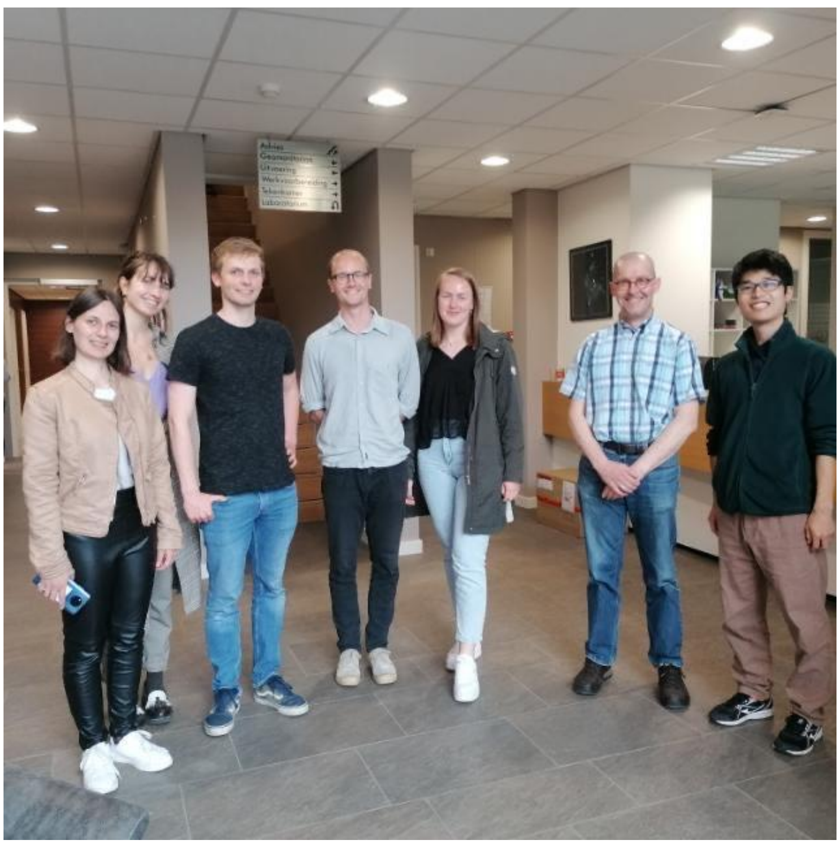
Skimming the surface: Analysis of vegetation stress in Lauwersmeer using remote sensing techniques

Davey de Groot, Shoyo Nakamura, Kristie Swinkels,

Persa Koutsouradi, Marieke Buuts



Commissioner: Wiertsema and Partners
Coach: Nandika Tsendbazar
Expert: Magdalena Smigaj

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Executive summary

Coastal regions worldwide are under pressure from recent environmental changes. The Netherlands is particularly sensitive to these pressures as it has many low-lying coastal areas. Particularly, coastal vegetations in the Netherlands have been facing salinization for over a century. Monitoring vegetation stress by remote sensing can provide information about the condition of canopy areas. Wiertsema and Partners is trying to extend their monitoring activities of vegetation stress caused by salinization in the Lauwersmeer area. Therefore, the objectives of the project are: 1) monitoring the trend in vegetation stress in the nature area from 1985 to 2021, 2) identifying whether a correlation exists between elevation and NDVI trend in the nature area, and 3) suggesting locations to put salinity monitoring wells in the agricultural area, and 4) making everything reproducible and easy to use for people with limited backgrounds on remote sensing. To meet the objectives, trends of the Normalized Difference Vegetation Index (NDVI) were derived from satellite data in both natural and agricultural areas. Trend analysis was conducted using LandTrendr and Theil-Sen regression algorithms. The overall NDVI trend over the Lauwersmeer National Park showed an upward trend, suggesting that there is not so much pressure on vegetation. Besides, no correlation between elevation and NDVI trend was found. The 15 potential salinity monitoring locations in the agricultural area were detected by identifying the intersection of low elevation and high stressed areas. The final products include easy-to-use applications, a report,t and a manual on Github to make everything reproducible and easy to understand for Wiertsema and Partners.

List of abbreviations

Abbreviations	Full name
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
GEE	Google Earth Engine
NIR	Near Infra-Red
LandTrendr app	Our first application using LandTrendr
Slope app	Our second application using Theil Sen regression
VI	Vegetation Index
AOI	Area of Interest
AHN	Algemeen Hoogetebestand Nederland
QGIS	Quantum Geographic Information System

1. Introduction

Wiertsema and Partners is a consultancy company that specializes in geo-monitoring of the subsurface. To monitor the subsurface, they have established a team to improve efficient exchange and use of their own acquired datasets. Moreover, Wiertsema and Partners want to extend their monitoring activities by improving the connection between available below- and above-ground datasets. This is especially valuable for one of their current projects: monitoring the salinization of the Lauwersmeer area, as monitoring the salinization below ground is costly. Through remote sensing (RS), they hope to link what happens above-ground to the salinization underground: RS could be used as a tool to find indicators of plant stress caused by salinization. However, at this moment, Wiertsema and Partners has little experience with using RS. That is why this report will present explorative research on how RS can be used to monitor salinity in the subsoil in the Lauwersmeer area.

The Lauwersmeer is a lake on the border of Friesland and Groningen and is surrounded by the National Park Lauwersmeer (Figure 1). It used to be an estuary but was closed off in 1969 for flooding safety. As water upstream is still discharged into the lake, the water has become fresh over the years and the water level is stable and low, as opposed to how it used to be before it was closed off. This stable, low and fresh water poses a danger to the fish stock, the riparian vegetation, and the bird populations (Beukema et al., 2016). Thus, nature conservation groups consider increasing the inlet of salt water to the lake to have a natural salinity gradient (Waterschap Noordzijlvest, 2021). However, it scares farmers as it might salinize their ditches, which would prevent them from using the water for irrigation (Berkenbosch, 2021).

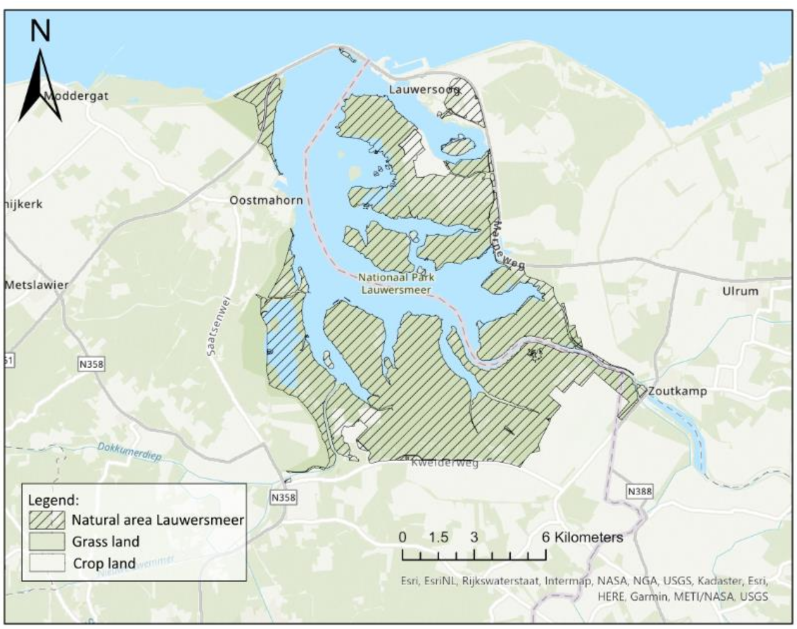

Figure 1 | Land use (2021) in the Lauwersmeer area, the Netherlands.

The report is structured as follows: firstly, background information that is needed to understand the rest of the report is presented. The project objectives of the explorative research have been drawn up in accordance with Wiertsema and Partners can be found in the section Objectives. Thereafter, the materials and methods used to attain the objectives will be described in Materials and Methods. The Results and Discussion show the results that follow from the research and discuss them. Lastly, the limitations of the research and technologies used are discussed and recommendations for the future are made.

