Die Bodenkultur: Journal of Land Management, Food and Environment
Volume 70, Issue 3, 131–145, 2019. 10.2478/boku-2019-0012
ISSN: 0006-5471 online, https://content.sciendo.com/view/journals/boku/boku-overview.xml

Research Article

SPECIAL ISSUE

with invited papers from the 47th International Symposium „Actual tasks on Agricultural Engineering“ (ATAE), 5th – 7th March 2019, Opatija, Croatia, http://atae.agr.hr/, Editor: Prof. Andreas Gronauer

Assessment of riparian environments through semi-automated procedures for the computation of eco-morphological indicators: Preliminary results of the WEQUAL project

Bewertung der Uferumgebung durch teilautomatisierte Verfahren zur Berechnung von ökomorphologischen Indikatoren: Vorläufige Ergebnisse des Projekts WEQUAL

Raimondo Gallo[1]*, Gianluca Ristorto[2], Alex Bojeri[2], Nadia Zorzi[3], Gabriele Daglio[1], Monica Fernanda Rinaldi[1], Giuliano Sauli[4], Fabrizio Mazzetto[1]

[1] Faculty of Science and Technology, Free University of Bozen (FUB), Piazza Università 5, 39100 Bolzano, Italy
[2] Mavtech srl, 39100 Bolzano, Italy
[3] Maccaferri Innovation Center srl, 39100 Bolzano, Italy
[4] Naturstudio srl, Bolzano, 39100 Bolzano, Italy

* Corresponding author: raimondo.gallo@unibz.it

Received: 11 June 2019, received in revised form: 2 August 2019, accepted: 4 August 2019

Summary

The aim of WEQUAL project (WEb service centre for QUALity multidimensional design and tele-operated monitoring of Green Infrastructures) is the development of a system that is able to support a quick environmental monitoring of riparian areas subjected to the realization of new green infrastructures (GI). The Wequal's idea is to organize a service center able to manage both the Web Platform and the whole data collection and analysis processes. Through a personal account, the final user (designer, technician, researcher) can get access to the service and requires the evaluation of alternatives GI projects. On the Web Platform, a set of algorithms runs in order to calculate, through automatic procedures, all the ecological criteria required to evaluate a quality environmental index that describes the eco-morphological value of the monitored riparian areas. For this aim, the WEQUI index was developed, which uses 15 indicators that are easy to monitor. In this paper, the approach for environmental data collection and the procedures to perform the automatic assessment of two of the ecological criteria are described. For the computation, the implemented algorithms use data including the vegetation indexes, Digital Terrain Model (DTM), Digital Surface Model (DSM) and a 3D point cloud classification. All the raw data are collected by UAVs (Unmanned Aircraft Vehicle) equipped with a 3D Lidar, multispectral camera and RGB camera. Interpreting all the raw data collected by these sensors, using a multi-attribute approach, the WEQUI index is assessed. The computed ecological index is then used to assess the riparian environmental quality at *ex-ante* and *ex-post* river stabilization works. This index, integrated with additional not-technical or not-ecological indicators such as investment required, maintenance costs or social acceptance, can be used in multicriteria analyses in order to evaluate the intervention from a wider point of view. The platform is expected to be attractive for GI designers and policy makers by providing a shared environment, which is able to integrate the method of detection and evaluation of complex indexes and a multidimensional evaluation supported by an expert guide.

Keywords: Remote sensing, environmental monitoring, web platform, ecological index, riparian restoration

Zusammenfassung

Das Ziel des Projekts WEQUAL (Web Service Center für qualitatives mehrdimensionales Design und ferngesteuerter Überwachung grüner Infrastruktur) ist die Entwicklung eines Systems zur Unterstützung einer raschen Umweltüberwachung von Flusslandschaften zur Umsetzung neuer grüner Infrastrukturen (GI). Die Idee des Projekts WEQUAL ist die Schaffung eines Servicecenters, welches sowohl die Web-Plattform, als auch den gesamten Datensatz und den Analyseprozess beinhaltet. Jeder Benutzer (Designer, Techniker, Forscher) kann mittels persönlichen Accounts auf die Plattform und die Auswertung alternativer GI-Projekte zugreifen. Die Web-Plattform nutzt ein Set von Algorithmen zur automatischen Berechnung aller benötigten ökologischen Kriterien zur Bewertung eines qualitativen Umweltindexes, der den ökologischen Status der überwachten Uferlandschaft beschreibt. Dafür wurde der WEQUI-Index entwickelt. In dieser Arbeit werden die Herangehensweise zur Umweltdatensammlung und das Verfahren zur automatischen Auswertung der ökologischen Kriterien beschrieben. Zur Berechnung verwenden die implementierten Algorithmen folgende Daten: Vegetationsindexe, Digital Terrain Model (DTM), Digital Surface Model (DSM) und eine 3D-Punktwolken-Klassifikation. Die gesamten Rohdaten werden über ein UAV (Unbemanntes Flugzeug) gesammelt, das mit einem 3D-LiDAR, einer multispektralen Kamera und einer RGB-Kamera ausgestattet ist. Die berechneten ökologischen Indexe werden dann zur Qualitätsbewertung von Uferlandschaften bei *ex-ante-* und *ex-post-*Uferstabilisationen verwendet. Dieser Index, welcher zusätzliche nichttechnische oder nichtökologische Indikatoren, wie nötiges Investment, Instandhaltungskosten oder soziale Zustimmung einschließt, kann für eine multidimensionale Analyse zur Bewertung der langfristigen Auswirkungen eines Landschaftseingriffes genutzt werden. Die Plattform ist für GI-Designer und Entscheidungsträger attraktiv, da sie eine gemeinsam nutzbare Umgebung zur Feststellung und Bewertung verschiedener komplexer Indizes mit einer multidimensionalen Bewertung, unterstützt durch eine professionelle Führung, bietet.

Schlagworte: Fernerkundung, Umweltüberwachung, Web-Plattform, Ökologischer Index, Uferbefestigung

1. Introduction

In recent years, the European environmental policies aimed to safeguard the biodiversity of the ecosystems, through the promotion and use of Green Infrastructures (GI) for river stabilization works. For instance, the Water Framework Directive (WFD-2000/60/EC) requires that water bodies are classified according to their ecological quality status, identifying the anthropogenic impacts on them, with the aim to improve the overall quality of river systems (European Parliament, 2000). Meanwhile, the Floods Directive (2007/60/EC) focuses on the design and planning phases of hydraulic structures and underlines the necessity of reducing fatalities and damages caused by natural disasters as floods, landslides or erosion and of safeguarding aquatic ecosystems (European Parliament, 2007; Rinaldi et al., 2016). The European project EFRE-FESR Südtirol-Alto Adige WEQUAL (WEb service centre for QUALIty multidimensional design and remote-survey monitoring of Green Infrastructures) aims at developing a series of methodologies and procedures, integrated with a web platform, able to quickly and automatically assess the environmental effects of longitudinal and transverse hydraulic structures. Therefore, the goal of the research project is to develop a tool based on tailored computational procedures, suitable to obtain objective information to support technicians, researchers, local administrators, stakeholders and decision makers in designing and evaluating river engineering solutions. This tool is intended to collect, organize and manage multiple, sometimes complex technical information, in an easy way, limiting burdens and costs of field surveys. All the interpretative procedures run on a web platform. The main idea is that the platform as well as all the survey activities will be managed by a service center. Set up by a team of technicians, the service center will carry out all the field activities, data processing and data interpretation in a very short period. By means of a personal account, the final user can login the web platform for free, he requires surveys in specific areas, consult the achieved outputs and manage indicators and results. In this way, it will be possible to carry out quick environment monitoring of watercourse reaches, in order to monitor the eco-morphological quality related to the present situation or to forecast how potential new hydraulic infrastructures can affect the eco-morphological status of the monitored river.

