Politecnico
di Torino

Master’s Degree in Environmental and Land Engineering

Climate Change

Automatic Mapping of irrigation grid of Cavour Channel using areal images in ArcGIS pro

Candidate

Donya Deris Zadeh , s301232

supervisors

Prof. Francesca Matrone

Prof. Stefania Tamea

Prof. Andrea Maria Lingua

2024

Abstract

The effective management of water resources is crucial for ensuring agricultural sustainability, especially in regions facing challenges associated with climate change. Irrigation networks, such as the Cavour Canal in Piemonte, Italy, are crucial in supporting agriculture. This research focuses on mapping the irrigation network of the Cavour Canal and extracting the flow direction of its channels using remote sensing data and geospatial analysis in the ArcGIS Pro software environment. The aim is to create a comprehensive and accurate representation of the irrigation grid, which can serve as a basis for future temporal analyses and climate adaptation strategies. The study uses high-resolution orthophotos and digital terrain models (DTM) provided by the Piemonte region's cartographic sector to identify and map the channels and their associated flow directions.

The Cavour Canal, originating from the Po River in Chivasso and extending to Galliate where it discharges into the Ticino River, plays a key role in the irrigation network of the Piemonte region. The canal is designed for spring-summer irrigation, with water flowing through the system from early May to mid-September. Given the increasing risks of climate change, such as prolonged droughts and extreme weather events, this research aims to determine whether the irrigation network will continue to meet the region's agricultural demands in the future.

The study employs a multi-step approach which includes facing challenges such as similarity of reflectance of water with other phenomenon such as asphalted roads when focusing on the RGB bands or with shadows when focusing on the Near Infrared band, and also the fact that in many parts of the study area the channels are substantially covered by branches of trees which can completely block visualizing the water beneath them .

First, a polygon shapefile of the irrigation network is generated using RGB and color infrared (CIR) orthophotos with 0.4-meter resolution. The first level classification which is of the CIR images is supervised, aiming to extract water pixels and categorize them into four classes: water, green vegetation, harvested vegetation, and built areas. The classification is performed using four different algorithms: Nearest Neighbor, Random Trees, Support Vector Machine (SVM), and Maximum Likelihood. To deal with the scattered nature of water pixels in the channels due to the resolution

limitations, the results from the four classifiers are aggregated. This aggregation step ensures the highest possible detection of water pixels.

A second level classification is conducted on the RGB images to distinguish water pixels from roads and shadows. A buffer is then created around each channel segment to separate water polygons of channels from those representing other water bodies like rivers or flooded areas.

The next step is extracting the full polygons of the channels from the scattered water polygons. This is achieved through a series of geospatial processes that involve converting water polygons into points, generating lines connecting the points, and creating rectangular polygons along these lines to form the channel geometry. The process is automated using ArcGIS Pro's ModelBuilder tool, allowing for efficient processing of large datasets and the application of the method to new input data. The model is further extended using iterative processes to ensure accurate mapping across the entire study area.

The second objective of the research is the extraction of flow directions within the channels. Using the DTM and line features of the channels, the study calculates the elevation of each point within the irrigation network. By connecting points with differing elevations, the direction of flow can be inferred. The model developed for this task ensures that the flow direction is from higher to lower elevations, as expected in natural watercourses. The results are validated by comparing them with known flow patterns in the study area.

The study concludes by addressing potential errors in the mapping and flow direction extraction processes. Commission and omission errors are identified, with the former representing areas incorrectly mapped as water and the latter representing true water areas missed by the model. Accuracy is assessed by comparing the results with ground truth data derived from orthophotos. The study also highlights the limitations of using medium-resolution satellite imagery, such as Sentinel-2, for temporal analysis of the irrigation network. Due to the small width of the channels (2-4 meters on average), the 10-meter resolution of Sentinel-2 images is insufficient for detecting water presence in the channels. Instead, higher-resolution satellite imagery or drone-based multispectral imagery is recommended for future studies.

Overall, this research provides a detailed methodology for mapping irrigation networks and determining flow directions using remote sensing data and GIS tools. The results can serve as a reference for future studies aimed at monitoring water distribution in the region, assessing the impact of climate change on irrigation networks, and developing more efficient water management strategies.

Introduction

About Canale Cavour

The Cavour Canal is an artificial waterway located in the Piemonte region of Italy, constructed to support agricultural activities, particularly rice cultivation. The canal begins at the Po River in Chivasso and flows almost 83 kilometers, eventually discharging into the Ticino River in the municipality of Galliate. This makes it the third-longest artificial canal in Italy. At its intake, the canal has a maximum flow rate of 110 m^3/s, which decreases to 85 m^3/s downstream, after crossing the Sesia River.

The canal's intake structure, which draws water from the Po River, is situated approximately 200 meters east of the Chivasso bridge on the left bank of the river and about 400 meters downstream from the road bridge that connects Chivasso to the nearby hills. The intake mouth is 40 meters wide at its base, with the first 460 meters paved with cobblestones and concrete, transitioning to stone and concrete slabs near the intake building itself. Roughly 600 meters from the intake, the flow is regulated by an entrance sluice that houses the floodgates controlling the canal’s flow. A small overflow channel, located upstream of the sluice, allows excess water to be diverted back into the Po River.

After flowing eastward for several kilometers, the Cavour Canal crosses the Dora Baltea via an aqueduct. It then receives additional water from the Farini Canal, which captures the Dora's waters near the town of Saluggia. The Dora Baltea's hydrological pattern, characterized by summer floods and winter low flows (in contrast to the Po's regime), plays a critical role in compensating for the low flow of the Po during the summer irrigation season.

From this point, the canal heads northeast, entering the rice-growing region of lower Vercelli near Lamporo. The Cavour Canal operates only during the spring and summer irrigation season, starting in early May and continuing until mid-September. Once the irrigation season concludes, the canal and its entire network are emptied and remain dry until the following spring.

The irrigation process is managed in a stepped manner. Irrigation begins at the upstream portions of the land, where each area is flooded for two to three weeks. After that, the water flows to the next section downstream, continuing in this manner until the water reaches the canal's outlet, where the Po and Sesia rivers meet. At this point, the remaining water is returned to the Po River basin.

Why Study the Irrigation Network of Piemonte?

The Cavour channel, along with other channels located on upper streams such as Depretis and Farini channel, has historically provided reliable irrigation to agricultural fields in the Piemonte region by utilizing water from the Po and Dora Baltea rivers. However, the rising effects of global warming, including shifts in hydrological patterns, more frequent and prolonged droughts, and increasingly extreme weather events, make it necessary to reconsider how water resources are managed, distributed, and consumed.

With future climate conditions expected to become even more severe, whether due to droughts or floods, it is essential to evaluate whether the existing channels network will continue to meet the region's irrigation demands. A more detailed management approach is critical to ensure the sustainability of water resources and agricultural productivity in the face of changing environmental conditions.

Aim and Expected Results

The primary objective of this study is to create a detailed map of the irrigation network as a polygon shapefile. This map will serve as a reference for multi-temporal analysis, allowing for the evaluation of changes in the presence and quantity of water within the channels over time. In addition, we aim to determine the flow direction of each channel section based on data from a digital terrain model (DTM), providing further insights into water distribution within the network.

Study Area and Data

The study area is a rectangular region located northeast of Torino, within the Piedmont region. The approximate coordinates for two opposite vertices of this rectangle are [8.000° E, 45.240° N] and [8.136° E, 45.198° N], covering a total area of approximately 51 square kilometers.

The Cartographic Sector of Regione Piemonte has provided several valuable topographic products for local-level planning, which are available in the Geomatic Lab of the Politecnico di Torino. This research has made use of RGB and CIR (color-infrared) orthophotos, both with a geometric resolution of 0.4 meters. The RGB orthophotos consist of three spectral bands: blue, green, and red. The CIR orthophotos are composed of green, red, and near-infrared bands, making them suitable for vegetation analysis and other specialized studies.

Each orthophoto is divided into smaller images measuring 6.5 by 5.7 kilometers. Since the study area covers two of these images, the images were mosaiced together and clipped to match the geometry of the study area. In addition to the orthophotos, a Digital Terrain Model (DTM) with a 5-meter pixel size and 1-meter resolution in elevation was provided. This set of data, collected in summer of 2010, covers the entire Piedmont region.