2. Background information

Coastal regions around the world are under pressure as a result of climate change, land-use change, sea-level rise, and anthropogenic activities (IPCC, 2021). As global changes accelerate, the pressure will increase even more in the coming decades (Taillie et al., 2019a) resulting in serious challenges to agriculture and the sustainability of natural areas (Galieni et al., 2021). The Netherlands is particularly sensitive to these pressures as it has many low-lying coastal areas (Oude Essink, Baaren & de Louw, 2010; Colombani et al., 2016; Rozemeijer et al., 2021).

Increasing pressures on coastal ecosystems cause stress on the local vegetation, where stress is defined as any unfavorable situation that affects or limits a plant's metabolism, growth, or development (Lichtenthaler, 1996). Nutrient imbalance, water shortage, and extreme temperatures are some of the most common environmental stressors for vegetation (Lichtenthaler, 1996; Baret et al., 2007). One of the challenges coastal vegetation in the Netherlands has been facing for over a century is salinization (Colombani et al., 2016; Taillie et al., 2019a). Salinity reduces the plant's ability to take up water, resulting in a rapidly decreasing growth rate (Munns, 2002; Daliakopoulos et al., 2016b; Kleefstra et al., 2018; Wen et al., 2020). Due to higher water availability at lower elevations, vegetation growing at lower elevations usually experiences less water stress compared to vegetation growing at higher elevations. However, in the case of groundwater salinization, vegetation in low-lying areas may be more susceptible to water stress than vegetation in higher-lying places (Kleefstra et al., 2018).

Monitoring and evaluation of vegetation stress by remote sensing can provide important information about the condition of canopy areas (Baret et al., 2007). Because of the enormous variety of internal and external plant structures, incoming wavelengths are being reflected in different ways resulting in many unique spectral signatures. As stress can change the physiology and biochemical responses of a plant, vegetation stress can be detected by exploring the change in vegetation spectral signatures (Campbell et al., 2007). Commonly used wavelengths for vegetation change detection are wavelengths in the red and the near-infrared (NIR) part of the spectrum, as chlorophyll is strongly correlated to absorption of radiation in the red and the mesophyll leaf structures strongly reflect NIR (Bannari et al., 1995; Pettorelli et al., 2005). Therefore, a decrease in absorption of red wavelengths can indicate a decline in chlorophyll concentration, and a decrease in NIR reflectance can indicate a decline in vegetation density or amount of leaf material in a canopy (Major, Baret & Guyot, 1990; Bannari et al., 1995).

The spectral reflectance of vegetated areas is a complicated combination of the type of vegetation, soil presence, moisture content, and other environmental variables (Price, 1994). To better interpret these spectral signatures and assess vegetation covers, vegetation indices (VIs) were developed. By combining two or more spectral bands, VIs can emphasize a specific plant property.

One of the most commonly used vegetation indices to assess vegetation conditions is the Normalized Difference Vegetation Index (NDVI). It captures the variation in red and NIR reflectance (formula 1) and thereby gives an indication of aboveground vegetation greenness and biomass and it correlates well with vegetation productivity (Liu et al., 2021). Healthy, unstressed vegetation has high absorption in the red part of the spectrum and high reflectance in the NIR (figure 2).

On the other hand, unhealthy or stressed vegetation absorbs and reflects less in the red and NIR, respectively (figure 2). Because of these characteristics, the relative health of vegetation in a given year can be determined by comparing NDVI values for several years at the same place (Quiring & Ganesh, 2010).

$$\text{NDVI} = \frac{NIR - red}{NIR + red} \quad (1)$$

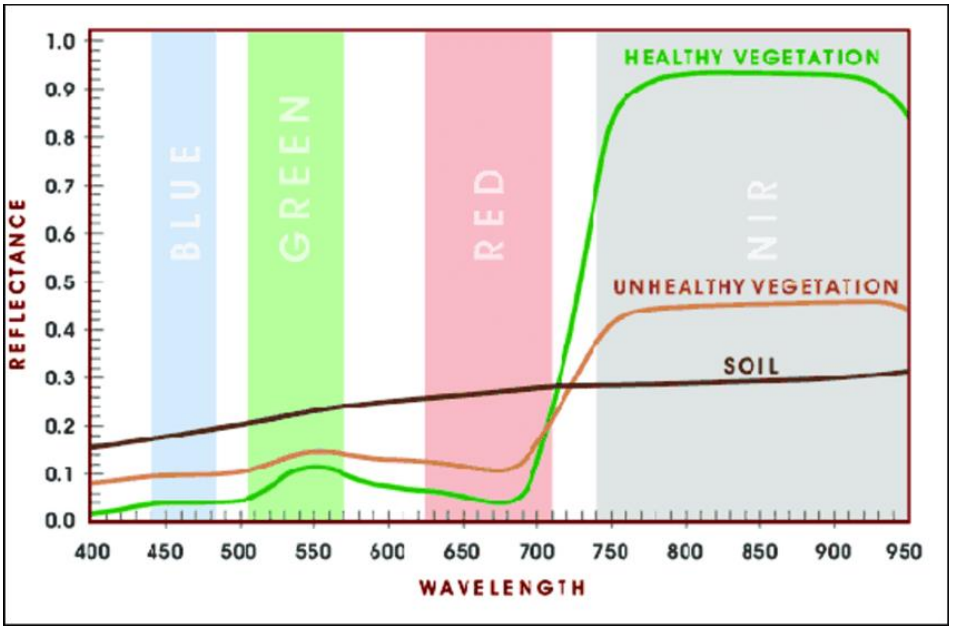

Figure 2| Spectral reflectance of healthy vegetation, unhealthy vegetation, and soil in visible and near-infrared (NIR) wavelength. (Chang et al., 2013)

3. Objectives

Considering the need of Wietsema and Partners for Remote Sensing technology to monitor the subsurface, the following project objectives have been drawn up in accordance with Wietsema and partners:

1. <u>Monitoring the vegetation stress in the Nature area from 1985 until 2021</u>
   Over the years, vegetation has responded to management strategies and environmental changes. Remote sensing may give an insight into vegetation changes.

2. <u>Evaluating the relationship between elevation and vegetation stress in the nature area</u>
   As mentioned in the introduction, elevation can influence vegetation stress. A negative relationship between them can indicate vegetation stress potentially due to salinity.

3. <u>Suggesting locations to put monitoring wells of salinity in the agricultural area</u>
   Locations, where the vegetation stress is highest over time, are interesting salinity monitoring locations to Wiertsema and Partners.

4. <u>Make the work reproducible for Wiersema and Partners</u>
   It should be easy for Wiertsema and Partners to reproduce the results of the other goals and possibly adjust them to other areas.

4. Methods

This section explains how remote sensing was used to meet the objectives. The workflow below gives an overview of this (Figure 3). Every step in this workflow was written down comprehensively so Wiertsema and Partners can understand and follow them. The proposed workflow consists of six main steps: 1) Data acquisition and preprocessing 2) Vegetation index calculation, 3) Time series trend analysis of a vegetation index for objective 1, 4) detection of stressed areas for objective 2, 5) correlation between vegetation stress and elevation for objective 3, and 6) quality and reproducibility assessment for objective 4 (Figure 3). This section will first discuss the tools that were used for the rest of the workflow. Secondly, the contents of the workflow will be discussed. Lastly, how the tools and preprocessed outputs are used to attain the objectives presented.