To perform these assessments, the procedures implemented in the platform apply multidimensional-analysis approaches according to a proper score system in order to obtain the WEQUI index. Due to the early stage of the project, the paper presents and describes two of the algorithms developed. These algorithms are able to classify in a semi-automatic way the land use coverage as well as the riparian vegetation on the river side banks. The obtained results are then used to compile part of the WEQUI index's questions.

2. Materials and methods

2.1 The general concept

Within the WEQUAL project, a new method, called WEQUI, has been developed to evaluate the eco-morphological condition of GI. The method aligns with the EU Water Framework Directive recommendations (2000/60/CE) about classifying and monitoring the ecological quality of watercourses. WEQUI (WEQUAL Eco-morphological QUality Index) was inspired by several ecological, morphological, hydrological evaluation methods proposed in the literature and already adopted by local authorities for monitoring purposes (Lenat, 1988; Petersen, 1992; Ghetti, 1997; Braioni and Penna, 1998; Raven et al., 1998; Barbour et al., 1999; Davenport et al., 2004; Kleynhans et al., 2005; McGinnity et al., 2005; Rosegen, 2007; Siligardi et al., 2007; Kleynhans et al, 2008; Kemp and O'Hanley, 2010; Buffagnier al., 2013; Rinaldi et al., 2016). However, the WEQUI method differs from other methods, for the following reasons:

1. *The purpose*: WEQUI is intended to be applied for two main purposes:
   a. classify the current eco-morphological condition of a watercourse, similar to what several other literature methods do, with special attention for watercourses where hydraulic structures are present. This kind of application is carried out recursively and allows to monitor the eco-morphological condition of a watercourse. In addition, in the case of design of a new hydraulic structure, one-shot evaluation of the WEQUI index allows the designer to become aware about the current environmental state of the site where the structures are planned to be built.
   b. forecasting, which is the long-term eco-morphological status expected in a watercourse, where new hydraulic structures are expected to be built. Such kind of application may support designers in coupling technical design and environmental considerations, encouraging the diffusion of nature-based solutions whenever possible.
2. *The holistic character:* the method includes physical, morphological, hydrological, ecological and biological indicators.
3. *Some new indicators:* WEQUI considers a couple of indicators related to carbon cycle of artificial structures (i.e., from the production/construction phase to the full-operating condition).
4. *The key role attributed to riparian/floodplain vegetation:* the method highlights the importance of riparian and floodplain vegetation in supporting aquatic and riparian ecosystems' functionality and considers three indicators concerning vegetation directly.
5. *The structure:* the method can be applied in an expeditious way for both aims "a." and "b.", and is supported by a database of typical effects related to different types of hydraulic structures. Furthermore, WEQUI can be evaluated with the support of remote-sensing surveyed data.

Basically, WEQUI consists of fifteen environmental quality indicators. For each indicator, five levels of quality are identified and characterized with short statements. Each statement is associated with a score. Once all the indicators are compiled, the final score is computed and classified, according to a proper rule. At the end, an evaluation of the eco-morphological quality of the watercourse is obtained. In the case of applications of type a), it accounts for the current quality condition, while in case of applications b), it accounts for the quality state expected some decades after the construction of new hydraulic structures. The fifteen indicators of the WEQUI index are assigned according to both qualitative and quantitative criteria. Quantitative criteria can be applied through semi-automatic procedures, while the qualitative criteria require a direct survey in the field or a computational system (Table 1). The number refers to the sequence of questions reported in WEQUI index. For each indicator, the score is assigned by choosing the most relevant answer in a list of five possible options. Depending on the indicator, the answer may require the observation of either the riverbanks, the channel or the whole reach corridor. Each answer is associated with an exponential score on basis two, from a minimum of one to a maximum of sixteen. Through this approach, it is possible to clearly identify the elements of low or high naturalness of the monitored environment. Adding up all the results obtained for each criterion included in the WEQUI index, it is possible to conduct an overall assessment of the eco-morphological quality on both to natural and to artificial rivers, characterized by engineering solutions (both traditional and soil-bioengineering solutions).

2.2. Raw data collection and elaboration for semi-automated procedures

During the year 2017, according to the sensors, three flights have been planned on the municipality of Lagundo (Province of Bolzano, North-East of Italy) in order to

Table 1. Indicators to be evaluated for the ecological assessment of fluvial areas. In the present table, the indicators are divided in automatically assessable or not.
Tabelle 1. Indikatoren zur Evaluation der ökologischen Bewertung von Flusslandschaften. Die Indikatoren sind unterteilt in automatisch bewertbar oder nicht automatisch bewertbar.

Indicators assessable through semi-automatic data processing	Indicators differently assessable
Land use	Vertical continuity
Lateral continuity	Hydrologic regime
Longitudinal continuity	Chemical quality
Morphological heterogeneity	Macrobenthos community
Retention capability	Carbon footprint
Fish suitability	
Riparian zone vegetation	
Riparian zone width	
Riparian zone continuity	
Carbon sequestration	

monitor a portion of about 400 m of length of the Adige river for a total area of approximately 6.5 ha. The in-field surveys were performed using remote sensing technologies. All the collected data was then processed through semi-automated procedures described below.

Thanks to their high operative flexibility and the rapidity with which missions could be set up and executed, Unmanned Aircrafts Vehicles (UAVs) have been used to carry out the transportation of the sensors necessary for the monitoring operations (Ristorto et al., 2017). The use of UAV aircrafts for monitoring purposes is possible even when the access is difficult, which is very common in riparian areas (for instance due to slopes, high density stands or slippery surfaces). During the monitoring operations, the UAVs have been equipped with three sensors:

- RGB camera Sony RX-100
- Multiband camera Micasense RedEdge-M
- YellowScan Surveyor LiDAR

The Sony RX-100 is a conventional camera with a resolution of 20.1 MP. During the photogrammetric surveys, the camera has been set in autofocus mode and with a fixed focal length at 8.8 mm, with a CMOS sensor of 13.2 × 8.8 mm, in order to achieve the largest angle of view. Meanwhile, the Micasense RedEdge-M is a camera able to acquire simultaneously images from 5 bands: Red, Green, Blue, Nir and Red edge wavelengths. The resolution of each image is 1 MP, with a fixed focal length at 5.4 mm and a sensor size of 4.8 × 3.6 mm. In every acquired image, the respective metadata geoinformation, which speed up the procedures of orthorectification, are also reported. Indeed, the Micasense RedEdge-M has the possibility to be connected to a GPS module. Depending on the flight altitude, the RGB camera and the multispectral sensor record images with different ground sampling distance. The minimum and maximum resolutions for the Sony RX-100 are 1.4 cm/pixel and 3.4 cm/pixel and Micasense RedEdge-M 4.1 cm/pixel and 10.2 cm/pixel, respectively, for 50 and 150 m of flight altitude. To obtain a useful dataset and orthophotos without distortions, the flight plan of the UAV (grid width) and the trigger signal to the sensor must be set to have a sidelap and an overlap of respectively 65% for the RGB camera and 75% for the multispectral camera. The missions during which we use these sensors were setup with parallel flight routes covering the portion of river targeted for monitoring including surrounding land to reach the overlapping percentages mentioned above, needed for this survey. The collected image datasets are processed with Pix4D software, obtain a mosaicking of the images. To orthorectify the final aerial images, during the flights, several ground control points have been measured using an RTK-GNSS device with an accuracy lower than 5 cm (Geomax Zenith 35 Pro). Beside these two sensors, a Yellowscan Surveyor LiDAR has been used to acquire a 3D model of the monitored surface. All the acquisitions are automatically orthorectified by the system thanks to the global navigation satellite module and the inertial measurement unit embedded in the sensor. The acquired data sets are also corrected using the RINEX files collected by the RTK-GNSS station placed in the middle of the monitored area (Figure 1c). Since the LiDAR is characterized by having a 2 echoes laser technique, from the obtained output, it is possible to generate Digital Terrain Model (DTM), Digital Surface Model (DSM) and Canopy Height Model (CHM) point clouds. The minimum resolution of the sensor is equal to

