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Dr. Alba Gallo obtained her Master’s degree in Geology in 2012, at University of Siena. She specializes in environmental subjects, particularly in pedology. She is a fellow research at Ca' Foscari University of Venice. Prof. Claudio Bini is a full professor at Ca’ Foscari Universiy. His teaching program is focused on pedology applied.

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Mapping environmental data with a Geographic Information System: the influence of land use changes on hydrodynamics in the Muson river watershed (TV), in relation to climate change.

Gallo Alba and Bini Claudio

Dept of Environmental Sciences, Ca' Foscari University of Venice (Italy)

Abstract

Climate change is a current issue: temperature and rainfall rise, glaciers and snow melt and the global average sea level is rising.

This causes an increase of natural hazards (such as flooding risk and landslides), that could become more frequent. In this context, resident population should adapt to global environmental and climate change.

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This study illustrates the land use changes of the Muson river watershed (Treviso province, Northern Italy), occurred in the last twenty years, and that contribute to conditioning the river hydrodynamic, in relation to climate change.

Key words: Muson river watershed; land use; climate change; river hydrodynamics; GIS technology.

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Introduction

Data concerning land use is the most frequently requested information in the formulation of strategies for a sustainable land management, and to evaluate the effectiveness of environmental policies. In this concern, a major issue is the transformation from natural conditions to an artificial (anthropogenic) use (Yaalon, 2007; Ritter et al., 2003). Often, this transformation determines the loss of soil and causes negative impacts to the environment, such as changes in the hydrodynamic level of rivers and microclimate. Moreover, climate change can cause negative effects on the environment, such as increased natural hazards (e.g. flooding, landslides), as a consequence of increased precipitation, rain intensity and distribution, and decreased water holding capacity. Yet, the amount of rainfall that flows along the slopes and arrives at the river bed depends on the soil cover: moving from forest, grazing and meadows to arable land and urban areas, the overland flow and the flooding risk increase.

A full environmental analysis of a certain area involves the collection and the processing of several data, concerning many disciplines such as geology, botany, zoology, economy, sociology and engineering.

The success of this analysis is linked to the effective integration, processing and interpretation of collected data.

The application of a Geographic Information System (GIS) to the multidisciplinary data analysis allows: (i) complex processing of different data and information, (ii) data integration and interpretation and (iii) data restitution as thematic maps.

This modern technology allows overlapping of such maps, thereby enhancing environmental knowledge and land management towards a sustainable use of resources.

The aim of this study was to ascertain the effects of land use change and of hydrometric level variations in the Muson river watershed (Northern Italy), in connection with the current climate change, by GIS technology.

What is GIS?

The acronym GIS stands for Geographic Information System, a computerized data management system used to acquire, store, manage, retrieve, analyze, and display geographically referenced information, i.e. data identified according to their location (Burrough, 1986).

The GIS system is composed of four principal components (Fig.1):

- Hardware: personal computer, workstation, network server or internet, plotter, digitizer, scanner, mouse, CD or DVD ROM, hard disk, etc.;
- Software: analysis software (e.g. ArcView, QGIS);
- Qualified staff (or human resource);
- Data: stored in a RDBMS (relational database management system).

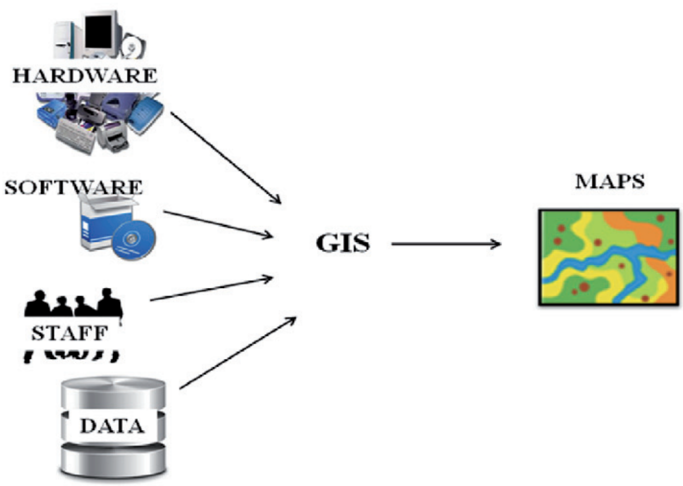


Figure 1 - The principal four components (hardware, software, staff and data) of a GIS and its products (maps)

Geographic information systems were initially developed as tools for storage, retrieval and display of geographic information. Its fast development is due to rapid increase in microprocessor speed, faster personal computer, decline in online storage costs and growth of networking (especially the Internet). Also, the development of the GPS and the greater numbers of remote sensing platforms (satellites and radars) allowed an easier georeferencing.

A GIS differs from other systems in different aspects:

- Data are georeferenced to the coordinates of an appropriate projection system (i.e. Lambert conformal conic, transverse Mercator or oblique Mercator). This allows correct placement of data on the earth's surface and maintains the spatial relationships among mapped features. As a result, commonly referenced data can be overlaid, and this overlay function is the basis of landscape studies;

- The GIS software uses relational database management technologies to assign attributes to each spatial feature, through tables. For example, a soil polygon can be linked to a table that contains its characteristics, such as chemical and physical properties, slope, exposure, land use suitability and other features;

- GIS combines several data into a composite data layer that may become a single layer in a geodatabase;

- GIS is data – rich and has excellent display capabilities.

The geodatabase is a data format used to collect, manage and edit geographic data (Zeiler, 2010).

It must have specific characteristics, such as:

- Safety: it has a local access protection to ensure data accuracy. In this way authorized persons only can modify and/or delete data;

- Integrity: data must be correct to avoid redundancy errors;

- Reliability: database must protect data by software and hardware failures;

- Data independence: capability to access the database for different purposes;
- Performance: database must grant fast queries;
- Managing concurrent data access: users can access a resource at the same time in order to consult and modify data.