Moreover, the line features of the main irrigation channels were supplied by the Ovest Sesia Organization of Irrigation.

Mapping of the channel network and extraction of flow direction was performed using ArcGIS Pro software, utilizing the provided orthophotos as a base. The DTM, together with the line features of the channels, was employed to determine the flow direction within the network of canals.

First Level Classification: CIR Image

The CIR image consists of three spectral bands: Near-Infrared (NIR), red, and green. A supervised classification was performed to extract water pixels, with training samples (polygons) collected from across the entire image. The classification includes four classes:

- 0 : Water
- 1 : Green vegetation
- 2 : Harvested vegetation
- 3 : Built areas, which include cities and roads.

When extracting samples for built areas, it is tried to avoid selecting vegetation within urban areas. Green vegetation includes forests, vegetation in cities, and agricultural fields that appear green. In contrast, agricultural fields affected by harvesting, where crops have been removed and there is some influence of soil or woody materials in the reflectance, are grouped under harvested vegetation.

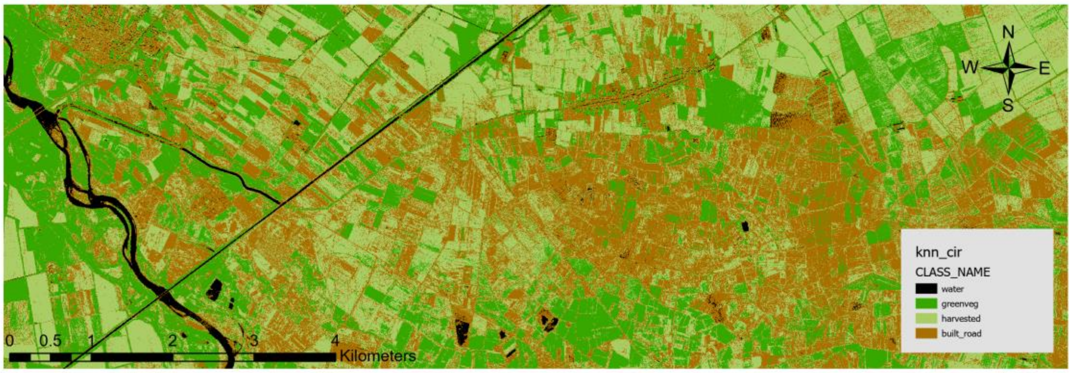
The classification process was carried out using four classifiers available in ArcGIS Pro:

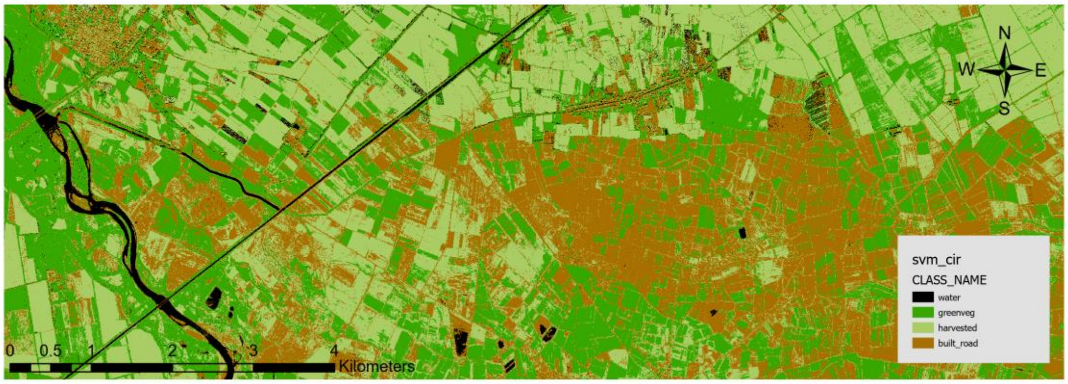
- Nearest Neighbor
- Random Trees
- Support Vector Machine
- Maximum Likelihood

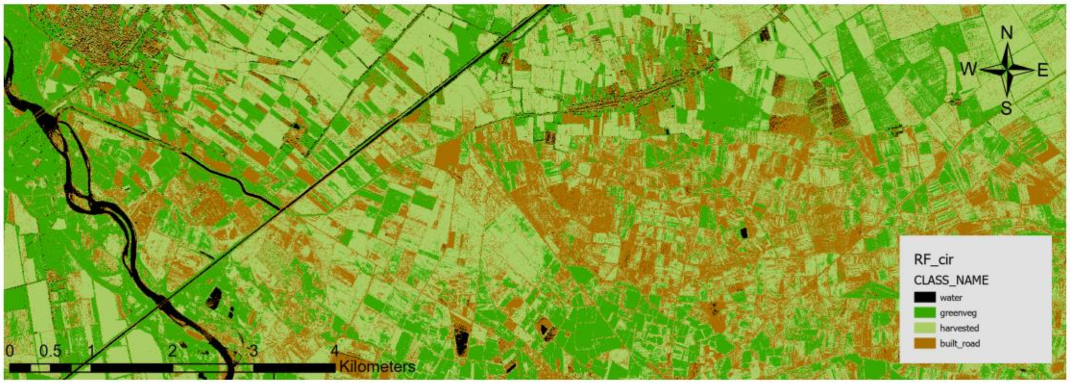
Each classifier produced a classified raster image, each with one band and four values, corresponding to the four classes. However, because water pixels in the channels were highly scattered due to the small size of the channels relative to the geometric resolution of the image, rather than validating and selecting the best classifier, the water polygons from all four classifiers were aggregated to maximize the capture of water pixels. This aggregation was performed using the "merge" tool.

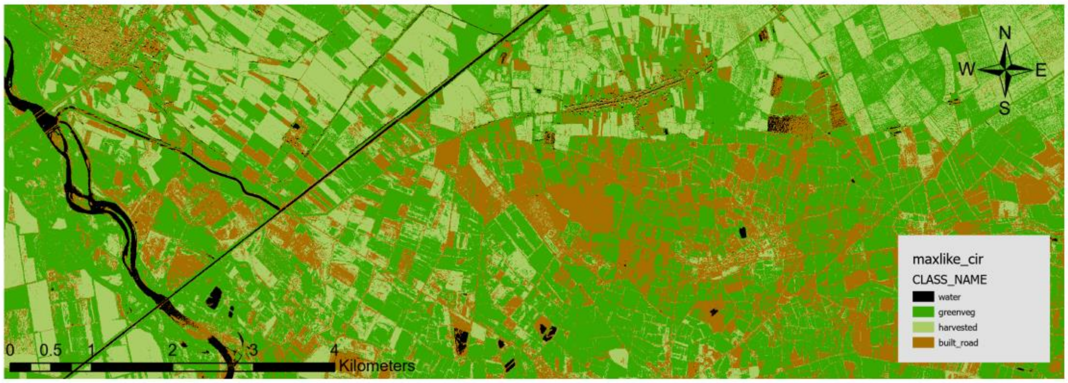
Since some pixels marked as water were actually shadows or roads (due to their similar reflectance in parts of the image) a subsequent classification was conducted using the RGB image to further differentiate and separate true water pixels from those misclassified as roads or shadows.

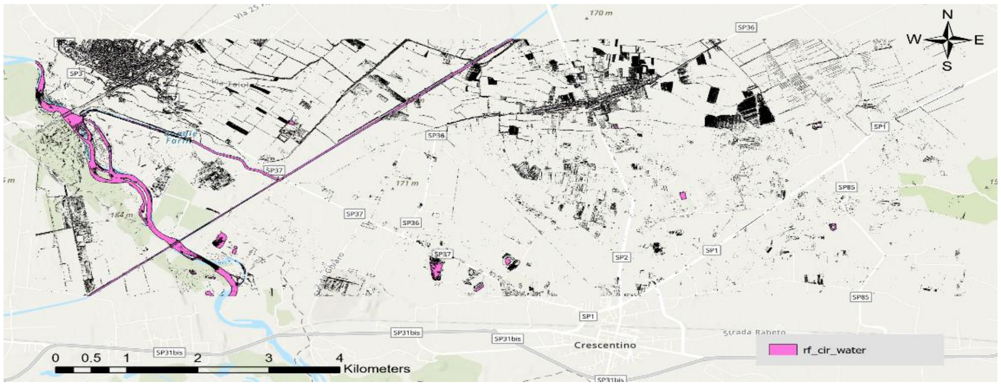
The water pixels identified in this step serve as input for the next stage, which involves classifying the RGB image.