100 point/m^2. In order to increase the accuracy of the collected point clouds, post-processing kinematic correction are carried out in POSPac MMS 8 software. The flight mission with the use of this sensor foreseen, after a period of sensor calibration at the beginning of each mission, only three passages over the whole monitored area. Two at 40 m height over the two river side banks, one at 30 m height following the river's axle. In this way, the system is able to acquire information related to the river, the vegetation and terrain profile of the riverbanks and of the lands nearby the river with very high details.
Due to the different weight of the sensors, the aerial fleet is composed of three UAVs with different propulsion systems, and flight performances (e.g., payloads and cruise speeds) (Figure 1):

- Mavtech AGRI-1900
- Mavtech Q4E
- DJI S900

The AGRI-1900 is a fixed-wing UAV developed to accomplish missions that require high flight endurance; it ensures a flight time of 30–45 minutes/mission. The declared cruise speed is around 12–15 m/s, which permits to cover up to 50 hectares for mission in the best flight conditions. Nevertheless, this aircraft requires a wide surface without obstacles for take-off and landing operations. Usually, this

Figure 1. The three aircrafts used for the monitoring purposes: (a) AGRI-1900, (b) Q4E, (c) DJI S900 with the RTK-GNSS base for RINEX files collection. The first two solutions are two prototypes specifically developed to answer to the project's requirement, while the third is a commercial UAV, which has been modified to carry the Yellowscan Surveyor sensor.
Abbildung 1. Die drei zu Überwachungszwecken verwendeten Flugobjekte: (a) AGRI-1900, (b) Q4E, (c) DJI S900 mit der RTK-GNSS-Basis für die Sammlung von RINEX-Daten. Die ersten beiden UAV sind Prototypen, die speziell für die Anforderungen des Projekts entwickelt wurden. Das dritte ist ein kommerzielles Flugobjekt, das für den Yellowscan Surveyor-Sensor modifiziert wurde.

UAV flies at 100–150 m of altitude, above ground level. Therefore, the use of this vehicle ensures the monitoring of large portion of land, but the collected data is affected by low resolution. The use of this aircraft has been planned to be used only in case of large monitoring. The payload of this UAV permits to install on-board only one sensor, like a camera, for a mission, which is attached at the lower part of the drone's fuselage.

Beside the fixed-wing solution, a light and a heavy rotary-wing UAVs have been developed. The two rotary-wing UAVs differ from each other because of the different transportable payload. As such, the Q4E and the DJI S900 have 0.6 and 3.5 kg of payload, respectively. Nevertheless, the physical and mechanic characteristics of these UAVs influence the overall mission's performances (Table 2).

Due to their characteristics, this solution of drones is more flexible than the previous one. They are capable to operate in extreme environments where wide surfaces for the take-off and landing maneuvers are not present. The rotary-wing drones have the capability to take-off and land vertical. Due to the small wingspan, these UAVs are limited to flights at an altitude lower than 70 m, covering less surface but with very high resolution. Besides, this family of drones has constraints on endurances, typically lower than 20 min and on cruise speeds, which can ensure a maximum coverage area of 5 hectares. Due to their payload, the Q4E can be equipped with two camera sensors, while the DJI S900 can be equipped with the LiDAR sensor. On the entire fleet of UAVs, an autopilot system is onboard. This tool automatically increases the aircraft stability and helps the pilot in controlling the vehicle during the mission. All the missions have been planned using the Mission Planner AutoPilot software, which helps draw the flight route as well as monitor all the flight parameters in real-time during the mission.

The collected data are then processed by a complex system called Inference Engine (IE). The IE can be considered as a machine learning application able to interpret and translate raw data into management information (Mazzetto et al., 2012). The IE is a set of algorithms and routines able to process, interpret and translate the raw data into information. Indeed, in literature, several solutions have already been proposed to carry out automatic crop and operative monitoring procedures in agricultural and forestry operative contexts (Gallo et al., 2013, 2017, 2018; Mazzetto et al., 2017). These procedures, integrated with a management information system, can be used to automatize all the elaboration and assessment procedures, from data collection to data consulting (Sørensen et al., 2011; Fountas et al., 2015a, 2015b). The final purpose of the Web platform would be the same as the management information system for agro-forestry contexts: develop an ICT tool that allows the end-user to obtain information in relation to the environmental quality of the monitored riparian area. Generally, all the procedures that characterize the IE are developed *ad hoc* according to the domain of monitoring in order to extrapolating all the information needed to compile WEQUI index. For this scope, some of the automatic procedures have been implemented taking inspiration from methodologies already described in the literature (Cavalli et al., 2008; Michez et al., 2013; Tompalski et al., 2017) and adapted to our case. While others have been developed specifically for this task.

Currently, the development and implementation phases of the entire set of algorithms and procedures which compose the IE are still under implementation and testing. In fact, so far, only two algorithms have been developed: the classification of the land use (criteria 1, Table 1) and the assessment of the riparian vegetation along the riverbanks (criteria 11, Table 1).

Table 2. Summary of the main features of the rotary-wing UAVs used for the environmental surveys.
Tabelle 2. Zusammenfassung der Hauptmerkmale der Drehflügel-UAVs, die für die Umweltuntersuchungen verwendet werden.

	Mavtech Q4E	Mavtech DJI S900
Number of rotors (-)	4	6
Weight (kg)	3.5	8.2
Diagonal wheelbase (m)	0.59	0.9
Endurance (min)	20–25	15
Cruise speed (m/s)	6	3
Maximum area coverable (ha)	4	5
Equipment installable on-board	SONY RX-100 Micasense RedEdge-M	Yellowscan surveyor

In this preliminary phase, the algorithms have been implemented entirely in MATLAB. Then they will be translated into open-source coding language that can be easily integrated with web platform.

2.3 Validation procedures

The two algorithms have been validated through visual comparison and manual measurements performed directly on the field. Indeed, to validate the algorithm for land use coverage, a visual recognition of the surface covered by vegetation, water and soil have been done using ArcGIS software. This assessment has been carried out for the entire surface interested by the monitoring. The outputs coming by the visual evaluation, performed on the orthophoto collected by RGB camera, has been then compared with the results obtained by the semi-automatic procedure. For the validation of the algorithm for the assessment of the riparian vegetation along the riverbanks, five squared plots with an area of 225 square meters have been randomly selected and analyzed. In each plot, the entire aboveground biomass (bushes and trees) has been measured by two technicians. The surveyors, using a clinometer vertex laser and a GNSS-RTK unit, have measured the heights and taken the coordinates of each individual inside a plot. In this way, a shapefile has been set-up, where all the individuals have been classified as shrub or tree if they were smaller or bigger than five meters height. The above-mentioned equipment has been selected as the most appropriate for this scope, since they are commonly used in forestry survey and forestry inventories. In this case, for each plot, the validation has been conducted overlapping the output achieved from the automatic assessment (a georeferenced raster map) and the data collected by the field survey. The presence of correspondences between these two informative layers have been analyzed. When the collected points overlapped with an area with the same classification, the identification has been considered appropriated.