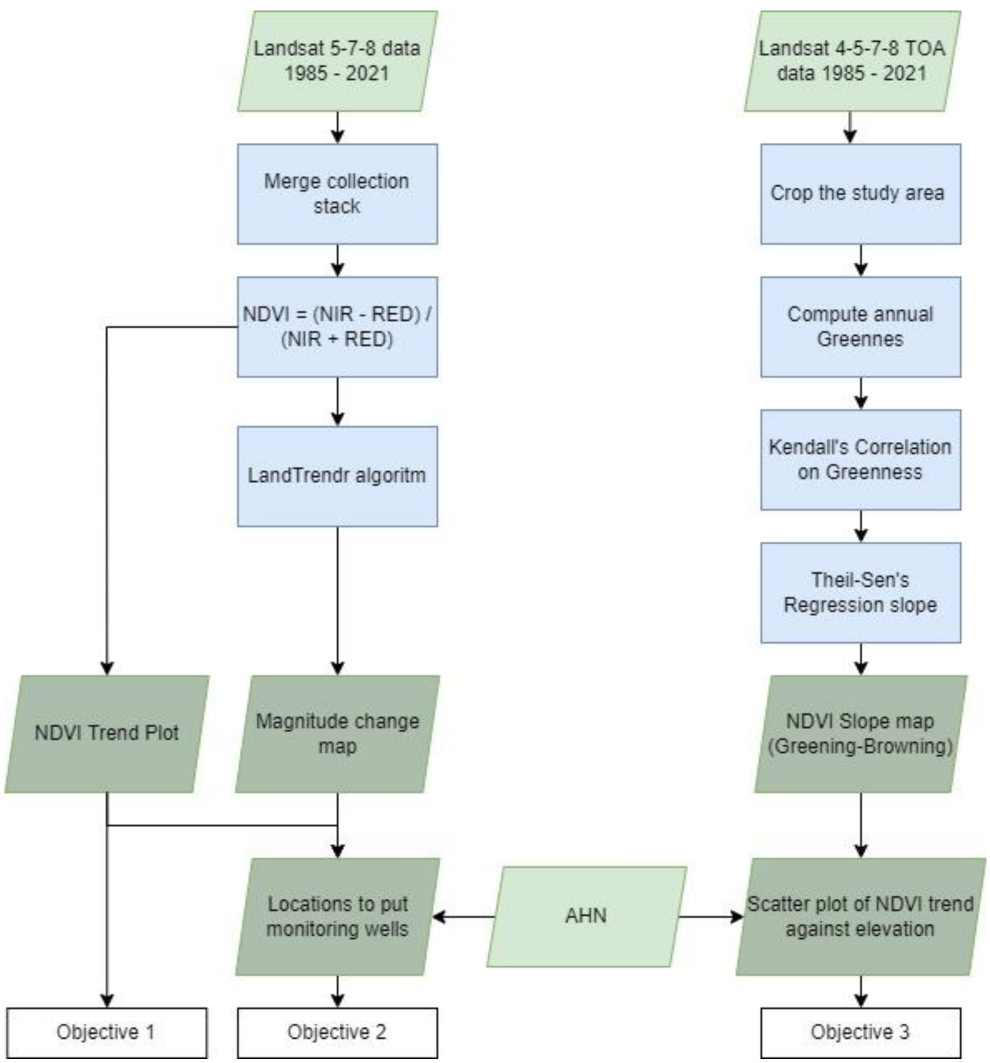

Figure 3 | The workflow of the project.

4.1 Processing tools

The main software used is QGIS and GEE. QGIS is an open-source Geographic Information System. It provides many geospatial data access, visualization, processing, and analysis functions. It was used for the visualizations and correlation between vegetation stress and elevation (part of the correlation in Microsoft Excel.

Moreover, the main tool used for this project is GEE. It is a cloud-based platform that allows users to run geospatial analysis. This cloud-based platform provides an accessible collection of ready-to-use data products, including long-term Landsat imagery series and advanced geospatial tools to handle and manipulate big earth observation data for large areas (Mahdianpari *et al.*, 2020).

As GEE is a platform, it can be used as a host to run applications. To do the processing steps in the workflow, existing applications were used. The applications were adjusted to optimally help meet the objectives. The applications are shortly elaborated on below.

4.1.1 LandTrendr application

To assess vegetation change, an algorithm was developed by Kennedy et al. (2010), called LandTrendr. The core of LandTrendr is, according to Yang et al. (2018), “removing noise-induced spikes from the time-series NDVI, identifying potential vertices (year, NDVI value), the fitting trajectory for the entire period, reducing the segments to simplify the trajectory model, determining the best model and filtering the change. The results of the algorithm are segmentations used for identifying change events. Furthermore, three specific sorts of information about the change event are supplied: year of detection, the magnitude of change and the duration of change event. This is explained in figure 4 and table 1. This algorithm was used in a LandTrendr application, and the application was used to produce part of the results of this report.

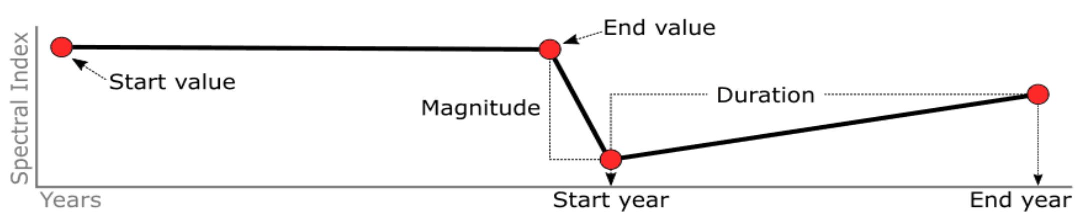

Figure 4 | Explanation of the output of the Landtrendr application (from: https://emapr.github.io/LT-GEE/landtrendr.html).

Table 1| Explanation of the concepts of the output of the Landtrendr application.

Output	Description
Year of detection	The LandTrendr detects the year in which the significant change starts to occur. In the figure below this is indicated as "Start year".
Magnitude of change	Magnitude refers to the change in the quantity of the spectral properties. The more the NDVI is changed, the more likely there is a change in the spectral properties and hence in magnitude of change over time. This scale goes from 0 to 1000.
Duration	Duration means the time when a consistent change is occurring, i.e., vegetation is recovering or decreasing (stress). The duration goes from Start year to End year.

4.1.2 NDVI Slope application

The second application is the NDVI Slope application, for which a code was adjusted from Zulian et al. (2022). The output is a raster which shows greening or browning, indicating respectively an increase in vegetation cover or health, or a downwards trend in vegetation cover or health. The first step the algorithm behind the application takes, is to take the greenest values from Landsat TOA (Top-of-Atmosphere) with a reflectance composite of 30 meters pixel size. The second step is to create another composite, identifying pixels that are classified at least once in the give period. As a last step a Theil-Sen regression analysis is performed (Theil, 1950; Sen, 1968) is performed at pixel level size to account for outliers. P-values are provided as it indicates whether the trend is significant or not. As opposed to the LandTrendr application, the NDVI slope application makes use of the *annual* median NDVI instead of the median NDVI *of the growing season*.

4.2 Processing steps

With the tool described above, the processing steps were done as presented in the workflow. How these tools were used to do these steps, is described below.

4.2.1 Data Acquisition

Important aspects to determine which imagery to use for a case study are Image resolution, number of spectral bands and revisit periods –how long it takes before a satellite revisits the same place (Berhane *et al.*, 2018). Considering the objectives of this research, long-term satellite imagery is required, and the Landsat program is the most suitable choice because the Landsat collection offers the longest continuous global record of the Earth's surface (Rocchio, 2022). Since the early 1970s, Landsat has continuously and consistently archived images of Earth; this unparalleled data archive gives the opportunity to perform change detection research (Zhang *et al.*, 2009). To be more specific, the Landsat data are coarse enough for global coverage, yet detailed enough to quantify spatial changes (30x30m) (Viana *et al.*, 2019). As an extra perk, Landsat satellites have many spectral bands. These bands can be used to compute spectral indices. These indices can aid in monitoring vegetation productivity (Viana *et al.*, 2019) and this would help in the monitoring of vegetation stress in the Lauwersmeer region.

In this project, a series of historical Landsat satellite images was used. This is the first action in the workflow (Figure 3). In GEE we created a series of Landsat Thematic Mapper (TM), Enhanced Thematic Mapper + (ETM+), and Operational Land Imager (OLI) spectral metrics for the period 1985 to 2021. The satellites have a resolution of 30 meters, a revisit time of 16 days and 8 spectral bands, including a NIR band.

Image collections were obtained for the growing season (date range from 1 May to 30 September). However, to compare satellite images within and between years, atmospherically corrected images are required. Therefore, either satellite images that are already pre-corrected need to be obtained, or images need to be atmospherically corrected. In this project we used a series of ready to use atmospherically corrected Landsat images (Surface Reflectance Landsat images).