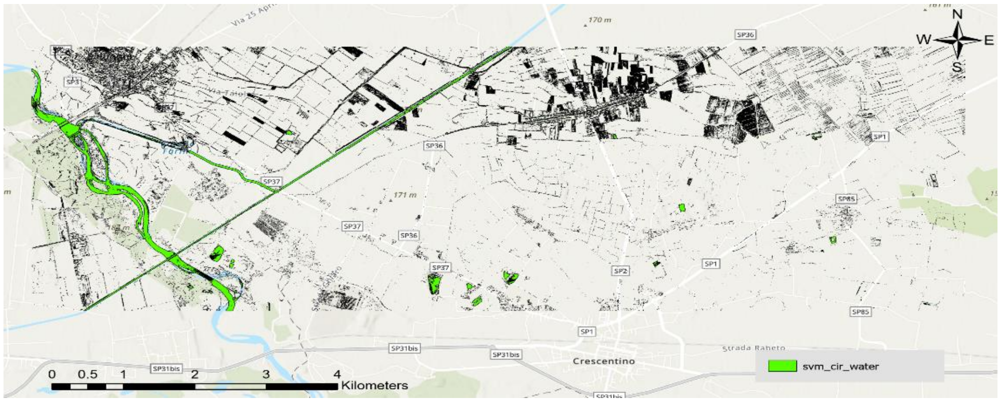

N
W
E
S
knn_cir
CLASS_NAME
water
greenveg
harvested
built_road
0
0.5
1
2
3
4
Kilometers

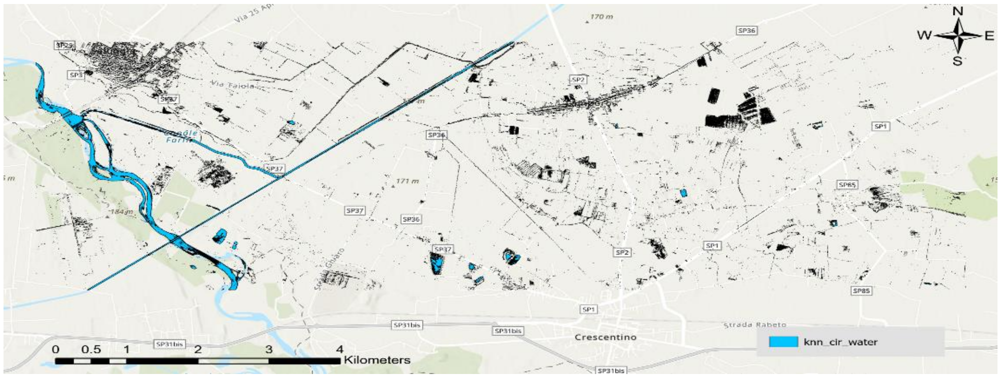

N
W
E
S
svm_cir
CLASS_NAME
water
greenveg
harvested
built_road
0
0.5
1
2
3
4
Kilometers

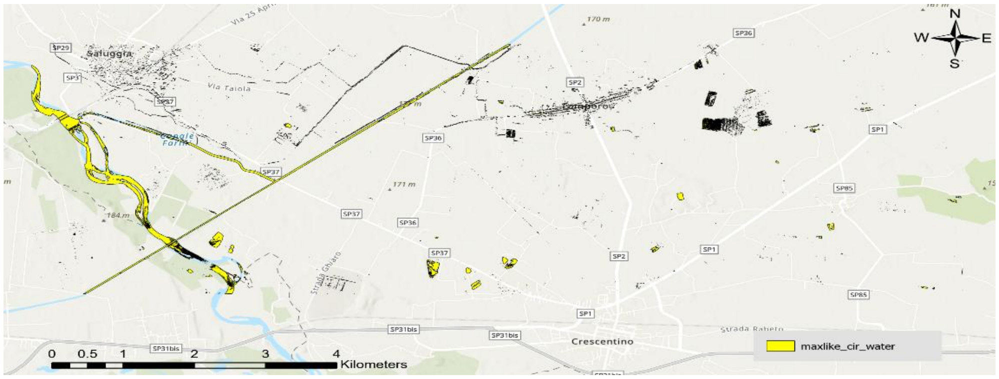

N
W
E
S
RF_cir
CLASS_NAME
water
greenveg
harvested
built_road
0
0.5
1
2
3
4
Kilometers

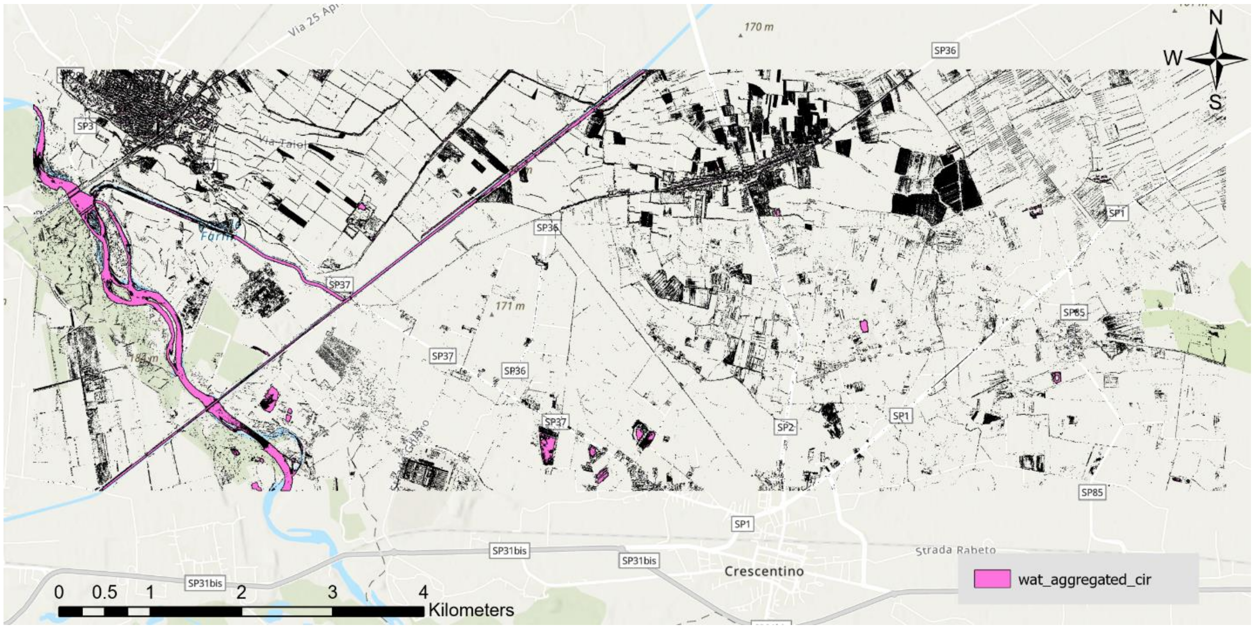

N
W
E
S
maxlike_cir
CLASS_NAME
water
greenveg
harvested
built_road
0
0.5
1
2
3
4
Kilometers