GIS software commonly uses two types of data: vector data and raster data.

Vector data

The vector data are represented by four spatial element types (feature classes): points, lines, polygons (geometric elements; Fig. 2) and annotations. The points describe isolated elements (e.g. site locations), lines are used to represent nets (e.g. fluvial or street networks), polygons describe areas with particular features (such as land use, soil type, province, etc.) and annotations are the geodatabase name for map text.

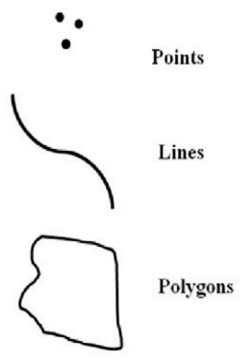


Figure 2 – The vector data elements: points, lines and polygons

All features can be single part or multipart, have 3D vertices, linear measures (called m – values), and contain parametrically defined curves.

Each point, line and polygon can be linked to tables, in which is stored information related to the considered spatial elements. This allows to create different thematic maps depending on the desired information.

Such tables can also be useful to specific research (query); for example, a selected polygon in a table can be easily displayed on a map within the other elements.

Raster data

Raster is the most common type of image files and it is used to represent digital images, such as digital aerial photographs, imagery from satellites, digital pictures and scanned maps. The typical formats are: .tif, .jpeg, .gif, .bmp, etc.

A raster data structure consists of a matrix of cells (usually rectangular or square), known as pixels, organized in a grid (rows and columns; Fig. 3), where each cell represents real – world phenomena, and its value represents some information of those phenomena, such as temperature, land use classes, elevation and other thematic classes.

This value can be negative, positive, integer (for discrete data) or floating point (for continuous data). Pixels can also have a NoData value, which signifies the absence of data.

The pixel attributes are displayed with colors to create an overall finished image: grayscale, RGB (Red – Green – Blue) or CMYK (Cyan – Magenta – Yellow – Black).

The raster data can represent thematic data, known as discrete data (e.g. forest stands), continuous data (e.g. elevation) and pictures from scanned maps or drawings.

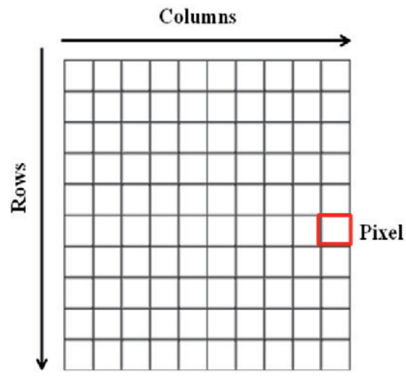


Figure 3 - The raster data structure: grid composed of rows and columns

Thematic and continuous data may be displayed as layers together with other geographic data; conversely, pictures raster are used as attribute in tables.

A raster includes geographic information, such as:

- A cell size (spatial resolution);
- The coordinate system;
- The count of pixels for row;
- The count of pixels for column;
- A reference coordinate of the first pixel located in the upper left corner of the raster.

The cell size determines the level of detail of the different features represented, and each cell has the same shape and size (width and height).

If the cell size is too large, information could be lost; conversely, a smaller cell size will increase the demand of computer storage space and the processing time.

Raster data are created from vector data, thanks to two different processes: the triangulation and the interpolation. The triangulation (Delaunay Triangulation) allows the creation of a triangulated irregular network (TIN), while the interpolation uses different methods: Thiessen, Inverse Distance Weighted (IDW), Splines, Kriging, etc.

These processes allow to attribute different value to overall raster image.

GIS application: an example in the Veneto region (Northern Italy)

Study Area

The Muson river basin is extended approx 15.000 ha from the pre-Alpine fringe (maximum altitude is 1775 m a.s.l at Mount Grappa) to the alluvial plain (minimum altitude is 42 m a.s.l at Castelfranco Veneto). Its area is totally included within the Treviso province, and it is part of the larger Brenta river watershed (Fig. 4). The Muson river takes origin from the hilly area of the municipality of Monfumo (NW Treviso province) and flows into the valley at the foot of the northern slope of the Asolo hills, in south – west direction up to Pagnano, where it turns in south direction and leads into the high alluvial plain between the Brenta and the Piave rivers.

Near to Spineda (Riese Pio X municipality, NW Treviso province) it receives, in the right, the contribution of the Lastego river, which flows down from the Monte Grappa slopes. At Castello di Godego it receives the Brentone stream and, in this area, the mountain basin of the Muson dei Sassi river ends of Castelfranco Veneto, after the confluence with the Avenale ditch. Proceeding to south, the canal of Muson river is, at first, dammed and then it becomes hanging, not receiving contributions from other streams. Finally, it joins the Brenta river, north of Padua, near Pontevigodarzere (ARPAV, 2008).