4.2.2 Data harmonization and masking

Two main pre-processing steps need to be undertaken before any further remote sensing process: images harmonization and masking (Kennedy *et al.*, 2018). Multi-temporal satellite data acquired under different series of satellites may have reflectance inconsistencies due to atmospheric and cloud contamination among others (Masek *et al.*, 2006). Therefore, there is a need to harmonize Landsat imagery. Image harmonization can be defined as the quantification of spectral reflectance transformations between the different satellite imageries in order to provide consistent long term imagery data (Roy *et al.*, 2016).

Clouds, cloud shadows, atmospheric water and snow can significantly influence the spectral bands of optical satellites (Zhu and Woodcock, 2012) and a variety of remote sensing activities, including image compositing (Roy *et al.*, 2010); correction for atmosphere effects (Vermote, El Saleous and Justice, 2002); calculation of vegetation indices (Huete *et al.*, 2002). Therefore, it is important to detect clouds, cloud shadows, atmospheric water and snow in satellite images, and remove them before any kind of remote sensing activity is performed. Accurate cloud, cloud shadow, and snow detection for satellite images can be quite challenging (Zhu, Wang and Woodcock, 2015). In this project the newly developed CFMask algorithm was applied to take an advantage of its capability to detect cloud, cloud shadow, atmospheric water and snow at the same time (Zhu and Woodcock, 2012).

4.2.3 Vegetation index calculation

To give an indication of vegetation stress in the Lauwersmeer area, the NDVI was used as it is one of the most common vegetation indices (Liu et al., 2021). For each pixel in the study area, the annual median NDVI was determined from the satellite images as the median NDVI is commonly used in time-series analysis (Gillespie et al., 2018; Gaw & Richards, 2021; Kumar et al., 2022) and it is less prone to outliers compared to, for example, the maximum NDVI (João et al., 2018).

As vegetation productivity greatly reduces in winter on the northern hemisphere, a date range was selected for the median NDVI determination. As the portion of the year in which conditions (e.g., rainfall, temperature, and daylight) are most optimal for plant growth range between May 1st and September 30th, often referred to as the growing season, this range was applied in the LandTrendr application.

4.2.4 Time series trend analysis of a vegetation index

For the LandTrendr application the season was assumed from the 1st of May to the 30th of September. The LandTrendr application was created from the original GEE code from the LandTrendr algorithm. This was adapted to the needs of this project, such as only selecting NDVI trend. How the application works in practice can be found in the manual. After obtaining annual median NDVI values of the growing season, a temporal trend analysis of vegetation stress was created. These trends can give an indication of the relative condition of vegetation. Both upward and downward trends were assessed and analyzed using the non-parametric Mann-Kendall and Theil-Sen methods (Fensholt et al., 2021; Lui et al., 2021; Kumar et al., 2022).

4.3 Project Analysis

This part of the methodology describes how all the previous steps discussed in the methodology are used to meet the goals.

4.3.1 Monitoring the vegetation stress in the Nature area from 1985 until 2021 - objective 1

Firstly, a polygon of the natural area was uploaded into the Landtrendr applicationa to make a graph of the NDVI trend over the whole area. Then, the Landtrendr application was used to make a map that shows the magnitude of change. Only changes that took longer than 10 years were deemed important, to filter out short events (e.g. dry years and crop cycles). For the rest of the filter settings, see figure 5. The other settings were all kept at default.

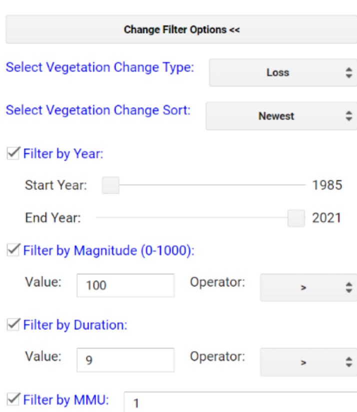

Figure 5| Settings of the LandTrendr application used for the detection of stressed locations

4.3.2 Relationship between vegetation stress and elevation - objective 2

As mentioned in the introduction, the elevation can influence vegetation stress. A negative relationship between them can indicate vegetation stress due to salinity. To assess the relationship between salinity and vegetation stress, the NDVI trend - as a proxy for stress - and the elevation levels were correlated. Firstly, the elevation was derived from Algemeen Hoogtebestand Nederland (AHN) and NDVI trend from the NDVI slope map (derived from the NDVI Slope Application). This was performed in QGIS. The correlation was done in Microsoft Excel. Appendix 1 shows how this was done.

4.3.3 Detection of the most stressed locations in the agricultural area - objective 3

When looking for possible monitoring locations, two things were considered: firstly, the magnitude of the NDVI-changes over time on that location, which was derived from the LandTrendr application. For the settings of the Landrendr application, see section 4.3.1. Based on visual inspection, bigger patches with the highest stress were marked (around 30). Secondly, besides magnitude of NDVI change, the elevation of the location was considered. Based on visual inspection, only the markers in relatively low areas were selected.

4.3.4 Reproducibility - objective 4

All the project deliverables were shared with Wiertsema and Partners through a Github repository. Github is an online platform which is often used for collaboration within a project as you can store, manage, track, and control changes in one central place. The central part of the Github repository is a README file. This file gives an overview of what can be found in the repository. Furthermore, it also contains links to our applications and the Google Earth Engine repositories with the scripts. As Wiertsema and Partners is also interested in re-using and modifying the codes, all steps in the scripts and the manual were provided with comments explaining what the step does.

5. Results and discussion

Even though this section goes deeper into discussing the outcomes of the goals, the applications should be seen as the main result of this exploratory research. Because firstly, the results of the goals that are presented later are just exploratory, and the applications can be used to get a deeper understanding of the results presented in this report (e.g. look on a more detailed scale to a general trend or to look at the nature of a trend in a proposed monitoring location). Secondly, one of the goals for this exploratory research was for the work to be reproducible for Wiertsema and Partners so it could be repeated if they would like to. However, writing scripts in GEE that Wiersema could adjust seemed unattainable – as it would take a lot of expertise for that to work well. That is why the applications were introduced for Wiertsema and Partners: they can now easily repeat the work and perform the same analyses in other areas in the Netherlands. The rest of the results section will be dedicated to discussing the results of the goals that were set.

5.1 Stress trends in the national park Lauwersmeer

Figure 6 shows the overall NDVI-trend over the Lauwersmeer National Park as a result of the LandTrendr application. It shows an upward trend. This could potentially mean that the saline vegetations, which has less foliage, have been replaced by 'greener' (i.e. broad leaf) vegetations. For more detailed inspection of NDVI trends, the pixel based NDVI plot function in the LandTrendr application can be used. Any pixel can be clicked and the trend in that pixel can be inspected.

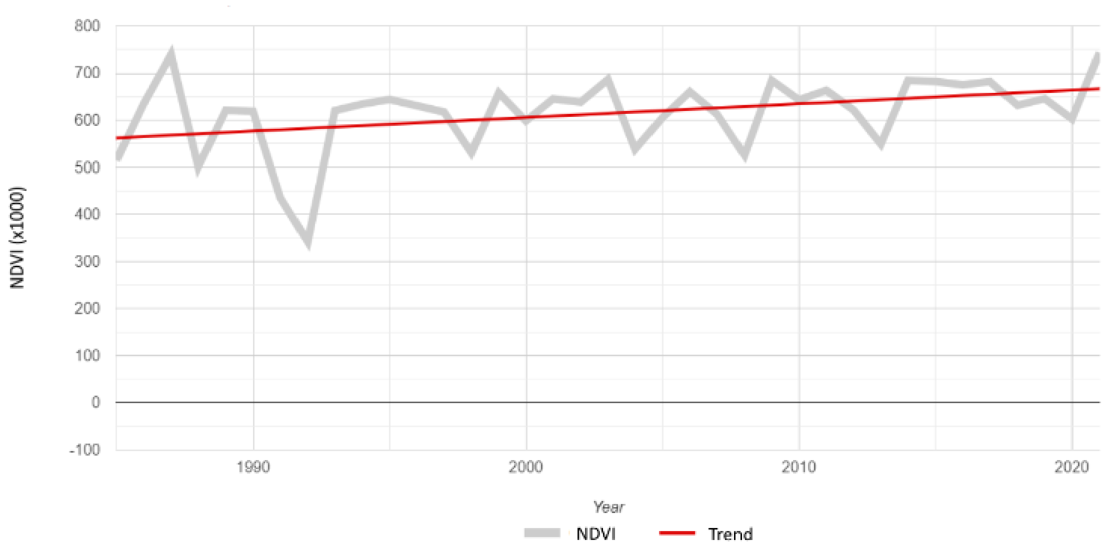

Figure 6| NDVI trend over the Lauwersmeer National Park.