3. Results and discussions

The two implemented algorithms use as a reference dataset the outputs obtained respectively by the raw elaborations of multispectral camera and LiDAR acquisitions. The outputs processed by the algorithms refer to the area of interest selected by the user.

3.1 Algorithm for land use coverage

For each survey, the orthophoto obtained by processing the multiband acquisition is processed by the algorithm to obtain the percentage of land use coverage, divided into vegetation, water and soil. The results are then summarized in a thematic map of the land use. Figure 2 shows the flowchart of the developed algorithm.
A simplified Machine Learning approach is used to recognize thresholds usable to distinguish vegetation from water or soil defining several Regions of Interest (ROI) of the land use. Firstly, the user identifies and draws one or more polygons over the multiband orthophoto, identifying one or more vegetated areas to be used as a reference. According to the reflectance data collected through the five images (one for each band), the algorithm computes several Vegetation Indexes (VI), such as NDVI, NDRE, SAVI and OSAVI. Then, analyzing the statistical distribution of the computed VIs, the algorithm selects the most representative index through an automatic procedure that considers the distance between the two distributions (Figure 3). The 5^{th} percentile of the relevant index distribution is set as the lower VEGetation THReshold parameter (VEG_THR) to discriminate the area covered by vegetation (VEGETATION_ROI) within the whole study area. All the pixels with the selected VI higher than the threshold VEG_THR are classified as vegetation.
Then, the user draws one or more polygons to delimit one or more areas covered by water. Also, in this case, the statistic distribution of the VI considered as representative is evaluated within the selected sample areas. The 95^{th} percentile of the distribution is set as the higher WATer THReshold (WAT_THR) suitable to discriminate the area covered by water. All the pixels with VI lower than WAT_THR are classified as water within the whole study area.
In the end, the remaining pixels of the study area are classified as soil (SOIL_ROI). Figure 4 shows the graphical result of the classification of the land use algorithm, where vegetation is represented by green pixels, water by blue pixels and soil by brown pixels. For each class, the land use algorithm calculates the coverage extent.

3.2 Algorithm for riparian zone identification

The second algorithm developed allows to obtain the shape of foot and head of the riverbanks in several sections along the river axis, as well as soil and vegetation classification within the riverbanks. Figure 5 shows the analytical procedure of the implemented algorithm. In this case, the Digital Terrain Model (DTM) and the Digital Surface Model (DSM) obtained from LiDAR point cloud are used to calculate the Canopy Height Model (CHM), which is mandatory to be able to proceed with the other algorithm's steps.

Firstly, the user draws the river axis over the RGB orthophoto, moving from upstream to downstream (Figure 6). Starting from the first point of the axis, the algorithm defines some transverse sections that are homogeneously spaced (Figure 7). The space between two transverse sections can be setup by the operator according to the accuracy required.

For each transversal section identified by the semi-automatic procedure, a moving average of the terrain elevation and its slope are computed (Figure 8). In this step, the algorithm searches the Points of Interest (POIs) necessary to delimit the riverbanks. The first two POIs identified (POI1 and POI2) represent the bottom and the top of the right riverbank respectively. The following POIs (POI3 and POI4) represent the foot and the head of the left riverbank. These points are identified analyzing if the first derivate of the terrain profile overpasses a well-defined threshold. The bottom of the riverbank is detected when the terrain slope exceeds the threshold, while the head of the riverbank is identified when the terrain slope drops below the threshold. The threshold can be modified by the user, depending on the slope of the transverse profile, in order to obtain the correct result.

The land use map obtained from the previous algorithm and the CHM calculated from the point cloud are then overlapped to the map where riverbanks are identified. The masking procedure permits to extract information related to the coverage of riverbanks and to classify the vegetation according to Kaufmann et al. (1999) as:

- Herbaceous: if CHM < 0.5 m
- Riparian shrubs: if 0.5 m ≤ CHM < 5 m
- Riparian arboreal: if CHM ≥ 5 m

As in the previous analysis, in this case also, the result is shown in a georeferenced thematic map, on which the classification of the riparian and floodplain vegetation are summarized (Figure 9), together with a table where the percentage of soil and classified vegetation of the riverbanks are reported.

3.3 Comparison between semi-automatic classification and ground surveys

All the results obtained by the semi-automatic procedure have been validated with those collected during in-field surveys. Due to the preliminary stage of the research, the validation of the results of the land use classification algorithm has been done only for two criteria considering the entire survey over Adige river. The visual interpretation consisted of overlapping the information obtained during the monitoring and the interpretation of the ROI during the postprocessing phase. Using ArcGIS software, through visual classification, the entire monitoring area have been classified as vegetation, water or ground. Then, the coverage area has been calculated for each land use class. The obtained results have finally been compared with the same results obtained through the automatic method. Table 3 shows the results. The results in Table 3 highlight that the implemented algorithm for the automatic land use classification is well able to recognize those areas where vegetation is present, while the identification of water and ground areas is affected by some uncertainties. Realistically, this result is related to possible inaccuracy in classifying zones of transition between water and soil and/or zones submerged occasionally. According to the hour and the season during which the UAV flights were carried out, portions of the collected images may be affected by a shaded band generated by the riparian vegetation. This shading effect causes a slight variation in the reflectance of transitional bands, affecting the data-processing and caus-

Table 3. Area in percentage obtained through the validation of the automatic analysis procedure.
Tabelle 3. Fläche in Prozent, die durch die Validierung des automatischen Analyseverfahrens erhalten wurde.

	Visual survey Area (%)	Automatic survey Area (%)	Differences Area (%)
Vegetation	53.2	50.3	-2.9
Water	27.2	21.0	-6.2
Ground	19.6	28.7	9.1

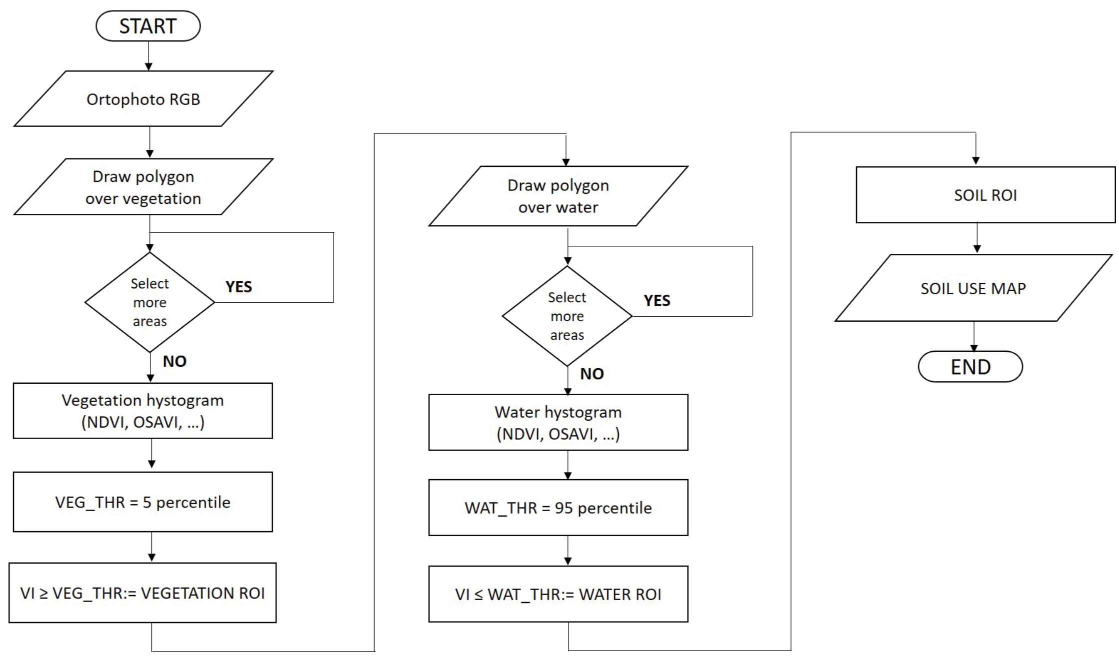

Figure 2. Land use algorithm flow-chart.
Abbildung 2. Flow-Chart des Bodennutzungsalgorithmuses.

ing an overestimation of the ground content. A further cause of overestimation of the soil class may be caused by a similar reflection between thin water layers within the river, and because their reflectance is very similar to those of gravel, cobbles and boulders, which partially or scarcely submerged. As a consequence of this similarity, the algorithm identified the selected ROI with an accuracy of approximately 90 %.