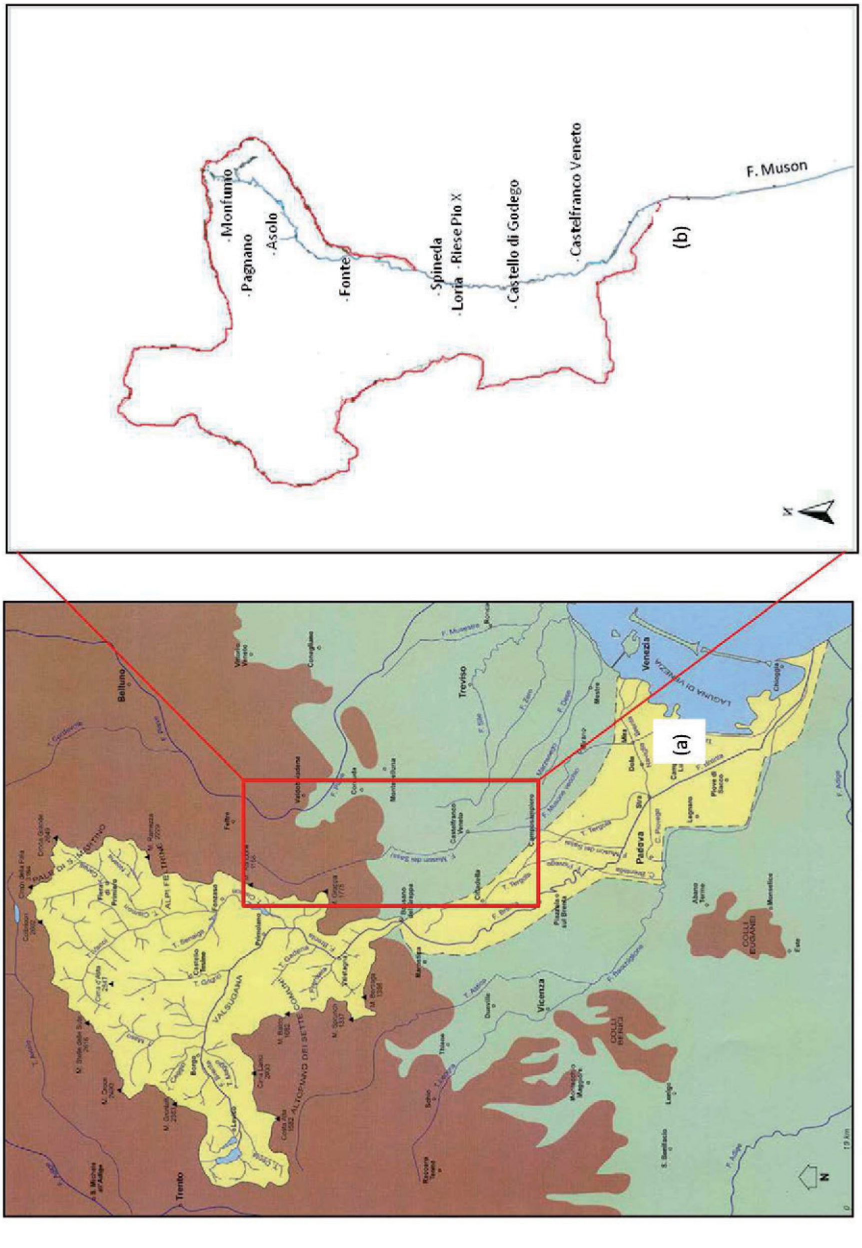


Figure 4 – Schematic map of the investigated area. (a): the Brenta river watershed is depicted in yellow, the pre – Alpine area in brown, the plain area in green, (b) the Muson river watershed (red line) and the Muson river (blue line) (ARPAV, 2008)

Historical framework

The name Muson is related to the "*mosa*" term, whose meaning is "marshy place", alluding to its repeated flooding (Talamini, 2012).

In the past, the Muson river was used as a natural boundary. In Roman times, it represented the boundary between the *Patavium* and *Altinum ager* (currently Padua and Venice provinces, respectively; Caravello, 2013) and, in the Middle Age, it was one of the delimitations of the Treviso province, known as "Marca Trevigiana". Moreover, it was an important trade route and it was exploited for military use: for example, in 1370 Francesco da Carrara, lord of Padua, changed the river banks with the aim to submerge the Aprilia territory (where there was a "Serenissima" Republic of Venice presidium) in case of flooding.

Many fortresses, as Stigliano, Mirano and Camposampiero, were also protected by the Muson river.

Geology and geomorphology

The landform morphology of the Muson watershed can be divided in three different sectors: the pre – Alpine, the hilly and the high plain.

The pre – Alpine area includes the southern slopes of the Mount Grappa; the hilly area is composed, to the east, of Asolo and Monfumo hills and of the Costalunga ridge and, to the west, of the Fonte and St. Zeno mountains and of the Paderno, Crespano and Borso del Grappa alluvial fans.

The alluvial plain area belongs to the Venetian high plain, close to the low plain.

The Mount Grappa is composed of limestone and calcareous marl (grey limestone, *biancone* and *scaglia rossa* of Jurassic and Cretaceous age) (Dal Piaz, 1964; ISPRA, 2004).

The morphological structure of the Mount Grappa is the result of several factors: tectonic uplift, valley incision by rivers and glacial processes. On the summit of

Mount Grappa there are several uplands, in which are recognizable forms of the ancient drainage network (e.g. hanging valleys and sinkholes) (Regione Veneto, 2006).

The piedmont area is occupied by hills and alluvial fans located at the foot of Mount Grappa. The fans are mostly formed of sandy and gravelly sediments of the Pleistocene (ISPRA, 2004), while the hills are composed of marly limestone, marls, claystone, siltstone, sandstone and conglomerates of the Tertiary (ISPRA, 2004).

During the Pleistocene, the deposition of gravelly sediments by the Brenta and Piave rivers led to the building of the high plain. Subsequently, in the Holocene, the Muson river has deposited a layer of clayey sediments at the confluence of the two coalescent fans (ISPRA, 2004).