Figure 7 shows the locations that with a significant negative trend in NDVI in the natural area surrounding the Lauwersmeer. The stressed areas are scattered all over the natural area, but a clear stress hotspot can be found in the southwest of the area. In this place, there is a pool where water levels change by climate conditions. One possible reason is that the water level has become higher, which can cause higher stress levels for vegetation. Another cause could be increased salinity. To assess whether the stress in these places could be caused by salinity, the trend values of 1985 until now are plotted against the elevation in these places.

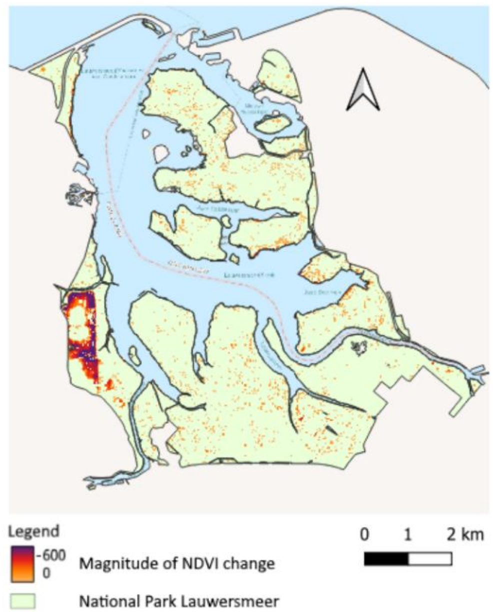

Figure 7| Significant negative changes in NDVI that lasted longer than 10 years in the National Park Lauwersmeer

5.2 Relationship between NDVI trend and elevation in national park Lauwersmeer

Figure 8 shows the result of correlation analysis between NDVI trend and elevation in the natural area. The correlation coefficient (R^2) was very low (0.0023), indicating that there is no linear relationship between them. It could mean that there are other stresses than elevation-related salinity that cause the change in NDVI. Even though the NDVI trend was not significant, it does not mean some of the stress is not caused by salinity nor that low lying areas are not impacted by salinity.

Something that might be debatable in about the methods of this research, is that absolute elevation was used in this research instead of relative elevation, as was done by Cramer et al. (2004). Their study *does* show a correlation between elevation and salinity. They found that a variation of 0.2 meter (over 10 meter) could already cause vegetation mortality due to the salinity. However, this relationship includes *relative local* elevation over 200 m –opposed to *absolute* elevation of the study area. Besides, the coarseness of our measurements is bigger than in the study of Cramer et al. (2004). Our study is looking at averages over 30x30 m, while they are looking at averages over 10m transects. For the future, relative local elevation might be a better variable to assess the relationship between salinity and NDVI trend.

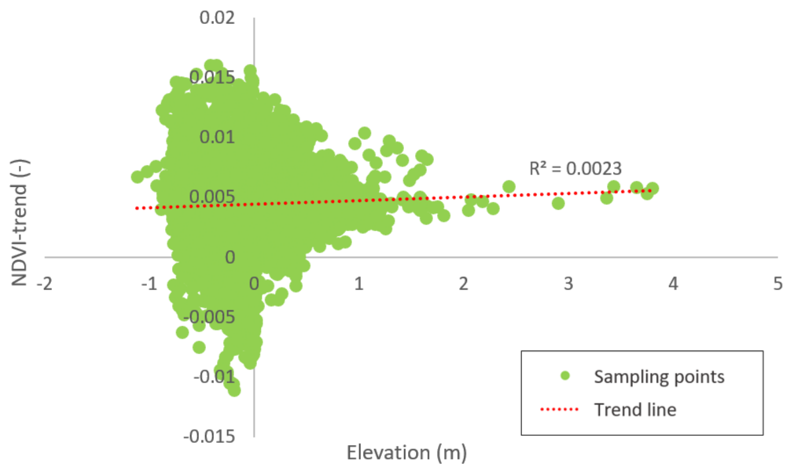

Figure 8| Correlation between NDVI-trend of all pixels within the nature area and elevation.

5.3 Salinity Monitoring Locations in agricultural areas

Figure 9 shows statistically significant ($p < 0.05$) negative changes in NDVI over time in the agricultural area surrounding the Lauwersmeer national park. This negative change indicates potentially highly stressed areas. However, it could also indicate a change in mowing or grazing regime for agricultural grasslands or the construction of buildings or infrastructure. The suggested salinity monitoring locations were based on these stress locations and an elevation map. They are presented in figure 10. The 15 points shown on the map are suggested locations but should be further explored (e.g. with the by clicking pixels in the LandTrendr application and further investigating trends at these locations (see fig. 11 for an example)).

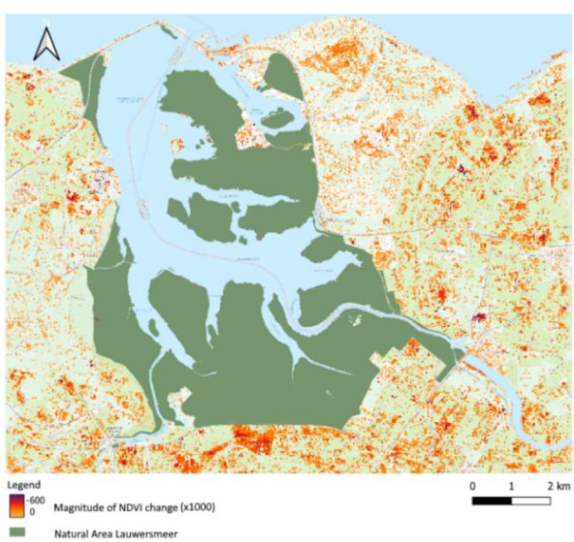

Figure 9| Magnitude of NDVI change in the agricultural areas surrounding the Lauwersmeer National Park.

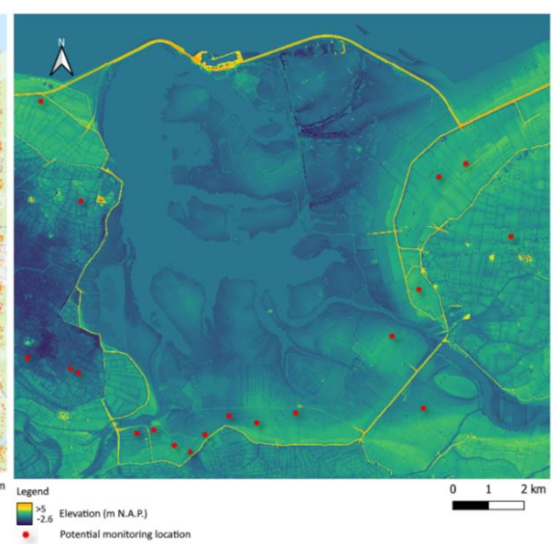

Figure 10| Elevation map with potential salinity monitoring locations in the agricultural areas surrounding the Lauwersmeer National Park.

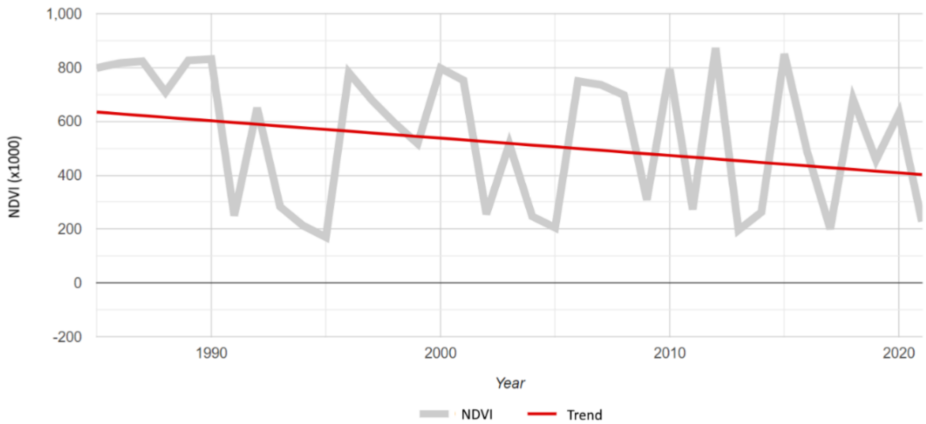

Figure 11| An example of the NDVI trend in the most northern monitoring location

5.4 Reproducibility

The output of this project must be reproducible and easy to understand for Wiertsema and Partners. Therefore, two interactive applications, including a step-by-step manual on how to utilize and interpret them, were provided.