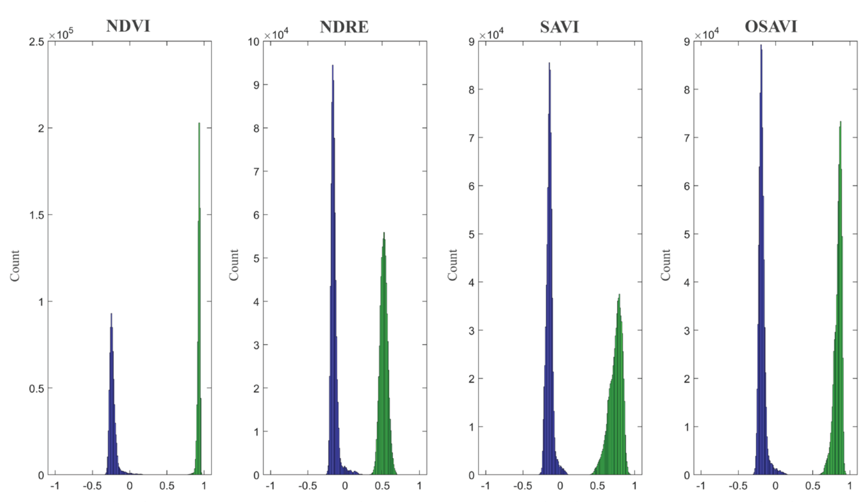

Figure 3. Histogram of the statistical distribution of the Vegetative Indexes for the selected area covered by vegetation (green histogram) and water (blue histogram). To distinguish between vegetation and water bodies, the procedure will select the most useful vegetative index, which has the biggest difference between the two distributions. In this way, a clear classification is expected.
Abbildung 3. Histogramm der statistischen Verteilung der Vegetativen Indizes für das ausgewählte Gebiet, das von Vegetation (grünes Histogramm) und Wasser (blaues Histogramm) bedeckt ist. Um zwischen Vegetation und Gewässern zu unterscheiden, wird jener Vegetationsindex ausgewählt, der den größten Unterschied zwischen den beiden Verteilungen aufweist. Auf diese Weise wird eine eindeutige Zuordnung erwartet.

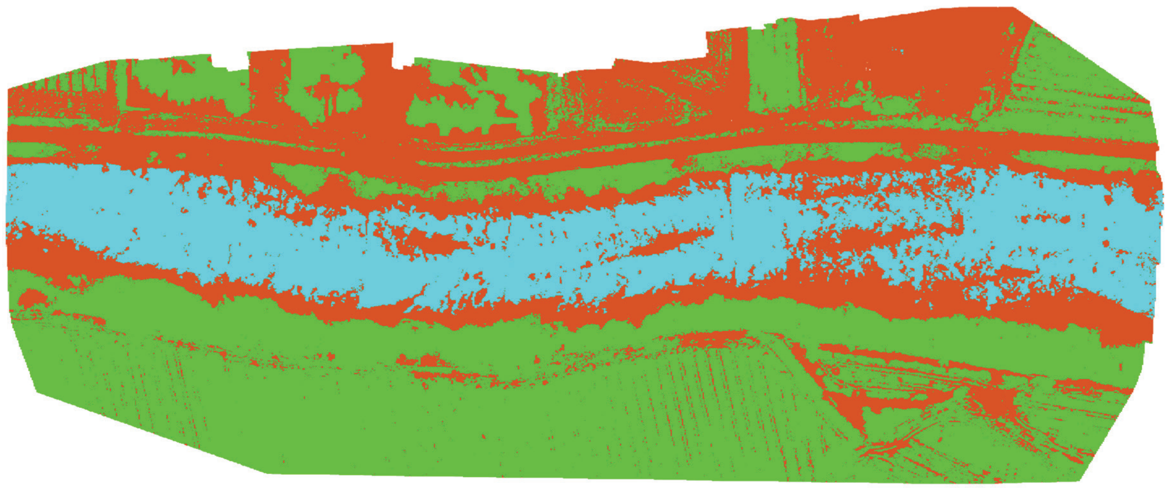

Figure 4. Land use thematic map of the Adige river, where green represents vegetation, brown soil and light blue water.
Abbildung 4. Thematische Landnutzungskarte der Etsch, wobei grün für Vegetation, braun für Boden und hellblau für Wasser steht.

For the validation of the algorithm used for the assessment of the riparian vegetation along the riverbanks, 38 trees and 37 shrubs (according to the adopted classification) have been measured and georeferenced during the field survey. The collected data has been used to develop a shapefile that was overlapped to the georeferenced raster map, output of the implemented algorithms. The semi-automatic procedure has been able to properly identify 82% of the individuals in the plots. This validation has been affected by uncertainty mainly in the classification of shrubs or trees close to the threshold (five meters) and errors due to wrong georeferencing. The discrepancy could be due to the intrinsic errors of the adopted measurement methodology or to the validation procedure. Indeed, the riparian environment can be considered as a very chaotic environment mainly if aboveground biomass is characterized by coppice or shrubs

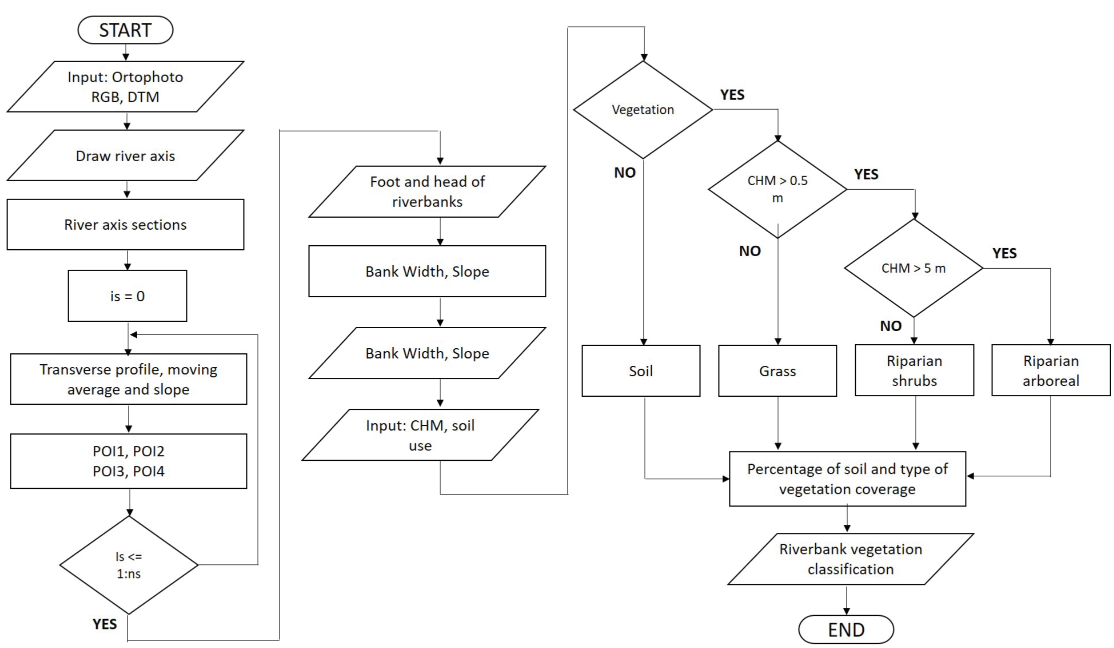

Figure 5. Flow-chart of the algorithm for riverbanks identification and the classification of the riparian strip vegetation.
Abbildung 5. Flow-Chart des Algorithmus zur Identifizierung des Ufers und der Klassifizierung des Bodens und der Ufervegetation.