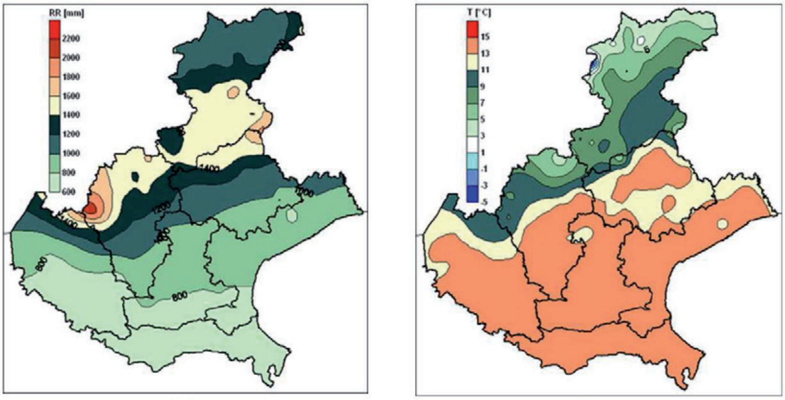
Climate

The climate of the study area may be subdivide into three districts, that correspond to the previously described morphological sectors: "*outer alpine district*", "*fore alpine district*" and "*alluvial plain district*" (ARPAV, 2011).

In the "*outer alpine sector*" the climate is characterized by average annual temperature of 7° C and rainfall of about 1.500 mm per year (Fig. 5), which are distributed mainly in autumn and spring seasons.

The climate of the hills ("*fore alpine district*") is distinguished by a lower amount of rainfall (1.300 – 1.000 mm per year) and higher temperature (10 – 12° C; Fig. 5).

In the plain ("*alluvial plain district*") the average annual temperature is around 13 – 14° C and the annual precipitation is around 1.000 mm (Fig. 5; ARPAV, 2011).



(a) (b)

Figure 5 – The average annual temperature (a) and precipitation (b) maps (1985 – 2009) (ARPAV, 2011)

Vegetation

The southern part of Mount Grappa is covered by beech forest. Due to the natural environmental changes, news species have developed, such as black locust, a typical infested plant grown in clear land and abandoned zone.

The hilly vegetation is characterized by thermophile community, such as manna ash – hop hornbeam woods and oak – hop hornbeam forests.

The original climax vegetation of the plain included oak – hornbeam forest, a mesic community, that now has disappeared.

Soils

The soil cover in the investigated area presents a huge mosaic of soil types, depending on the land morphology and the parent material.

As reported by ARPAV (2008), in the mountain sector of Mount Grappa, on hard limestone, soils on slopes are thin, well drained, highly permeable, loamy-skeletal, calcareous, mixed, mesic: Lithic and Typic Hapludolls (USDA, 2006) and Epileptic or Rendzic Phaeozems in the WRB, 2006, whereas at the foot of slopes soils are fine – textured, moderately deep with clay accumulation and moderate permeability (Lithic, Typic, Inceptic or Ultic Hapludalfs fine to fine-silty, mixed, mesic; USDA, 2006) (Cutanic, Endoleptic Luvisols or Cutanic Alisols; WRB, 2006). The main land use in the mountain district is permanent pasture and forest.

In the pre-alpine hilly area, close to Monfumo, the prevailing soil type is a deep, well differentiated, clayey skeletal to loamy, non-acid mixed, mesic: Typic Hapludalf (USDA, 2006) or Cutanic Luvisol according to WRB, 2006, developed from gravelly sand in the apical sector of Brenta and Piave alluvial fans. Subordinate to the previous one is a thin, loamy – skeletal, carbonatic, mesic: Entic Hapludoll (USDA, 2006) or Rendzic Phaeozem (WRB, 2006).

The gently undulated hilly area near Asolo, with moderate slopes formed of marlstone, hosts mainly fine-silty, (calcareous), mixed, mesic: Oxyaquic, Typic and Fluventic Eutrudepts (USDA, 2006) or Endogleyic Calcisols (WRB, 2006). These soils are moderately deep and have low permeability, consistent with the fine texture; a calcic horizon, together with redoxymorphic features, forms in the Bkg horizon, at bottom of the profile. The main land use in the whole area is permanent meadow.

Downstream, north of Fonte village, on steep to moderately steep landforms formed of cemented gravels, the soil cover ranges from very deep, moderately permeable, fine-skeletal, acid, mixed, mesic: Typic Paleudalfs (USDA, 2006) or Cutanic Luvisols (WRB, 2006), to shallow, fine-skeletal over coarse-skeletal, calcareous, mixed, mesic: Lithic Udorthents (USDA, 2006) or Epileptic Regosols according to WRB, 2006.

Forest and permanent pasture is the prevailing land use on these landforms.

Proceeding in southern direction, towards Spineda, Riese Pio X and Godego, the prevailing soils developed on Holocene alluvial deposits are deep, fine to fine – loamy, mixed, mesic: Inceptisols (Typic, Vertic and Oxyaquic Eutrudepts according to USDA, 2006), i.e. Haplic and Fluvic Vertic Cambisols (in the WRB, 2006, classification).

Approaching the town of Castelfranco (the main settlement in the Muson river basin), and downstream towards the river mouth, the soil cover develops from late-glacial alluvial deposits which constitute the high plain, sometimes with depressed morphology.

The soil typological units range from loamy-skeletal, non-acid, mixed, mesic: Typic Hapludalfs (USDA, 2006) or Cutanic Luvisols (WRB, 2006) to coarse loamy, non-acid, mixed, mesic: Dystric Eutrudepts (USDA, 2006) or Haplic Cambisols (WRB, 2006), at more elevated sites, and to low permeable, fine-silty, calcareous, mixed, mesic: Oxyaquic and Fluventic Eutrudepts (USDA, 2006) or Haplic and Fluvic Cambisols, and Endogleyic Calcisols; (WRB, 2006), in lowlands.

Agriculture land is the main use; however, in recent times urbanization has strongly developed, “eroding” the agricultural soils up to 13% of the whole surface.

Materials and methods

Photo-interpretation and Map processing

Aerial photographs of the land use in the Muson river watershed, taken in the period 1990 – 1992, were compared with satellite images of the same area taken in the 2009, in order to ascertain land use changes occurred over a period of 20 years.