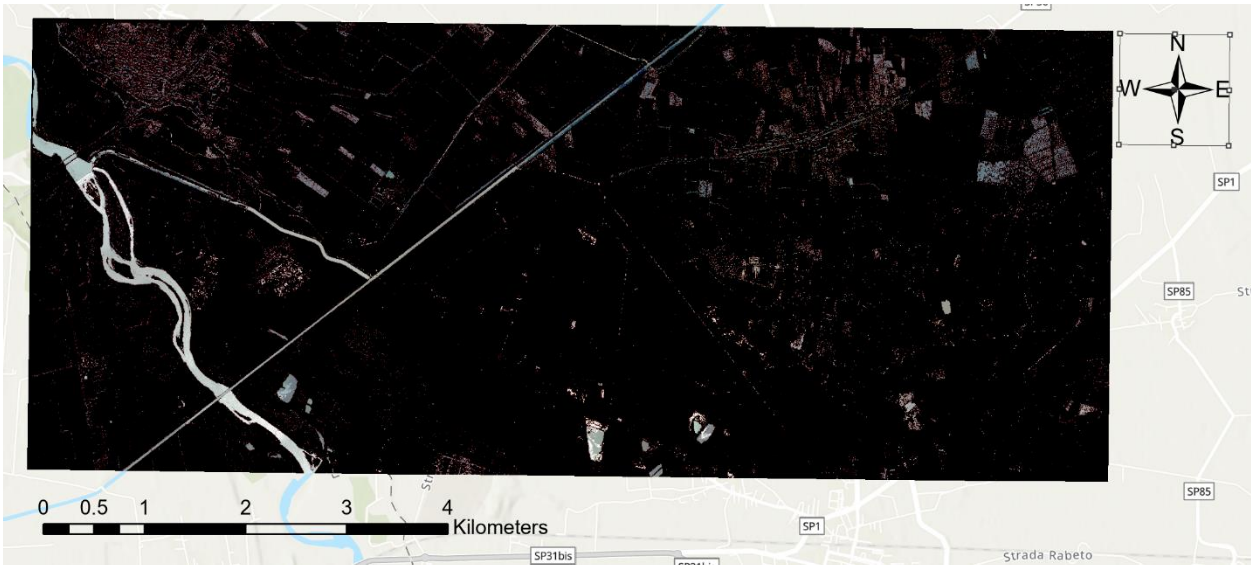

N
W
E
S
rf_cir_water
0
0.5
1
2
3
4
Kilometers
Crescentino
SP1
SP2
SP3
SP36
SP37
SP85
SP31bis
Strada Raheto
170 m
171 m
184 m
Via Taiola


N
W
E
S
svm_cir_water
0
0.5
1
2
3
4
Kilometers
Crescentino
SP1
SP2
SP3
SP36
SP37
SP85
SP31bis
Strada Raheto
170 m
171 m
Via Taiola


N
W
E
S
knn_cir_water
0
0.5
1
2
3
4
Kilometers
Crescentino
SP1
SP2
SP3
SP29
SP36
SP37
SP85
SP31bis
Strada Raheto
170 m
171 m
184 m
Via Taiola


N
W
E
S
maxlike_cir_water
0
0.5
1
2
3
4
Kilometers
Saluggia
Crescentino
SP1
SP2
SP3
SP29
SP36
SP37
SP85
SP31bis
Strada Raheto
170 m
171 m
184 m
Via Taiola





این عکس رو عوض کنم با ورژن ارک جیس اش/اگرگیت شده ی این کلسیفیکیشن هم اسکرینشات کنم

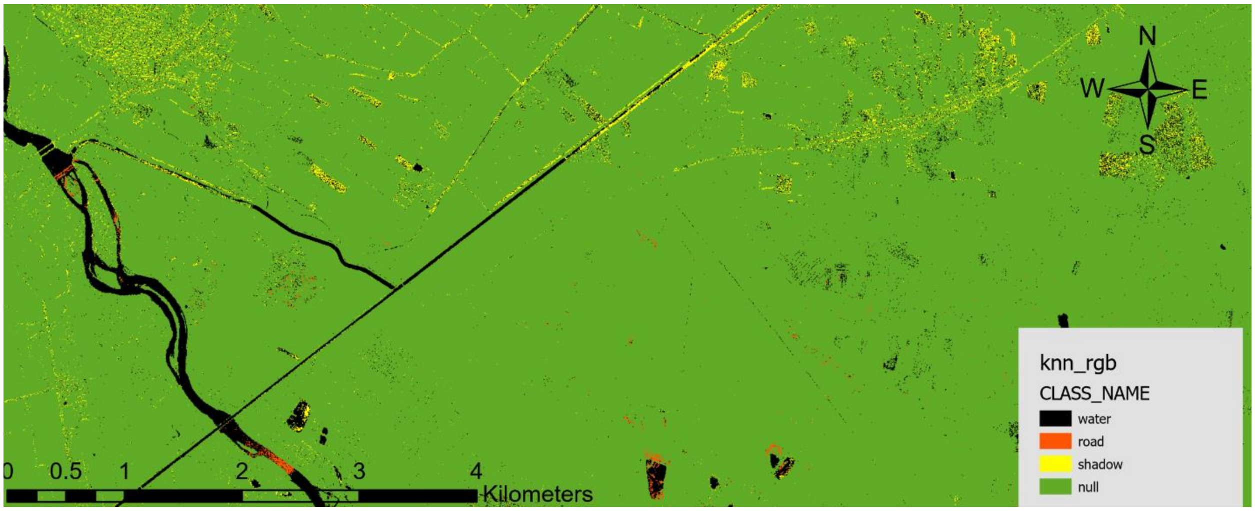
Second Level Classification: RGB Image

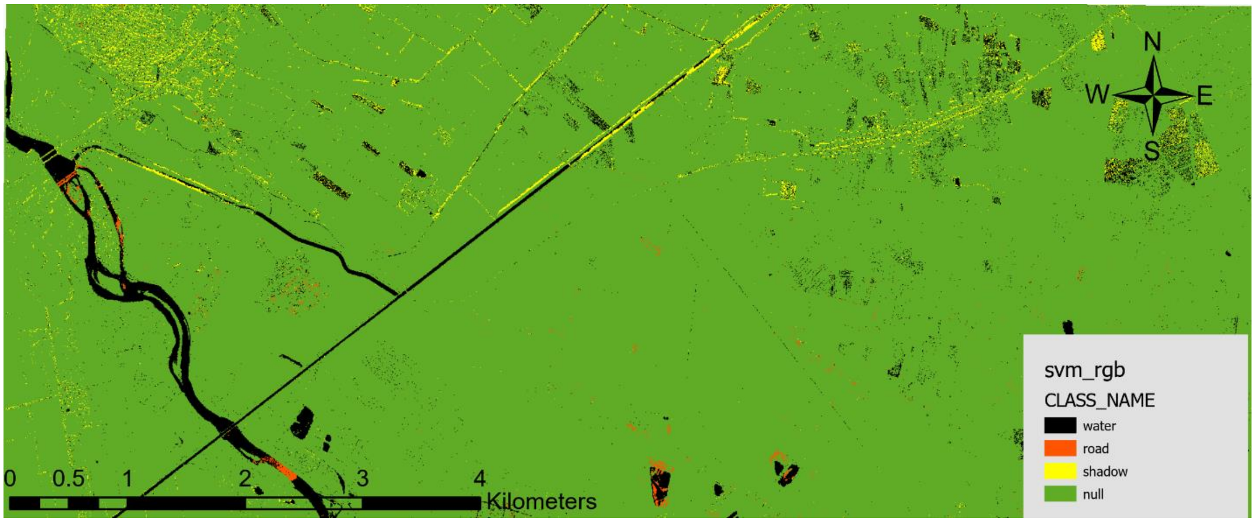
In this stage, the input image consists of the water polygons from the previous step, overlaid onto the RGB image in ArcGIS Pro using the "Extract by Mask" tool. This classification is also supervised, with training sample polygons assigned to four classes:

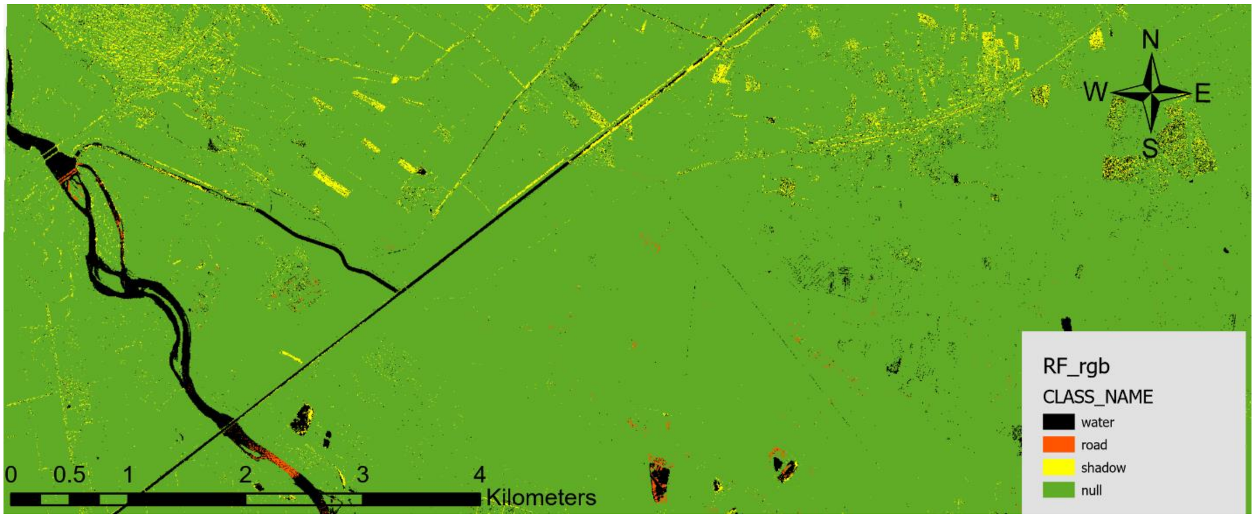
- 0: Water
- 1: Road
- 2: Shadow
- 3: Masked areas