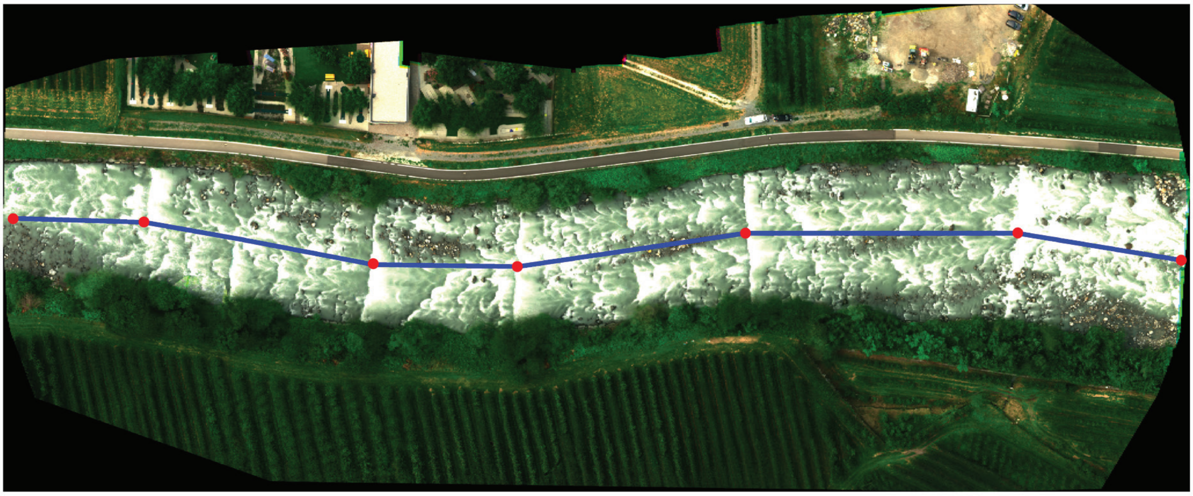

Figure 6. Example of river's axle drawing (blue line). Red dots correspond to the building points selected to draw a line segment. In this example, the river's flow is from left to right.
Abbildung 6. Beispiel der Zeichnung der Flussachse (blaue Linie). Rote Punkte entsprechen den Punkten, die zum Zeichnen eines Liniensegments ausgewählt wurden. In diesem Beispiel fließt der Fluss von links nach rechts.

(brambles) that vegetate on very steep land. This steepness does not permit a proper positioning of the GNSS device and a proper distance between the surveyor and the tree when measuring the height, using the clinometer. Besides this, the presence of the coverage, mainly if the plant has leaves, affects the accuracy of the measurement causing a slight drift of the acquisition from the real position. In the end, also the inclinometer can be affected by errors because the height measurement is based on the distance and angles assessment between surveyor and tree. Therefore, a not correct identification of the top or the bottom of the plant can influence the measurement of the angles, so the height, up to a couple of meters. This error is emphasized when the assessment is performed at narrow distances. Indeed, it sometimes happens that the surveyor during the assessment was unable to reach the best place to perform the acquisition because it was not accessible due the presence of branches with thorns or for terrain steepness.

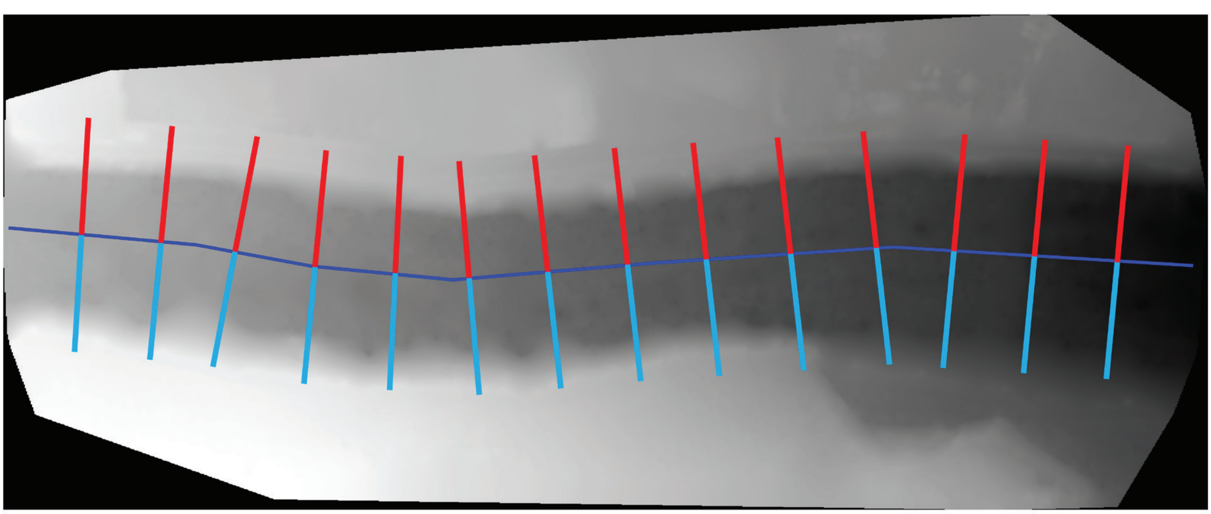

Figure 7. Automatic definition of the river's transverse sections using the middle line of the river (dark blue line). The transverse sections are colored in red or light blue line depending on the side of the bank (right or left).
Abbildung 7. Automatische Definition der Flussquerschnitte anhand der Mittellinie des Flusses (dunkelblaue Linie). Die Querschnitte sind je nach Uferseite (rechts oder links) rot oder hellblau eingefärbt.