Photographs taken in 1990 cover the plain sector of the Muson watershed, ending at the hilly sector. The flight altitude and the scale of the aerial photographs are respectively 3.000 m and 1:20.000 (Regione del Veneto, 1990).

The hilly and pre – Alpine areas, instead, are included in the aerial photographs take in 1991 – 1992. The average flight altitude is 2.700 m and, consequently, the images scale is variable around 1:18.000 (Regione del Veneto, 1992).

The frames format of both flights are 23 x 23. All aerial photographs, which covered the study area, were printed in A4 format, causing the reduction of the images size: the new format was 19.5 x 19.5, the new scale of the first images was 1:23.000 and of the second ones was 1:21.000.

The frames used to interpreter the land use of the whole watershed are 81 for the plain and 57 for the hill and the pre – Alpine zones (138 in total).

The aerial photographs, of the 1990 – 1992, are available at the Department of Environmental Sciences (Ca' Foscari University of Venice, Italy), while the 2009 series were downloaded from the Veneto Region database, as vectorial data, and they belong to the flights operated by Veneto region.

The two series of images were analyzed with two different methods:

- Interpretation of aerial photographs (1990 – 92) with a mirror stereoscope;
- GIS elaboration of soil cover data (2009 vectorial data).

Before the interpretation of the frames, it is important to choose the land use legend. Concerning the frames 1990 – 1992, the scale used has allowed the recognition of the following uses:

- Urban areas (U);
- Arable land (S);
- Forest (B);
- Permanent crop systems (IS);
- Meadow and permanent pasture (P);
- Afforestation (r);
- Riparian vegetation (R);
- Quarrying (E).

This has led to the creation of two land use maps.

After photo – interpretation, thanks to the software Esri ArcGis 10, it was possible to create the 1990 – 1992 land use map at the scale of 1:50000 (see attachments A, B, C and E).

The vectorial data was used for the creation of the land use map related to 2009 satellite images; this was elaborated with the same software Esri ArcGis 10.

In order to allow a comparison between the two land – use maps, it was necessary to simplify the satellite image legend accordingly. In particular, the following land uses are recognized:

- Urban area (U): airports, buildings areas, industrial and commercial areas, residential complexes, greenhouse horticulture, isolated residential buildings, continuous urban fabric;

- Arable land (S): bare areas, maize in irrigated/not irrigated areas, sunflower in irrigated areas, beet in irrigated/not irrigated areas, cereals in irrigated/not irrigated areas, soybean in irrigated/not irrigated areas, tobacco in irrigated/not irrigated areas, horticulture in irrigated/not irrigated areas, railway, secondary road network, fast road network, irregular urban fabric, beaches, dunes and sand plains;

- Afforestation (r): sparsely vegetated areas, green urban areas, conifers and deciduous wood stands, areas with black locust population;

- Riparian vegetation (R): willows and other riparian vegetation;

- Permanent crop system (IS): orchards, olive groves, vineyards, cultivated areas with poplar and birch, nurseries in irrigated/not irrigated areas, shrubs;

- Meadow and pasture (P): different pasture, different herbaceous vegetation not subject to crop rotation, permanent pasture, set – aside areas, cultivated areas with forage in irrigated/not irrigated areas;

- Quarrying (E): quarrying areas and landfills;
- Forest (B): ravine ash-lime forests with hop hornbeam, alder swamp woods, white alder woods, broadleaved deciduous forest, chestnut of mesic and xeric soils, high mountain beech forests, outer alpine beech forests, sub – alpine beech forests with hop hornbeam, macrotherm dwarf mountain pine scrubs, mesotherm dwarf mountain shrubs, manna ash – hop hornbeam woods, oak – hornbeam forests and sessile oak forests;
- Other (A): canals, waterways, rivers, streams, ditches, scree.

Some examples of forcing the satellite original legend are:

- The roads and railways were included in the arable lands, because they are common in the plain where the main land use is agricultural. It results difficult to separate graphically roads and railways from the arable lands;
- Greenhouse horticulture is an agricultural activity, but it is included in urban land use because greenhouses are permanent structures, and so the land covered by them is impermeable;
- Bare areas are included into the arable land group;
- Stands of black locust are characterized by spontaneous afforestation of *Robinia pseudoacacia* L., and, for this reason, it is included in the afforestation category;
- Irregular urban fabric is characterized by isolated houses common in the plain. This feature is included in the arable land class because it is difficult to discern the single houses from the surrounding arable land;
- Landfills are in quarrying class because they are generally abandoned quarries;
- Set – aside areas are in the meadow and pasture groups due to their herbaceous cover;

- Broadleaved deciduous forest are groves of trees used to produce wood or to burn. They are included in the forest category.

Moreover, several surveys have been carried out in the study area to control photo – interpretation and to avoid possible mistakes.

From the 2009 general land use map (scale 1:50.000) (Att. I), four thematic maps (scale 1:50.000) representing the most significant land uses were derived:

- Forest, afforestation and riparian vegetation (Att. E);
- Meadow, permanent pasture and permanent crop system (Att. F);
- Arable land (Att. G);
- Urban area (Att. H);.

The quarries are not reported because of their scarce presence in the study area.

Climate aspects

In this study we have used climate data obtained from studies carried out by the ARPAV (Regional Meteorological Center, Teolo, Padua). These studies analyzed meteorological data of the period 1956 – 2004 and allowed identification of a significant climatic change in the period 1987 – 1988, when the average annual temperature increased from 14,7° to 16,2° C, possibly owing to variations in atmospheric circulation and, in minor scale, in land – use (Chiaudani, 2010).

The Meteorological Center of Teolo provided also the rainfall data recorded at two pluviometers in the Muson watershed. The first one is located a little outside the Muson basin, but it is representative of the meteorological conditions in the hilly area; the second one is indicative of precipitation in the plain sector.