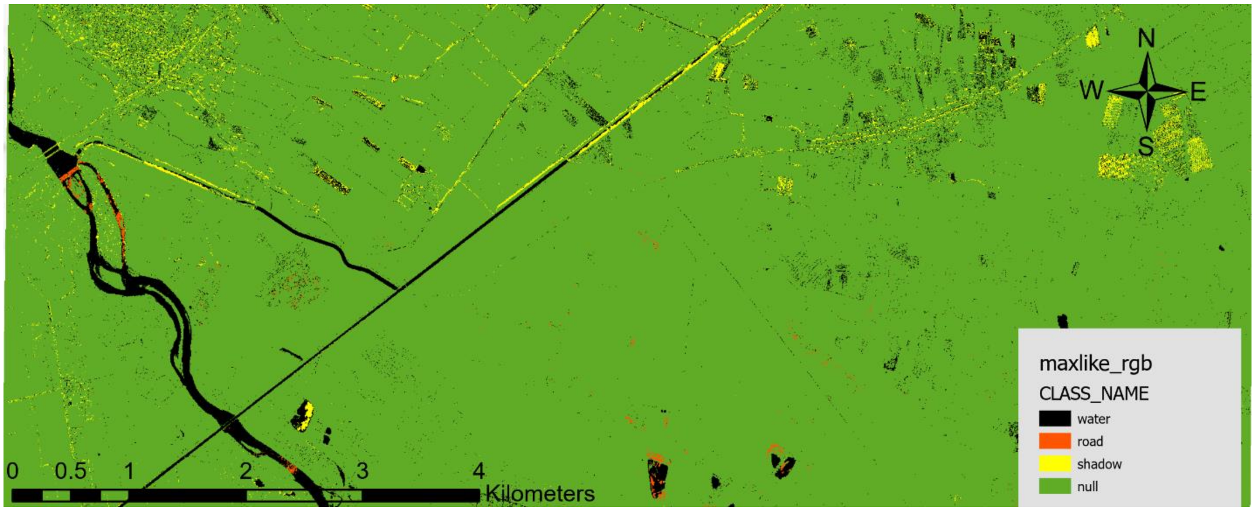
The classification process was again conducted using the same four classifiers as in the previous step: Nearest Neighbor, Random Trees, Support Vector Machine, and Maximum Likelihood. As with the first level classification, the scattered nature of the water pixels meant that instead of selecting the best-performing classifier, the results from all four classifiers were aggregated.

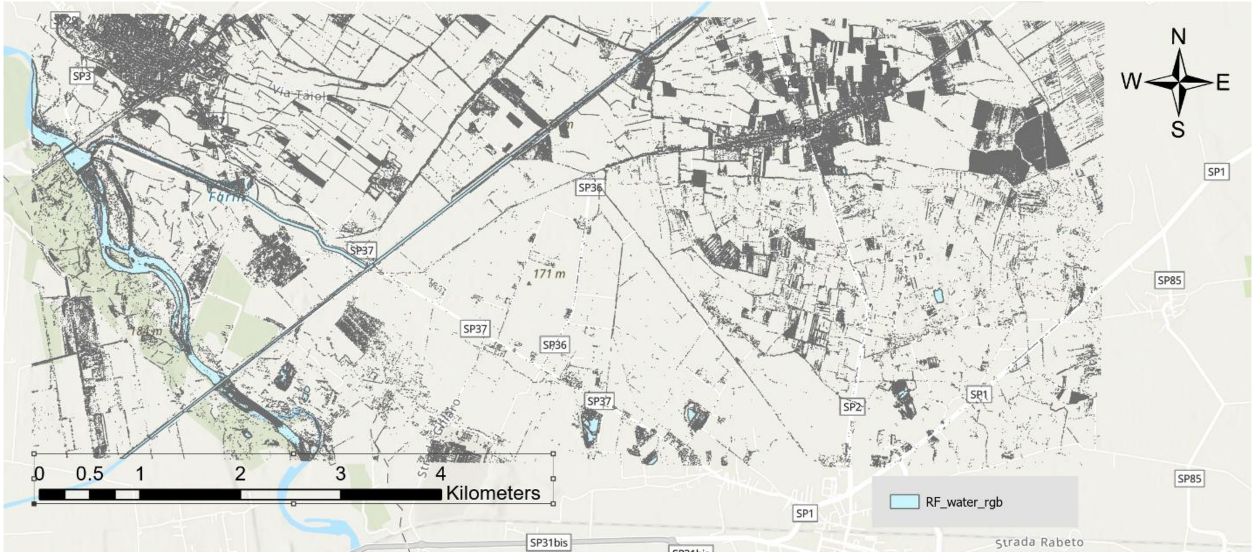
The RGB classification successfully separated water pixels from road pixels to a satisfactory degree. However, it still encountered difficulties in fully differentiating between water and shadow. As a result, the water polygons from this step include not only actual water pixels but also shadow and a very small amount of road pixels. Additionally, these water polygons include various water features, such as rivers, puddles, and irrigation-flooded areas.