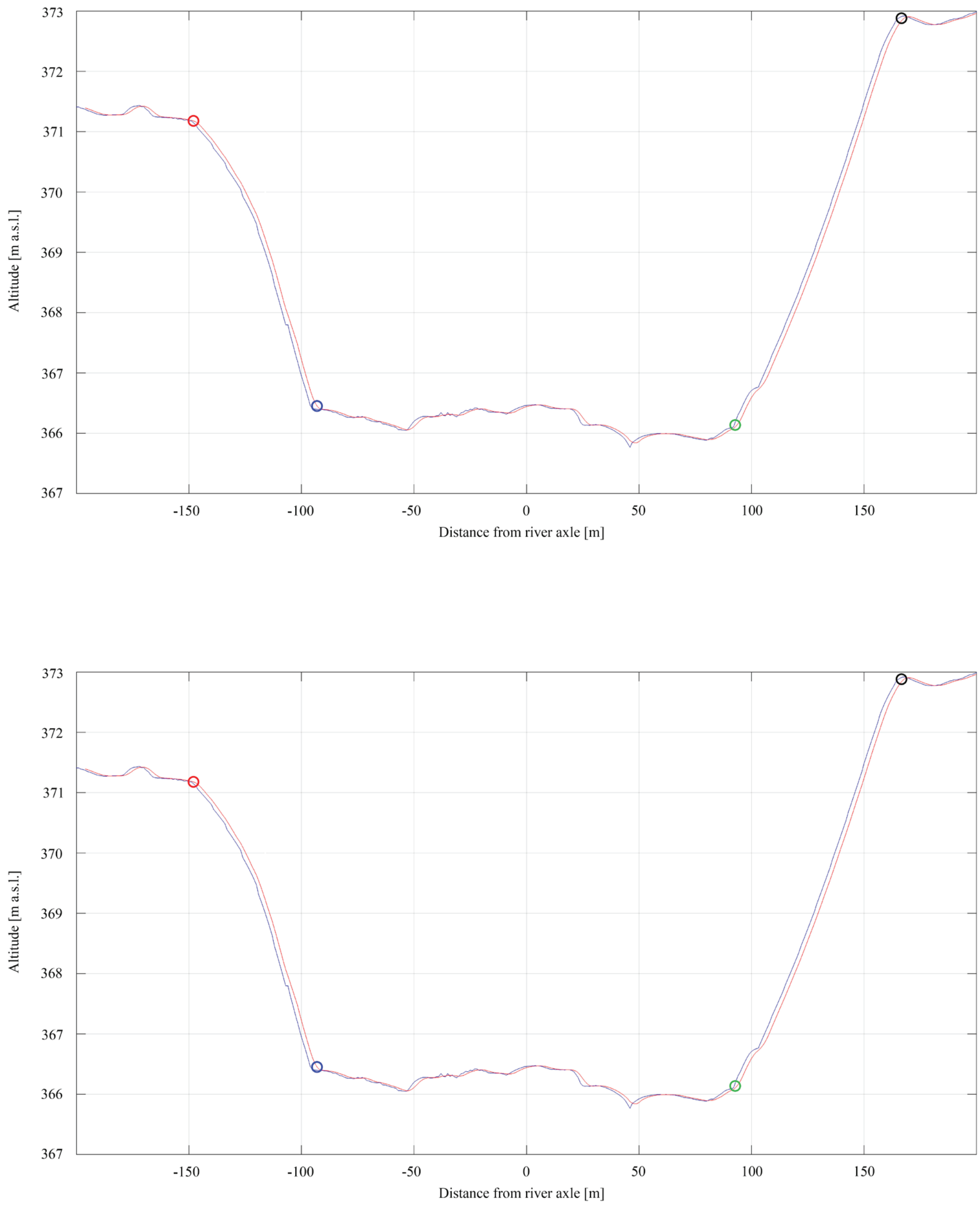

Figure 8. Procedure for the identification of the bottom and top of both riversides and the terrain profile for each transversal section previously identified. In a), the blue line represents the first derivative (slope) of the section, while the red one represents the moving average of the calculated first derivative. The black dashed line represents the thresholds used to detect the POIs: when the moving average of the derivate overpasses these thresholds, the POIs are set-up, identifying the top (POI1) and bottom (POI2) of the left riverside (red and blue circle) and the bottom (POI3) and top (POI4) of the right riverside (green and black circle). In b), the riverside terrain profile is reported. The blue line represents the actual height of the section, while the red line represents the moving average of the height of the section. Also, the four POIs are reported in this figure.
Abbildung 8. Verfahren zur Identifizierung der Unter- und Oberseite beider Flussufer und des Geländes für jeden zuvor identifizierten Querschnitt. In a) repräsentiert die blaue Linie die erste Ableitung (Steigung) des Abschnitts, während die rote den gleitenden Durchschnitt der berechneten ersten Ableitung darstellt. Die schwarze gestrichelte Linie stellt die Schwellwerte dar, die zum Ermitteln der POIs verwendet werden: Wenn der gleitende Durchschnitt der Ableitung diese Schwellwerte überschreitet, werden die POIs eingerichtet, die den oberen (POI1) und unteren (POI2) Bereich des linken Flussufers (roter und blauer Kreis) sowie die Unterseite (POI3) und die Oberseite (POI4) des rechten Flussufers (grüner und schwarzer Kreis) identifizieren. In b) wird das Profil des Flussgeländes dargestellt. Die blaue Linie stellt die tatsächliche Höhe des Abschnitts dar, während die rote Linie den gleitenden Durchschnitt der Höhe des Abschnitts abbildet. In dieser Abbildung sind auch die vier POIs eingezeichnet.

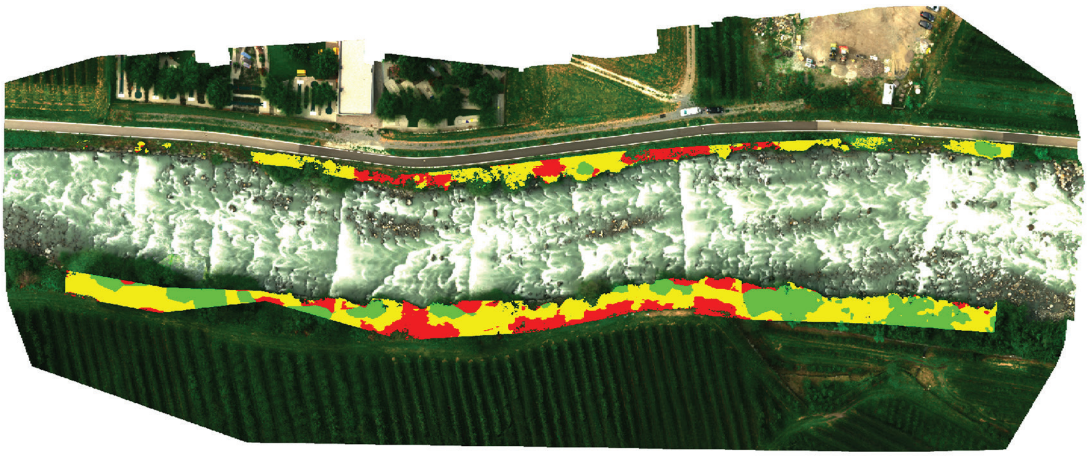

Figure 9. Classification layer overlapping an RGB image in the study area. Graphical result of algorithm procedures for riverbanks, riparian and alluvial riparian vegetation (the red, yellow and green colors refer to the herbaceous layer, riparian shrubs and riparian arboreal, respectively).
Abbildung 9. Klassifizierungsebene, die ein RGB-Bild im Untersuchungsgebiet überlappt. Grafisches Ergebnis der Algorithmen für Flussufer, Auen- und Ufervegetation (die Farben Rot, Gelb und Grün beziehen sich auf die krautige Schicht, die Auensträucher bzw. auf die Auenbäume).

4. Conclusions

The objective of the WEQUAL project is the realization of a web platform able to provide decision support for the assessment of the eco-morphological quality of fluvial environment. The assessment procedure is based on the answering of the WEQUI matrix, which is composed by 15 indicators. Answers can be supported by means of semi-automated analyses and/or field survey. In this paper, preliminary results obtained by the development of two semi-automated procedures to a test case study are presented. The algorithms of the two procedures have been implemented specifically support the evaluation of the indicators: i) Land use and ii) Riparian zone vegetation. The algorithm for land use assessment has shown to be enough accurate in identifying vegetation, but less accurate in the differentiation between ground and water, due to a not proper identification of transition and scarcely submerged zones. Also, the second algorithm has shown to be enough accurate in the recognition of the aboveground biomass even if the validation test has been performed in highly chaotic and not easily walkable environment.
For the research goal, achieving an assessment error around 15% can be considered a reasonable outcome since the proposed system is intended as a tool to support designers in weighting properly the environmental effects of different design solutions and not, for example, define structural details of hydraulic structures. Besides, as shown before, probably the methodologies followed for the validation tests are not the most accurate due to the presence of intrinsic errors in the evaluation, such as the presence of shadows, similar reflectance values for different substrates, drift phenomena or not correct identification of plant portions as consequence of the environmental conditions. To increase the accuracy of the validation, further surveys could be planned in environment where the vegetative and orographic conditions are less disrupted in order to facilitate all the field surveys ensuring a more accurate data for the validation procedures.