Data are related to the hydrological series from 1992 to 2011, but we have processed them from 1998 to 2009 in order to compare precipitation with the available hydrometric data.

Hydrometric levels

Concerning the hydrometrics levels, we used the monthly maximum and average values recorded from 1998 to 2009 at the hydrometer installed at the Borgo Vicenza bridge (Castelfranco Veneto) (Fig. 6), and provided by ARPAV and Treviso Civil Engineering Service.

Figure 6 – Hydrometer at Borgo Vicenza bridge (Castelfranco Veneto)

A hydrometer is an instrument used to measure the hydrometric level, i.e. the raising or lowering of water level in lakes and rivers.

This level is calculated as the difference in height between the water surface and the vertical datum that may be the mean sea level (m.s.l.) or the “hydrometric zero” (the elevation above the m.s.l. for a specific hydrometer).

In this study, a beam hydrometer is used with numbered marks that show the water level (Fig. 6).

<u>Results</u>

The comparison between aerial photographs taken in 1990 – 92 and 2009 shows that, in the last decades, urbanization has greatly increased in the alluvial plain (Tab. 1), and significant land use modification has affected also the mountain and hilly areas, with serious consequences on the river hydrodynamics. The major area of the Muson river watershed is presently occupied by arable land (5.225,3 Ha, 36% of the total area) followed by forest, afforestation and riparian vegetation categories (4.059 Ha, 28%). Meadow, pasture and permanent crop systems cover 3.329,7 Ha, 23%, while the urban areas occupy 1.935,6 Ha, 13% (Tab. 1).

Table 1 – Present Land use of the Muson river watersheed (2009)

Land use	Percentage of the total surface	
	1990-1992	2009
Arable land	42	36
Forest stands	30	28
Meadows and permanent pasture	21	23
Urban areas	7	13

Thanks to the comparative analysis of the land use maps, it was possible to ascertain the land use changes in the study area (Tab. 1).

The pre – Alpine area has not undergone significant changes (the major land use is permanent pasture).

In the piedmont sector an increase of urban areas is evident, causing a decrease in arable land, meadows and pasture; conversely, there is an increase in permanent crop systems (the main are vineyards). Moreover, there are new olive groves in the southern slopes of Asolo hills and some pastures and meadows are present in previously afforested areas. The riparian vegetation almost entirely disappeared.

Concerning the plain area, the major land use is agricultural, even if there is an increase of urban areas (shopping centers, industrial areas and new towns). This causes a deviation of natural water discharge, which is canalized into the artificial water – supply system. There is also a decrease in meadow areas, producing loss of biodiversity and problems of water retention. Moreover, forest and afforestation are no more present in the high plain, indeed there are new vineyards and there is also a decrease in riparian vegetation.

The analysis of rainfall data evidenced different trends in the 1991 – 2004 period in comparison with the previous decades (1961 – 1990): an increase of mean rainfall during spring and autumn was recorded, from 80 – 100 mm to 120 – 160 mm, and the persistence of snow cover has undergone a reduction by 12% (ARPAV, 2011).

The average winter precipitation in the plain area was between 80 and 150 mm, changing considerably with respect to the previous three decades (135 – 200 mm) (ARPAV, 2011).

In the pre – Alpine and alpine areas, the comparison of the same periods, shows a decrease in winter rainfall of about 120 – 150 mm, changing from 200 – 400 mm to 80 – 300 mm (ARPAV, 2011).

Moreover, a dramatic reduction of small glacier and snow line elevation was observed: the average snow line elevation is decreased by 35% and the maximum by 16% (ARPAV, 2011).

The recorded variability of cumulative annual precipitation (in the period 1998 – 2009) is shown in Figure 7, while Figure 8 represents the average monthly precipitation recorded for the same period.

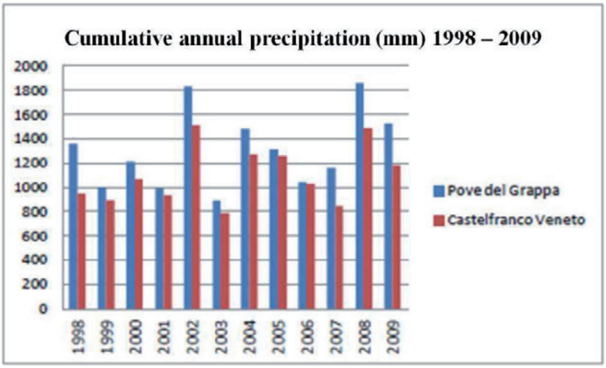


Figure 7 – Cumulative annual precipitation (1998 – 2009) recorded by pluviometers at Pove del Grappa (in blue) and Castelfranco Veneto (in red)

Rainfall is concentrated in spring and autumn, with maximum values (123,6 mm) on September at Castelfranco Veneto station and on November (160,7 mm) at Pove del Grappa station (Regione Veneto, 2006).

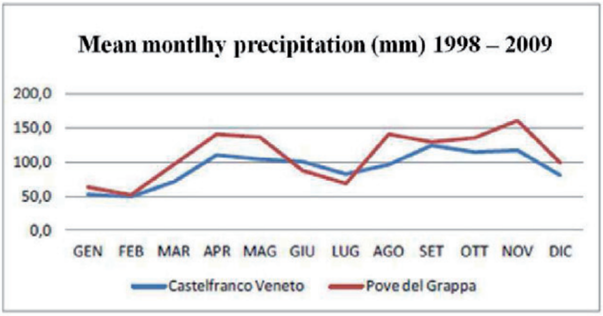


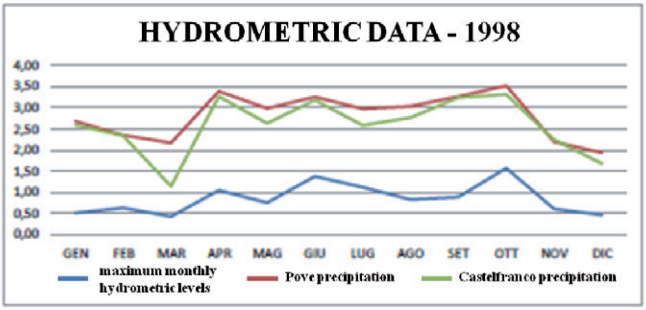
Figure 8 – Mean monthly precipitation (1998 – 2009) recorded by pluviometers at Pove del Grappa (in red) and Castelfranco Veneto (in blue)