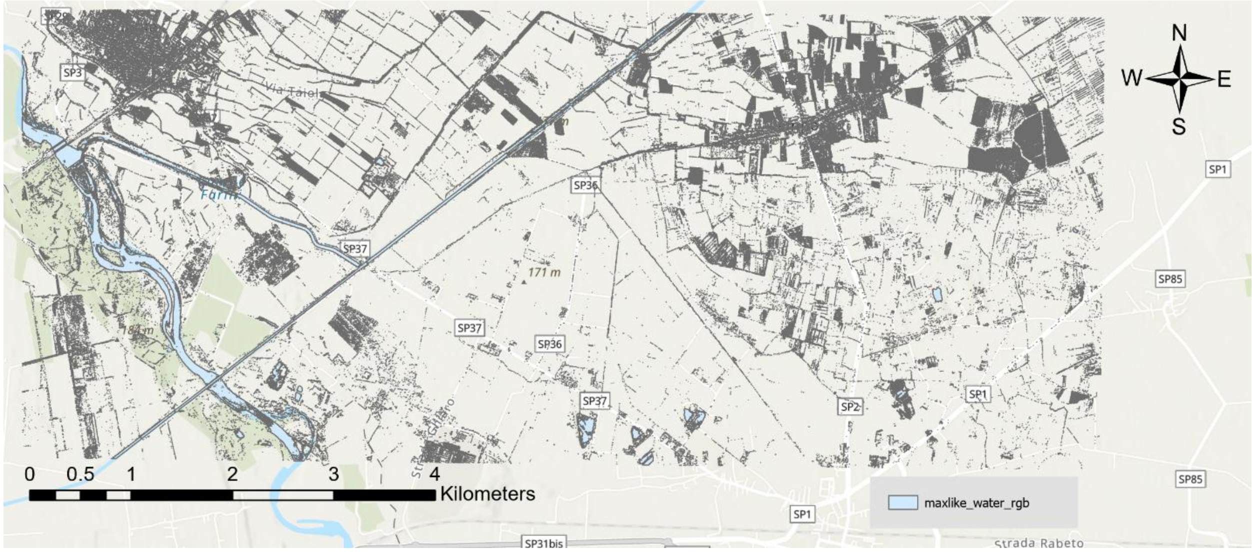

N
W
E
S
knn_rgb
CLASS_NAME
water
road
shadow
null
0
0.5
1
2
3
4
Kilometers

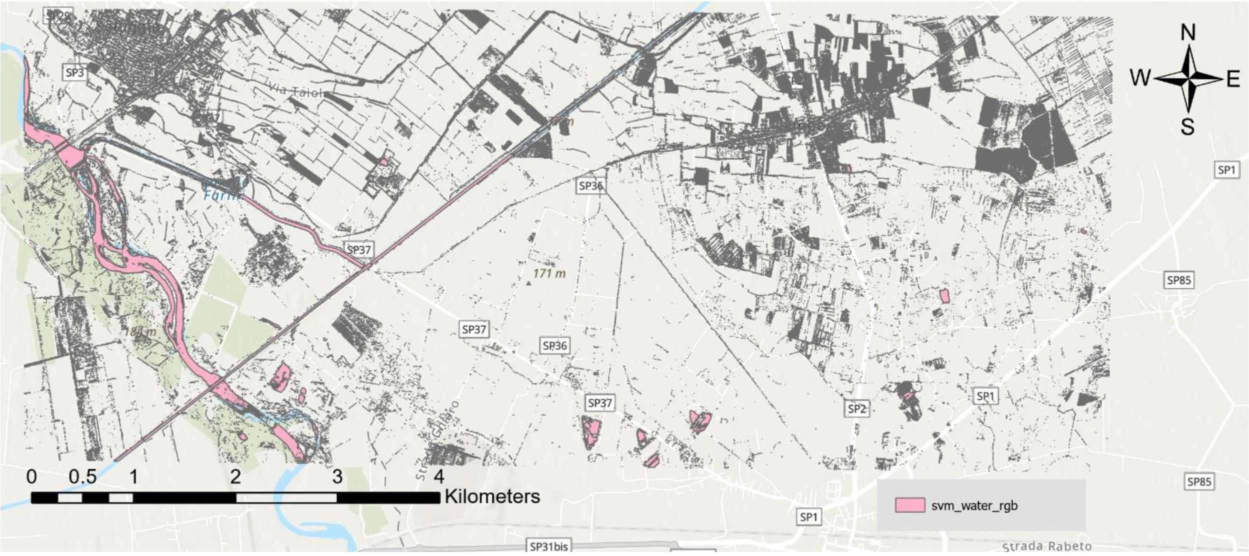

N
W
E
S
svm_rgb
CLASS_NAME
water
road
shadow
null
0
0.5
1
2
3
4
Kilometers

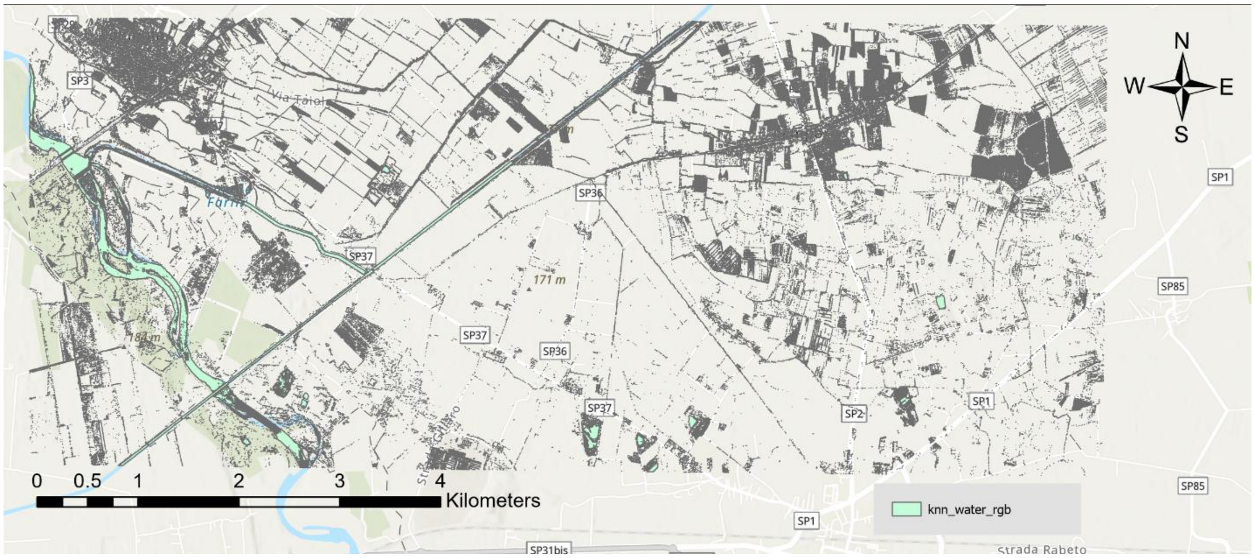

N
W
E
S
RF_rgb
CLASS_NAME
water
road
shadow
null
0
0.5
1
2
3
4
Kilometers


N
W
E
S
maxlike_rgb
CLASS_NAME
water
road
shadow
null
0
0.5
1
2
3
4
Kilometers


N
W
E
S
SP3
Via Taiola
SP36
SP37
171 m
SP37
SP36
SP37
SP2
SP1
SP1
SP85
SP85
SP1
SP31bis
Strada Rabeto
0
0.5
1
2
3
4
Kilometers
RF_water_rgb


N
W
E
S
SP3
Via Taiola
SP36
SP37
171 m
SP37
SP36
SP37
SP2
SP1
SP1
SP85
SP85
SP1
SP31bis
Strada Rabeto
0
0.5
1
2
3
4
Kilometers
maxlike_water_rgb


N
W
E
S
SP3
Via Taioli
Farini
SP36
SP37
171 m
SP1
SP85
SP2
SP31bis
Strada Rabeto
0 0.5 1 2 3 4
Kilometers
svm_water_rgb


N
W
E
S
SP3
Via Taioli
Farini
SP36
SP37
171 m
SP1
SP85
SP2
SP31bis
Strada Rabeto
0 0.5 1 2 3 4
Kilometers
knn_water_rgb

Creation of Buffer for Channels

Since the aim is to map only the water within the channels, it is necessary to separate the water pixels associated with the channels from other water pixels. To achieve this, a buffer must be created around each segment of the channel. The buffer should be designed to encompass all the water polygons relevant to each part of the channel while excluding any unwanted polygons from other areas, including shadow of nearby trees, or other water pixels that do not belong to channels.

Extraction of Channel Polygons

In this step, the complete polygons representing the channels are created by connecting the scattered water polygons. Figure () shows an example of scattered polygons representing a segment of a channel.

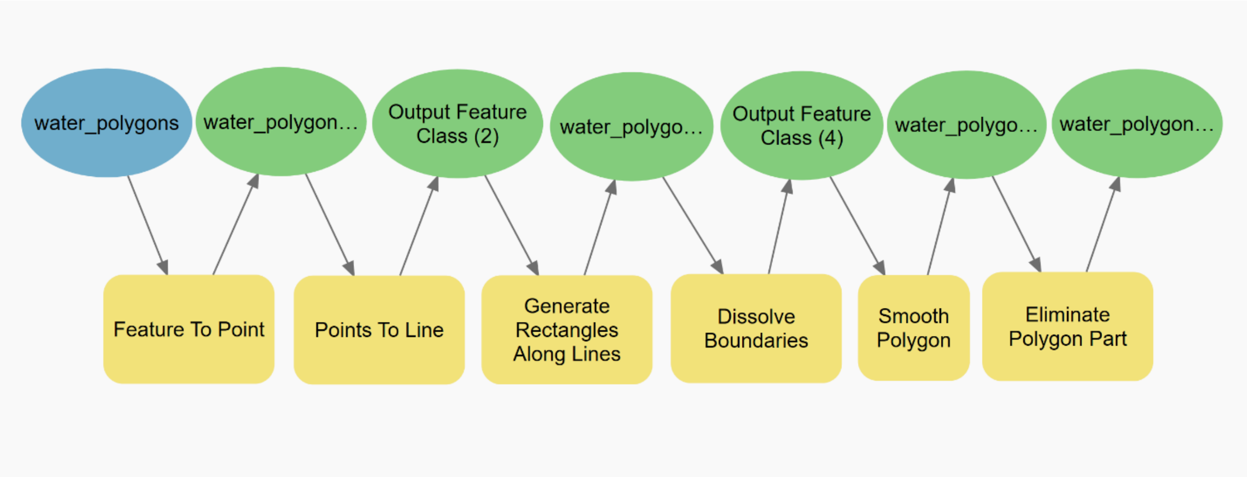
To generate a continuous polygon for each channel segment, the polygons are first converted into points based on their central locations. Next, lines are generated by connecting the points that belong to the same channel segment. Along these lines, rectangles with predefined dimensions are created. These rectangles are then dissolved into a single feature. For a better visual appearance, the polygons are smoothed, and any voids within them are eliminated. This process is carried out using the following sequence of tools:

- Feature to Point
- Point to Line
- Generate Rectangles Along Lines
- Dissolve Boundaries
- Smooth Polygons
- Eliminate Polygon Part

To streamline and speed up the process, this sequence of tools can be combined into a single model using the Model Builder tool, allowing for all steps to be executed with one click.