The slope-application shows the slope of the NDVI trend over the years. This application shows the NDVI slopes over 1985 to 2021 for the entirety of the Netherlands by default. The slope-application can be used to quickly assess temporal NDVI trends. Therefore, Wiertsema and Partners can also use this application for exploring NDVI trends outside the Lauwersmeer area. Even though a downward NDVI trend does not necessarily mean that there is vegetation stress as there could be other causes, this application can give a good first indication of stressed locations.

The LandTrendr application has two main functions. The first main function is to get a better overview of the course of the NDVI over the years. The application outputs a graph with the NDVI trend over the years on a pixel basis once the pixel is clicked. In addition, a polygon can be drawn by the user whereupon the application will provide the NDVI-trend within the polygon. This can be useful for, for example, monitoring of ecosystem productivity. The second main function of the LandTrendr application is to get an overview of an AOI of where and when significant changes happened. Like the slope-application, the LandTrendr application can be used outside the Lauwersmeer area.

As these applications make use of satellite images, they can provide information on a long period of time. Therefore, they can not only give an indication of the relative present-day vegetation condition, but the temporal trend of the NDVI can also be used for identifying drivers of vegetation change (Singh, 2003; Lui et al., 2021). By identifying the drivers of vegetation change, suitable restoration, management, or monitoring strategies can be applied.

5.5 Quality assessment

Figure 12 shows all the observations that contain the study area from 1984 to 2022 taken by Landsat 5, 7 and 8. We took median NDVI in the whole region as representatives. Although data till 1995 are limited, there are a lot of data available afterwards. In particular, after Landsat 7 start working, the amount of data increased. Therefore, for this project, quality may not be high enough before 1995, but is probably high afterwards.

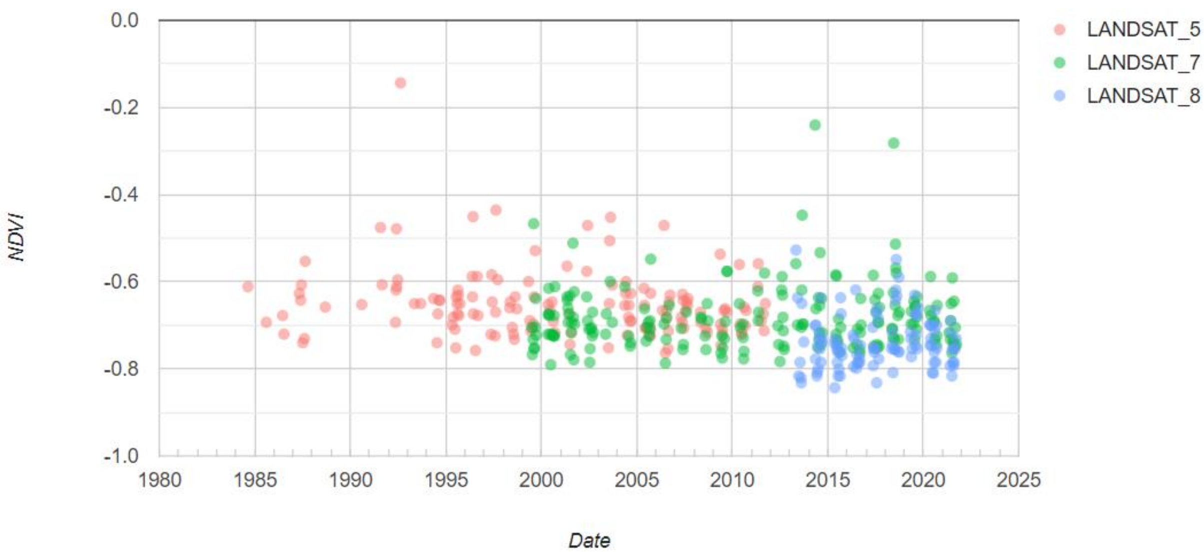

Figure 12 | All the observations taken by Landsat 5, 7 and 8 from 1984 to 2022.

6. Limitations and Recommendations

6.1 Vegetation Indices

The LandTrendr application and the maps in the results show a trend in NDVI, which is used as a proxy for vegetation stress: significant change in NDVI is interpreted as vegetation stress or vegetation change (Singh et al., 2003). However, a decreasing NDVI trend does not per se mean vegetation stress. It could also mean that the vegetation was replaced by buildings, or forest being changed into agriculture.

Besides the NDVI, there are more vegetation indices that could be useful for identifying vegetation stress. For the extent of this case study, the NDVI suffices as an indicator of vegetation stress. However, if Wiertsema and Partners would want to do research in very densely vegetated areas like shrubs and forests, they could use the Enhanced Vegetation Index as a vegetation index (Huete et al., 2002). It considers more information that will give more accurate results. Another vegetation index that is more often used in agricultural areas, is the Vegetation Condition Index (VCI) (Quiring & Ganesh, 2010). Nonetheless, there are many more indices that could indicate plant stress but there is no 'one size fits all' index. Which index would be best to use, should be evaluated based on situations. By validation through ground truth data of a variable (e.g., EC measurements), you can evaluate how well the selected VI can be used as an indicator for that variable. Still, NDVI is the most used indicator and as such is suitable for most situations.

6.2 Application & GEE

One limitation of using satellite data for monitoring is that it is impossible to monitor real time stress. The Landsat satellite only passes over the area approximately once every 8 days. In addition, some of those days will be clouded which means the images from these days cannot be used for monitoring. This removes some data. However, throughout a growing season it is seldom the case that there are not enough satellite images because of clouds masking, and calculations can be done to most years, if not all.

Another temporal limitation, us that the scope of the period is only 1985 to the present. Making it go back further is a lot more work. Besides, every year the code needs to be adjusted to view the previous year. This can be done by adjusting the code, with a simple step of changing the date.

There are not only limitations in time span of the project, but also in space: the scope of this research project is limited to the Lauwersmeer. Even though the product can easily be easily used in other areas. The size of areas that can be exported is limited due to a pixel limit of 10e9 pixels. This comes down to a roughly 20-kilometer resolution, for both LandTrendr and slope-applications. Computation times will increase with large resolutions. Using maximum resolution computation and export time is around 10 minutes.

Some things to keep in mind when it comes to GEE, is that products that follow from it may not be sold. They may, however, be used for evaluation purposes without a commercial license (Google, 2022). Besides, it would be wise to copy the code before it is edited, because the code is very sensitive to errors. The code is however always available on the GitHub if the original is needed.

Important note: Changing the code is possible, but at own risk. Especially the application is prone to errors if small changes are made. It is strongly recommended that no changes are made without the supervision of the creators or GEE experts. The original is also always available on the GitHub if wanting to play around.

6.3 Analysis

The maps that follow from the Landtrendr app are based on changes in NDVI that last longer than 10 years and only the newest trends are taken into account (if there are two negative trend segments in the last two years, only the most recent trend is shown in the output of LandTrendr). As dynamics of salinization are not within our expertise, using different settings that these could be better for indicating salinization. Further investigation will be necessary for better detections of locations where vegetation experiences salinity stress. Besides, they should definitely be seen as just an indication for what *could* be a suitable location, as the NDVI trend is just an indicator for vegetation stress by salinity.

Although there was no linear relationship found between elevation and NDVI-trend, does not mean it cannot be used to predict salinity of the soil. In research by Yahiaoui et al. (2015), a more advanced approach to identifying soil salinity through remote sensing data was used (than using just the NDVI-trend and elevation). Yahiaoui et al. predicted EC values of the soil based on elevation, soil type and a VI (SASI). They predicted salinity levels of the soil over a study area with 45% accuracy based on a multiple linear regression model using some EC-measurements and soil type, elevation- and satellite data.