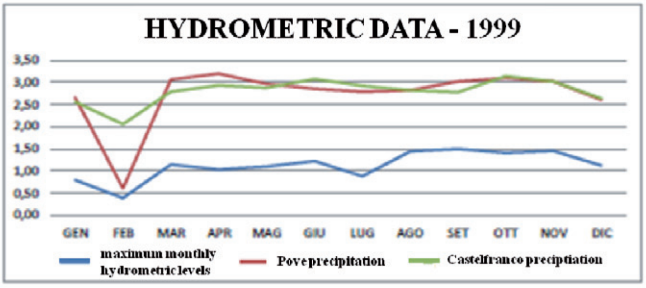
The driest period is winter, with minimum values on February for both stations (49,3 mm at Castelfranco Veneto and 51,5 mm at Pove del Grappa) (Regione Veneto, 2006).

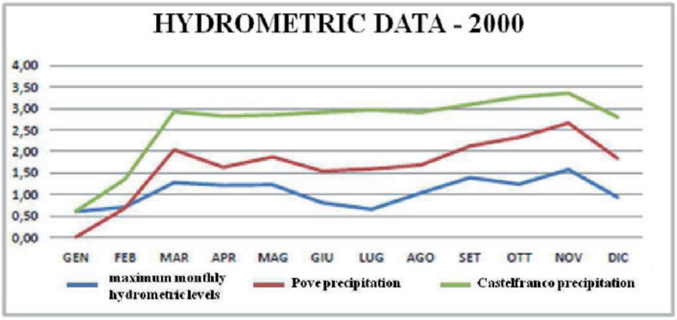
Moreover, the monthly variations of rainfall intensity are greater in the piedmont area (Pove del Grappa station) than in the plain (Regione Veneto, 2006).

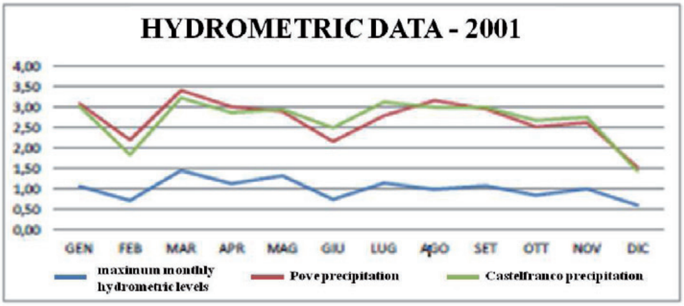
In the pre – Alpine area the maximum annual average rainfall (up to 1.771 mm) was recorded (Regione Veneto, 2006); more than half of the rain (1.099,55 mm) infiltrates feeding the karst aquifer (Regione Veneto, 2006), without conditioning the hydrodynamics of the Muson river.

Our results (Fig. 9) showed that the hydrometric levels increased in the rainy seasons (i.e. spring and autumn) (ARPAV, 2011), irrespective of the soil water retention capacity. Indeed, it is possible to observe (Fig. 9) that the difference between inflow (precipitation) and outflow (hydrometric levels) is significantly ($P < 0.05$) constant.






HYDROMETRIC DATA - 2000
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
GEN FEB MAR APR MAG GIU LUG AGO SET OTT NOV DIC
maximum monthly hydrometric levels
Pove precipitation
Castelfranco precipitation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3,00
2,50
2,00
1,50
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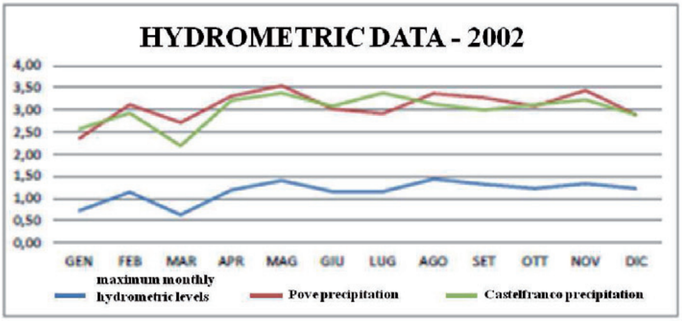
GEN FEB MAR APR MAG GIU LUG AGO SET OTT NOV DIC
maximum monthly hydrometric levels
Pove precipitation
Castelfranco precipitation