Advantages of Using ModelBuilder

- **Time Efficiency**: By automating the workflow, ModelBuilder saves significant time, as all steps can be executed with a single click rather than running each tool individually.
- **Optimized Data Management**: ModelBuilder allows for saving only the result of the final step, reducing the need to store intermediate data and thus saving storage space.
- **Reproducibility**: The model can be easily reused with new input data, allowing the procedure to be repeated consistently for similar tasks or different datasets.



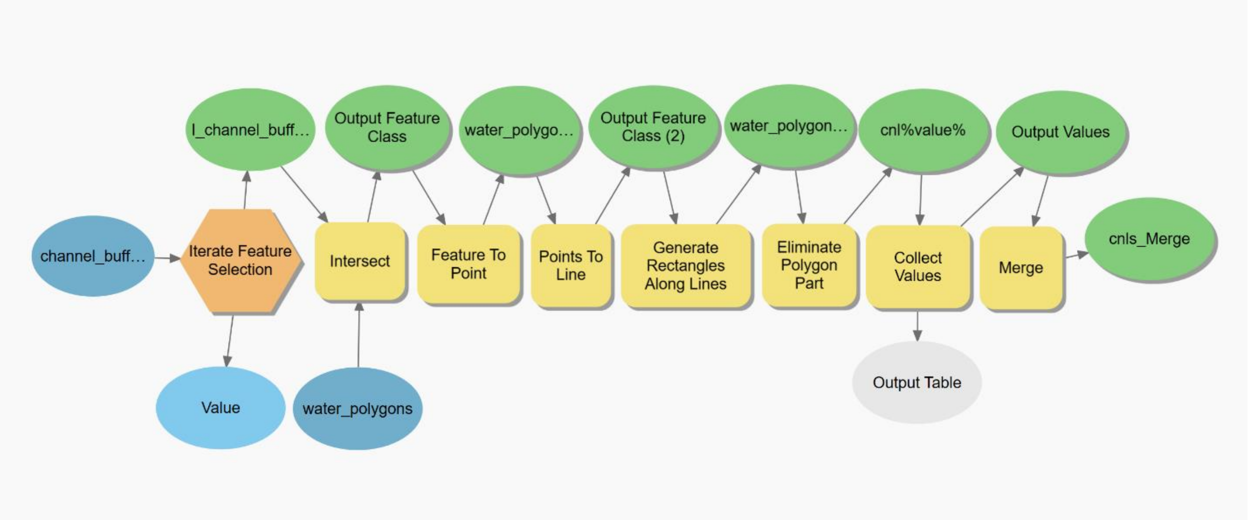
Propagation of the Model over the Entire Area Using Iteration

For a smaller subset within the study area, channel buffers are manually created for all the channels in the subset. These buffers are generated to ensure that all water polygons belonging to each section of the channel are aligned in a straight line, so when the direction of the channels or is meandering, the buffer is also divided into 2 on the spot that direction changes, in a way that finally every polygon is more or less a long rectangle . The main RGB and CIR orthophotos are used as a base map to verify that these polygons indeed represent water channels. This subset, with a quasi-triangular shape, is located between the cities of Crescentino and Saluggia, northeast of Torino, covering an area of approximately 19.8 square kilometers, with the center located at coordinates [8.076 east, 45.215 north]. (Figure [ ]).

The purpose of creating the channel buffers, besides excluding unwanted polygons marked as water, is to group the water polygons within each channel section to facilitate the creation of the channel geometry. The manual buffer creation for the study subset took around 10 hours, resulting in 337 polygons.

Once each buffer is intersected with the entire image of water polygons, the polygons inside that buffer can be selected and processed through the model to create the channel geometry. A new model, built using ModelBuilder with iteration, can automate this task. (Figure [ ]).

Using the iteration component in the model, the process of intersecting the channel buffer with the water polygons is performed sequentially for each buffer polygon, using the ID field as a counter. At the final stage of the model, the results of each iteration are collected using the "Collect Values" tool, a specific function of ModelBuilder. Finally, the "Merge" tool is used to combine the output from each iteration, creating a complete feature class of the channel polygons.



Accuracy Assessment:

Deficiencies/Issues with the Results

One potential issue that may introduce errors when running the model occurs if a channel buffer covers only a single water polygon. In this case, the model converts the polygon into a single point, making it impossible to generate a line from just one point. This issue can be resolved by splitting that water polygon into smaller segments. With multiple polygons converted into points, lines can then be created, allowing the subsequent steps to be carried out as expected. (Figure [before/after]).

Another issue arises when a large water polygon located at the endpoint of a channel is converted into a point, and the model subsequently generates a new polygon from that point along with others. In this scenario, a substantial portion of the channel may be omitted. Additionally, the resulting polygons may include areas that do not, in reality, belong to the water channel. (Figure [ ]).

To assess the model's accuracy, two types of errors are introduced: commission and omission errors.

- **Commission errors** are areas incorrectly mapped as water but are not water in reality.
- **Omission errors** are areas that represent part of the water channel but are not captured by the model.

To evaluate the extent of these errors, the real geometry of the channels is created for two sample areas based on the orthophotos, which can be considered as ground truth data. The area of commission error is identified by subtracting the accurate ground truth data from the model-generated channel geometry, while omission error is determined by subtracting the model-generated geometry from the accurate ground data.

Both the area of commission and omission errors are calculated and presented in the table, along with the percentage of each error, which is determined by dividing each error by the area of the accurate ground truth data. (Table [ ]).

According to the table, the percentage of commission error appears significant. This could be attributed to both the predefined width of the channel and instances where vegetation obscures the channels.

Determining the Flow Direction in Channels

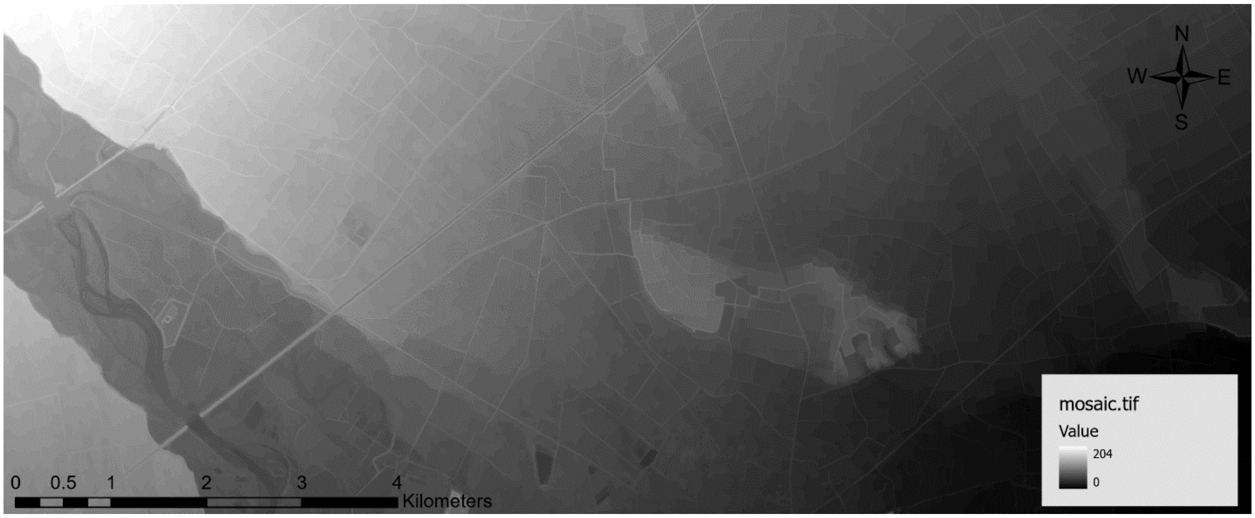
The data used for this objective includes the line feature of the channels and a DTM (Digital Terrain Model) of the area, with a 5-meter pixel size and 1-meter resolution in elevation. Since the study area overlaps two images, the images are mosaiced and clipped to match the study area.