Acknowledgements

Research funded by the program EFRE-FESR 2014-2020 for South Tyrol – WEQUAL Project – CUP I52F16000840005.

References

Barbour, M., Gerritsen, J., Snyder, B.D. and J.B. Stribling (1999): Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton benthic macroinvertebrates, and fish. U.S. Environmental Protection Agency – Office of Water. Washington DC, pp. 337.

Braioni, M.G. and G. Penna (1998): I nuovi indici ambientali sintetici di valutazione della qualità delle rive e delle arie riparie. Wild State index, Buffer Strip Index,

Environmental Landscape Indices: il metodo. Biologia Ambientale 6, 3–48.
Buffagni, A., Demartini, D. and L. Terranova (2013): Manuale di applicazione del metodo CARAVAGGIO - Guida al rilevamento e alla descrizione degli habitat fluviali. Istituto di Ricerca Sulle Acque, Roma, 293 pp.
Cavalli, M., Tarolli, P., Marchi, L. and G. Dalla Fontana (2007): The effectiveness of airbone LiDAR data in the recognition of channel-bed morphology. Catena 73, 249–260.
Davenport, A.G., Gurnell, A.M. and P.D. Armitage (2004): Habitat survey and classification of urban rivers. River Research and Applications 20, 687–704.
European Parliament (2000): Directive 2000/60/EC of the European Parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy.
European Parliament (2007): Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.
Fountas, S., Carli, G., Sørensen, C.G., Tsiropoulos, Z., Cavalaris, C., Vatsanidou, A., Liakos, B., Canavari, M., Wiebensohn, J. and B. Tisserye (2015a): Farm management information systems: Current situation and future perspectives. Computers and Electronics in Agriculture 115, 40–50.
Fountas, S., Sorensen, C.G., Tsiropoulos, Z., Cavalaris, C., Liakos, V. and T. Gemtos (2015b): Farm machinery management information system. Computers and Electronics in Agriculture 110, 131–138.
Gallo, R., Grigolato S., Cavalli R., and F. Mazzetto (2013): GNSS-Based operational monitoring devices for forest logging operation chains. Journal of Agricultural Engineering 44, 140–144.
Gallo, R., Nalli F., Cortese L., Knollseisen D., Noggler, W. and F. Mazzetto (2017): Chainsaw vibrations, a useful parameter for the automatic tree volume estimations and production assessment of felling operations. Chemical Engineering Transactions 58, 655–660.
Gallo, R., Carabin, G., Vidoni, R., Sacco, P. and F. Mazzetto (2018): Solutions for the automation of operational monitoring activities for agricultural and forestry tasks. Die Bodenkultur: Journal of Land Management, Food and Environment 69, 131–140.
Ghetti, P.F. (1997): Indice biotico esteso (IBE). I macroinvertebrati nel controllo della qualità degli ambienti di acque correnti: manuale di applicazione. Provincia Autonoma di Trento - Agenzia Provinciale per la Protezione dell'Ambiente, pp. 222.
Kemp, P.S. and J.R. O'Hanley (2010): Procedures for evaluating and prioritising the removal of fish passage barriers: a synthesis. Fisheries Management and Ecology 17, 297–322.
Kleynhans, C.J., Louw, M.D., Thirion, C., Rossouw, N.J. and K. Rowntree (2005): RiverEcoClassification: Manual for EcoStatus determination. Joint Water Research Commission and Department of Water Affairs and Forestry, Pretoria, 1–210.
Kleynhans, C.J., Louw, M.D. and M. Graham (2008): Module G: EcoClassification and EcoStatus determination. River EcoClassification: Index of Habitat Integrity. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 377-08.
Kaufmann, P.R., Levine, P., Peck, D.V., Robison, E.G. and C. Seeliger (1999): Quantifying physical habitat in wadeable streams. EPA/620/R-99/003, U.S. Environmental Protection Agency, Washington, D.C.
Lenat, D.R. (1988): Water Quality Assessment of streams using a qualitative collection method for benthic macroinvertebrates. Journal of the North American Benthological Society 7, 222–233.
Mazzetto, F., Sacco, P. and A. Calcante (2012): Algorithms for the interpretation of continuous measurement of the slurry level in storage tanks. Journal of Agricultural Engineering 43, e6.
Mazzetto, F., Gallo, R., Importuni, P., Petrera, S. and P. Sacco (2017): Automatic filling of field activities register, from challenge into reality. Chemical Engineering Transactions 58, 667–672.
McGinnity, P.M., Mills, P., Roche, W. and M. Müller (2005): A desk study to determine a methodology for the monitoring of the morphological condition of Irish rivers: synthesis report. ERTDI Report Series 26, Environmental Protection Agency.
Michez, A., Piégay, H., Toromanoff, F., Brogna, D., Bonnet, S., Lejeune, P. and H. Claessens (2013): LiDAR derived ecological integrity indicators for riparian zones: Application to the Houille river in Southern Belgium/Northern France. Ecological Indicators, 34, 627–640.
Petersen, R.C. (1992): The RCE: a riparian, channel and environmental inventory for small streams in the agricultural landscape. Freshwater Biology 27, 295–306.
Raven, P.J., Holmes, N.T.H., Dawson, F.H., Fox, P.J.A., Everard, M., Fozzard, I.R. and K.J. Rouen (1998):

River habitat quality: The physical character of rivers and streams in the UK and Isle of Man. Environmental Agency, Bristol, 86 pp.

Rinaldi, M., Surian, N., Comiti, F. and M. Bussettini (2016): IDRAIM – Sistema di valutazione idromorfologica, analisi e monitoraggio dei corsi d'acqua – Versione aggiornata 2016. ISPRA – Manuali e Linee Guida 131, Roma, Italy.

Ristorto, G., D'Incalci, P., Gallo, R., Mazzetto, F. and G. Guglieri (2017): Mission planning for the estimation of the field coverage of unmanned aerial systems in monitoring mission in precision farming. Chemical Engineering Transactions 58, 649–654.

Rosgen, D.L. (2007): Watershed assessment of river stability and sediment supply (WARSSS). Wildland Hydrology, Fort Collins, CO, USA.

Siligardi, M., Avolio, F., Baldaccini, G., Benabei, S., Bucci, M.S., Cappelletti, C., Chierici, E., Ciutti, F., Floris, B., Franceschini, A., Mancini, L., Minciardi, M.R., Monauni, C., Negri, P., Pineschi, G., Pozzi, S., Rossi, G.L., Sansoni, G., Spaggiari, R., Tamburro, C. and M. Zanetti (2007): IFF 2007 – Indice di Funzionalità Fluviale. Agenzia Nazionale per la Protezione dell'Ambiente e per i Servizi Tecnici, Trento, Italy, pp. 336.

Sørensen, C.G., Pesonen, L., Bochtis, D.D., Vougioukas, S.G. and P. Suomi (2011): Functional requirements for a future farm management information system. Computers and Electronics in Agriculture 76, 266–276.

Tompalski, P., Coops, N.C, White, J.C., Wulder, M.A. and A. Yuill (2017): Characterizing streams and riparian areas with airborne laser scanning data. Remote Sensing of Environment 192, 73–86.