Lastly, the NDVI slope app provides the slope in units of NDVI per year. This is calculated for all areas, not regarding the significance of change. The significance can be viewed by using the p-value map. If overlaying these two, it is easy to assess significant changes, instead of just NDVI change.

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Appendix I:

As a more detailed methodology, this section shows you step by step how the correlation between two rasters (NDVI trend and elevation) were calculated in this project using QGIS & Excel. This was done using (1) Algemeen Hoogtebestand Nederland (AHN) and (2) the output from the LandTrendr application provided with the main report -a raster with NDVI trend values.

First, sampling points were created. These points contained the data of the NDVI trend and the AHN values. Then, the NDVI trend and AHN values were exported to Excel to calculate correlation. Figure 1 illustrates what this looks like in QGIS.

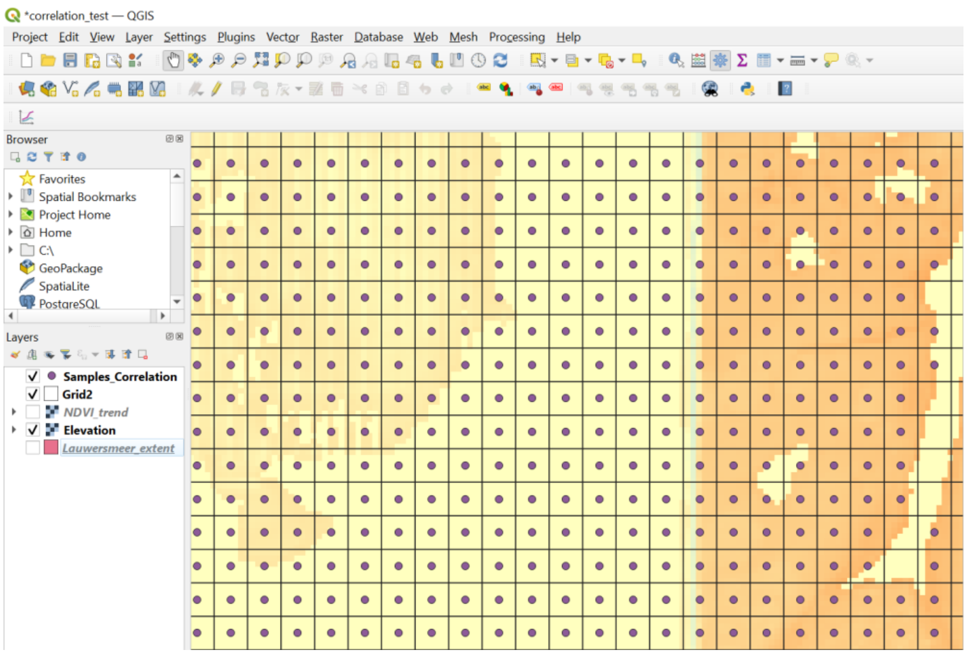


Figure 1: A grid with sampling point to sample the elevation and the NDVI trend.

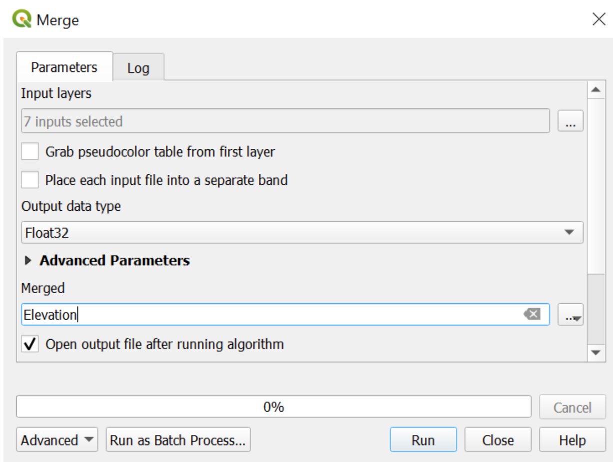
Open a project in QGIS and take the following steps:

Data input & pre-processing:

1. Add the ANH tiles (rasters) into QGIS.
   - Merge the AHN-tiles into a single raster (In the toolbar click “Raster” → “Miscellaneous” → “Merge”)

   Settings of the tool:

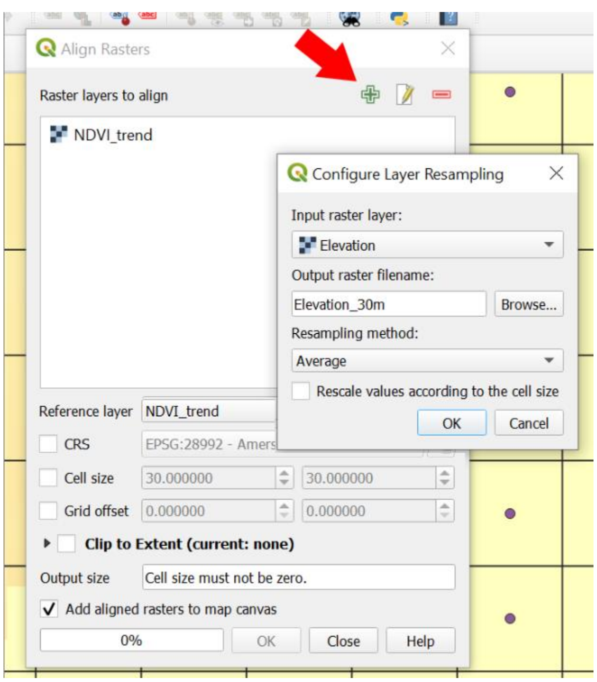
   - Input layers: click the 3 dots besides input layers and select all AHN-tiles
   - Merged: desired name of the output raster



2. Add your area of interest (AOI): Lauwersmeer_extent in figure 1.
3. Add the NDVI-trend raster.
4. Resample raster with highest resolution to the raster with the lowest resolution. The AHN has a resolution of 5m, while the NDVI trend map has a resolution of 30m. The AHN will be resampled to 30m. An average of the values within these 30m will be taken (In the toolbar click “Raster” --> ''Align Rasters...”

   Settings of the tool:

   - Click the red plus and add both rasters: the Elevation (AHN) and the NDVI_trend raster.
   - When adding the elevation raster, pick “Average” as a resampling method.
   - Reference layer: NDVI_trend
   - The rest fills out automatically. Click “Ok”.



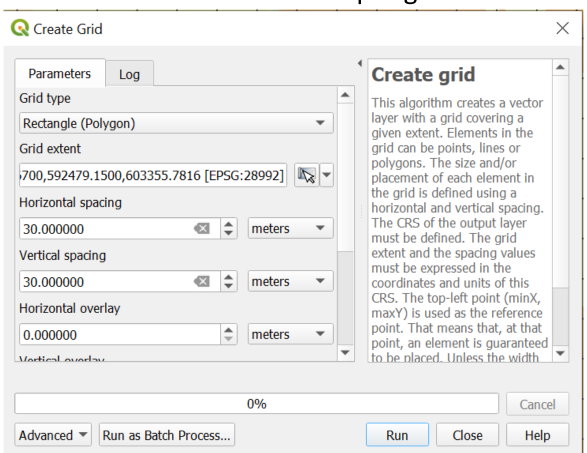
If everything went well, you now have two rasters with the same resolution. Check whether the two rasters have the same coordinate reference system before you go on (Under layers, right click the raster and select “properties” --> “information” --> “Coordinate reference system”). If not, use the “warp” in the toolbox.