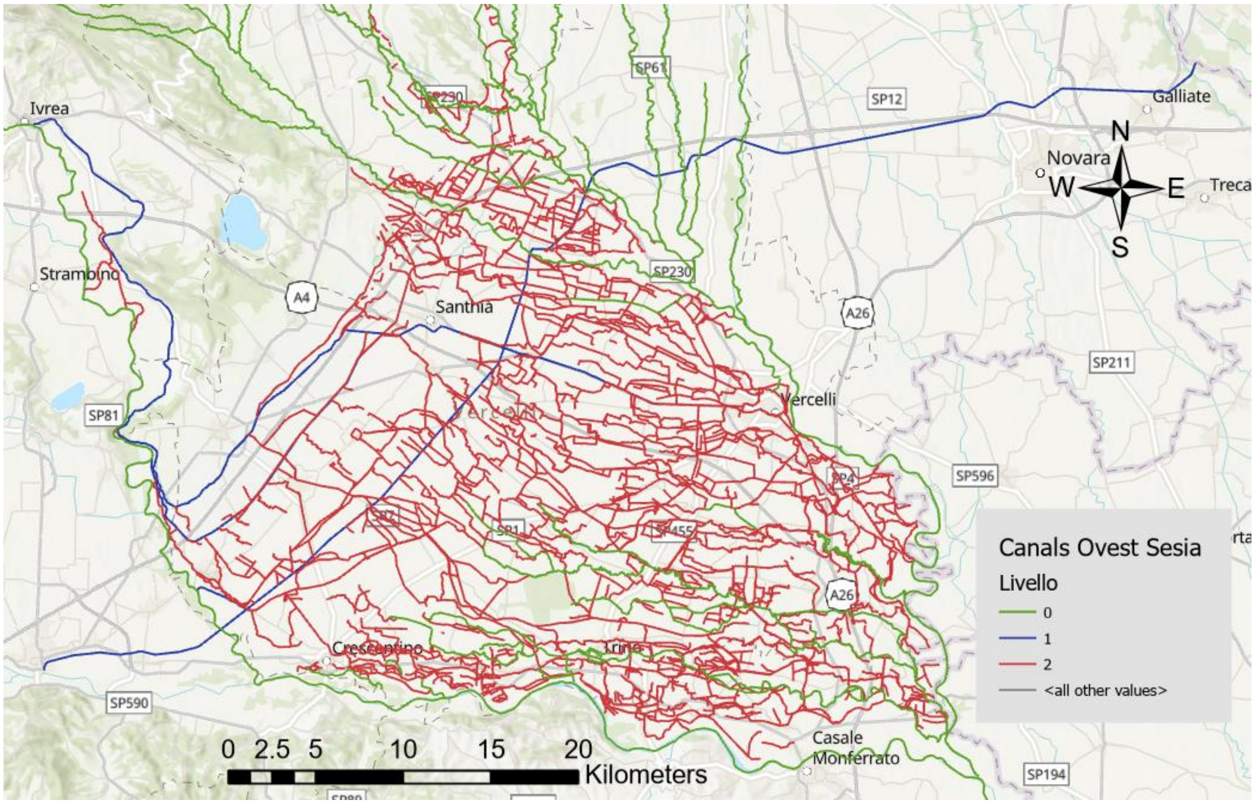
A collection of point features is then created, representing the endpoints of each line or key vertices along the channel lines. Using the "Value to Point" tool, each point is assigned the DTM value of the pixel on which it is located, representing the elevation of that point. At this stage, it is assumed that the channel bed elevation is equal to the ground elevation.

(Figure)

Next, a line with arrow symbology is created to connect two of these points. By sorting the line based on the elevation values of the points, the arrow direction will point from the lower elevation to the higher one. However, since water flows from higher to lower elevation, the elevation values are negated using the "Calculate Field" tool.

With the negated elevation values, when the points are sorted, the generated arrowed line between the two points will be directed from the higher elevation to the lower one, correctly indicating the flow direction.





Model Builder for Flow Direction

To automate this process, a new Model Builder tool is created. The model takes the point features, converts them into a line, and assigns the arrowed line as its symbology.

Before running the model, it is essential to manually select the two endpoints of a channel. The model then executes based on these selected points.

It's important to note that the model works effectively only when the two points are far enough apart to exhibit an elevation difference of more than one meter. If the points are too close and their DTM-based elevation values are similar, the derived flow direction will be inaccurate or misleading.

Discussion

The final polygons of the channels can serve as a reference geometry for temporal analysis on the presence of water within the channels or to detect changes by overlapping the channel geometry with satellite images. This method was tested using Sentinel-2 images. For each image, corresponding to different times of the year—such as summer, when irrigation channels are expected to be full of water, and winter, when channels are typically empty—or before and after flood events, the geometry of the channels was overlapped with the Sentinel-2 images. For each overlapped result, the Modified Normalized Difference Water Index (MNDWI), which uses the normalized difference of the "green" and "SWIR" bands, was calculated. However, the results did not provide values that accurately reflected the presence of water.

In contrast, when the Normalized Difference Vegetation Index (NDVI), based on the normalized difference between the "red" and "NIR" bands, was calculated, the index values indicated the presence of vegetation within the polygons. This suggests that for a 10x10 meter Sentinel-2 pixel, through which a water channel passes with an average width of 2-4 meters, the pixel's reflectance is more likely to capture the presence of vegetation, which covers a larger portion of the pixel, rather than the water itself.

Therefore, for temporal analyses on channel geometry, Sentinel-2 images with a 10-meter pixel resolution are not sufficiently detailed for this purpose. To overcome this limitation, requesting higher-resolution images from satellites such as GeoEye and WorldView-3, which offer much finer spatial detail, could provide more accurate data. Another potential solution is to use drones to acquire multispectral images with very high resolution, down to a few centimeters. These drone images could also be valuable in the initial mapping of the channel geometry, further improving the resolution of results to the centimeter scale.

Conclusion

This study provides a comprehensive analysis of the Cavour Canal's irrigation network using remote sensing and GIS techniques to map the channels and determine their flow directions. The importance of this research lies in the increasing pressure on water resources due to climate change and the need for effective irrigation management to support agricultural production in Piemonte, Italy. The mapping of the irrigation grid, achieved through the use of high-resolution orthophotos and DTM, offers an accurate and detailed representation of the channel system, which can be used for future monitoring and analysis.

The method developed in this research demonstrates the value of integrating supervised classification techniques with GIS tools to extract meaningful information from remote sensing data.

The aggregation of results from multiple classifiers ensures the highest possible accuracy in identifying water pixels, while the subsequent classification of RGB images refines the distinction between water and non-water features. This process, combined with the creation of channel buffers and the extraction of channel polygons, enables the accurate delineation of the irrigation network.

The automated process developed using ArcGIS Pro's ModelBuilder significantly enhances the efficiency of the mapping procedure, allowing for the processing of large datasets and the potential to replicate the method in other regions or with new datasets. The iterative approach ensures that each segment of the irrigation network is accurately mapped, with minimal manual intervention required.

The extraction of flow directions using DTM data and point-based elevation values provides an effective method for determining the flow patterns within the irrigation network. The model developed for this task ensures that the flow direction is from higher to lower elevations, as expected in natural and artificial watercourses. This information is critical for understanding the movement of water through the network and for ensuring that the irrigation system operates efficiently.

Despite the success of the mapping and flow direction extraction processes, the study also identifies several limitations. The presence of commission and omission errors highlights the challenges of accurately mapping small features like irrigation channels using remote sensing data with limited resolution. While the use of orthophotos provided sufficient detail for the mapping process, the medium-resolution satellite imagery (Sentinel-2) was inadequate for temporal analysis due to its inability to capture small-scale features like narrow channels. As a result, the study recommends the use of higher-resolution satellite imagery or drone-based imagery for future analyses aimed at monitoring changes in the irrigation network over time.

In conclusion, this research offers valuable insights into the application of remote sensing and GIS tools for mapping and analyzing irrigation networks. The methodology developed in this study provides a robust framework for future research on water resource management in agricultural regions. By improving our understanding of the distribution and flow of water within irrigation systems, this research contributes to the development of more sustainable and efficient water management strategies, particularly in the context of climate change.