Processing in QGIS:

5. Create a grid for sampling(In the toolbar click “Processing” → “Toolbox” → search “Create grid”):

   Settings of the tool:

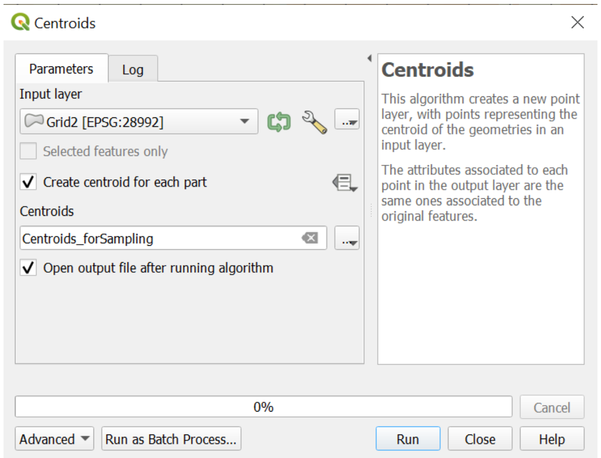
- Grid Type: ‘Rectangle’
- Grid Extent: Calculate from later → your AOI
- Horizontal- + vertical spacing: the same size as the input raster with the lowest resolution
- Grid: desired name of the output grid



6. Insert centroids into the grid as sampling points (In the toolbar click: “Vector” → “Geometry” “Tools” → “Centroids”)

   Settings of the tool:

- Input: the grid you made in the previous step
- Centroids: desired name of the output points

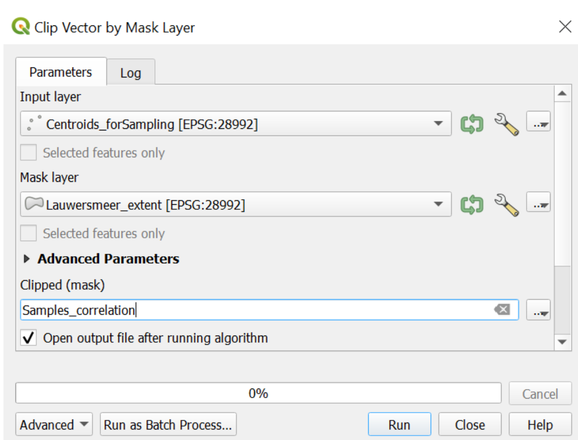


-

7. Clip the centroid points by the mask of the AOI so you only sample the AOI and not the whole grid (In the toolbar click: “Processing” → “Toolbox” → search “Clip Vector by Mask Layer”)

   Settings of the tool:

   - Input layer: the centroids made in the last step
   - Mask layer: your AOI
   - Clipped (mask): desired name of output points



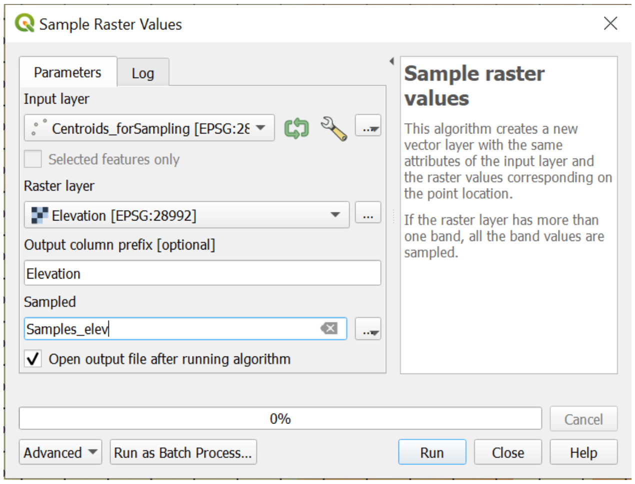
8. Add the raster values of the NDVI trend and the AHN to the clipped points (In the toolbar click: “Processing” → “Toolbox” → “Sample Raster Values”).

   You will have to use this tool twice: once to add the AHN values to the points, and once to add the NDVI values to the points. The second time you select the output of the first time.

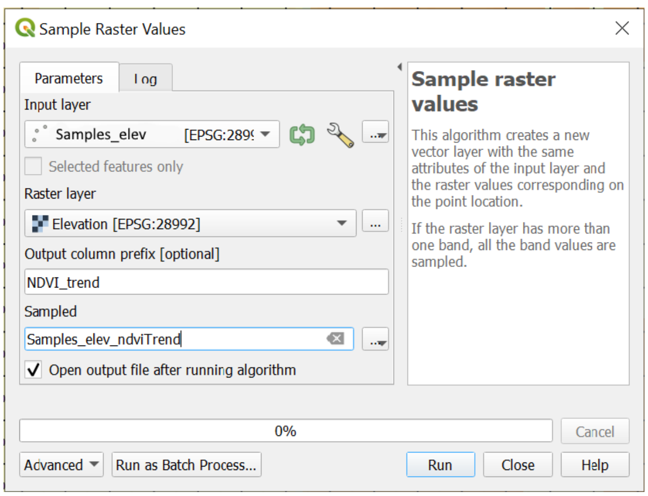
   Settings of the tool:

   - Points: the points you clipped to the mask of the AOI
   - Raster Layer: (1) the NDVI change map & (2) the merged AHN
   - Output column prefix: “NDVI” for NDVI, and “AHN” for AHN.
   - Sampled: give a name to the file.

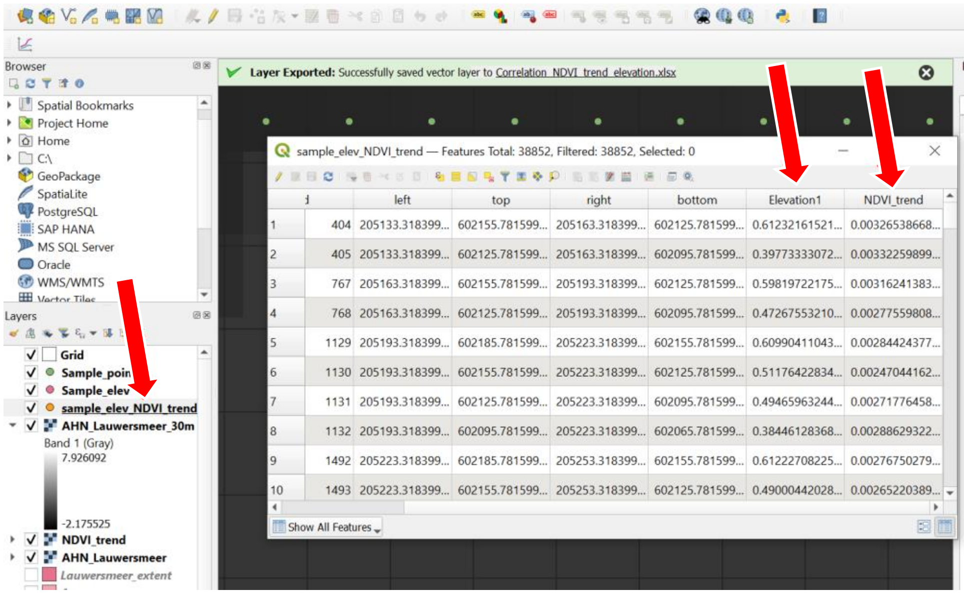
   (1)



(2)



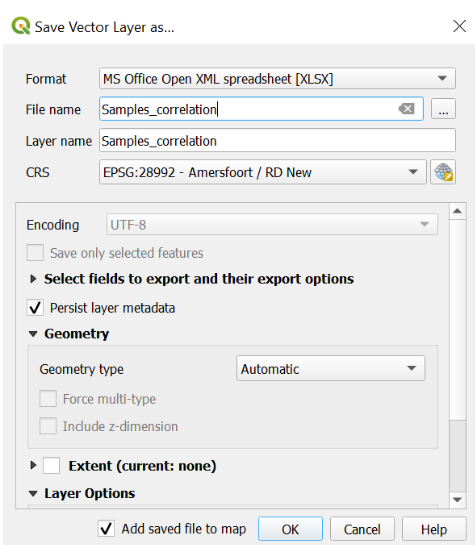
After this step, right click the layer with the samples and select “attribute table”. It should look as follows:



The red arrows show the attributes that you just added.

9. Now the points have the values of the AHN and the NDVI, they can be exported to excel, and a scatter plot can be made to do the correlation. (Right click the layer containing the points --> “export” --> Save Feature As...)
   Settings of the tool:

   - Format: “XLSX”



Correlation in Excel:

10. Open the XLSX-file in excel.
11. Select the NDVI_trend- & Elevation values and filter out the elevation values of 0.00 (water).

12. In the toolbar, click “insert” → “scatter” and select the first scatter plot icon.