HYDROMETRIC DATA - 2002
4,00
3,50
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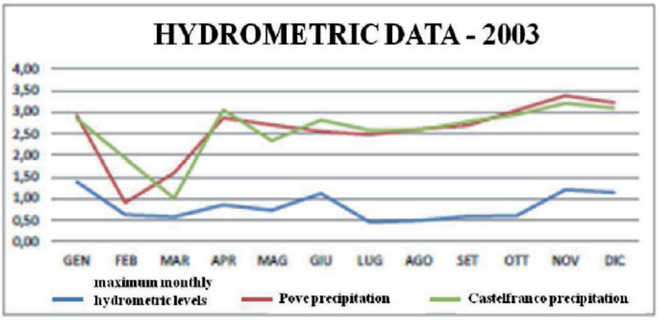
GEN FEB MAR APR MAG GIU LUG AGO SET OTT NOV DIC
maximum monthly hydrometric levels
Pove precipitation
Castelfranco precipitation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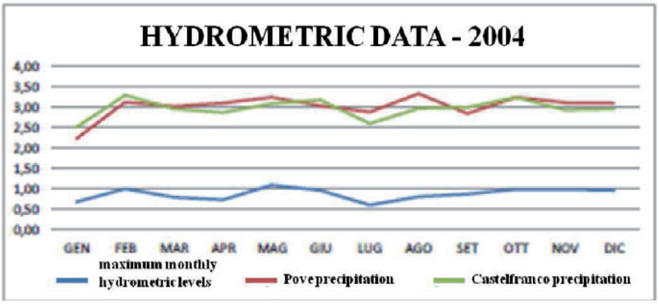
GEN FEB MAR APR MAG GIU LUG AGO SET OTT NOV DIC
maximum monthly hydrometric levels
Pove precipitation
Castelfranco precipitation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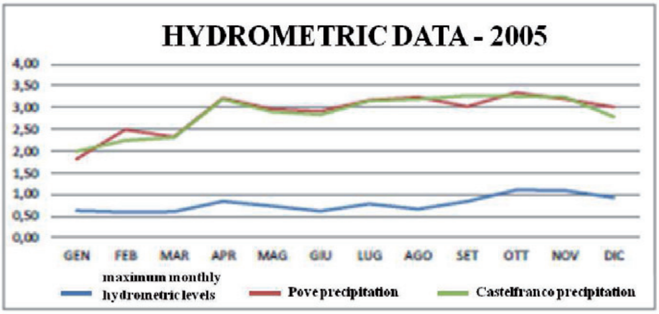
maximum monthly hydrometric levels
Pove precipitation
Castelfranco precipitation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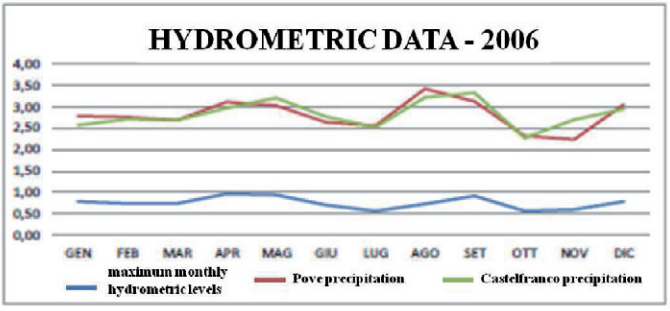
maximum monthly hydrometric levels
Pove precipitation
Castelfranco precipitation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maximum monthly hydrometric levels
Pove precipitation
Castelfranco precipitation

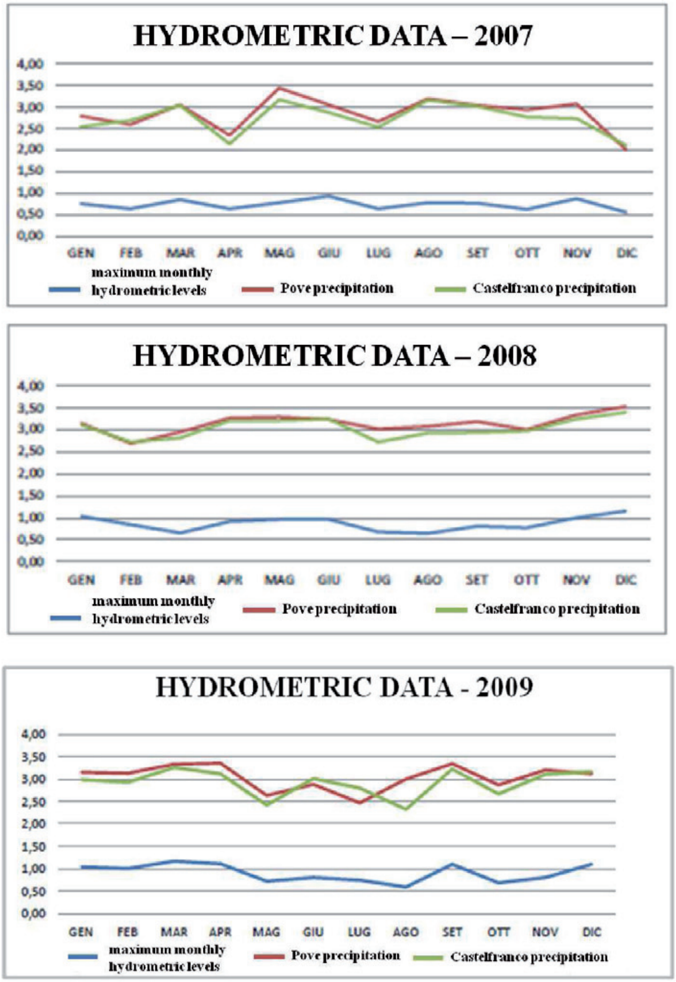

Figure 9 - Hydrometric levels (in blue) associated with the rainfall amount (in red and green). Original data are transformed by the logarithmic function ($\log_{10}(x_i)+1$), where x_i is the original data (in mm)

From Figure 9 it emerges that hydrometric levels present a decreasing trend in the period 2000 – 2009, consistently with rainfall distribution. Precipitation at Pove del Grappa (red line, Fig. 9) resulted to increase in 2009 in comparison to 2000 (+300 mm on yearly basis), with minor peaks in spring and autumn. Conversely, at Castelfranco (green line, Fig. 9) a decreasing trend (-56 mm on yearly basis) was recorded for the same period (2000 – 2009), with minor peaks corresponding to those of Pove rainfall and hydrometric levels. The more uniform rainfall distribution in the region is likely due to changing climate conditions recorded in the last decade in the mountain and hilly areas.

Conclusions

In this study we found out that the most important land use changes involved the urban areas especially in the plain, with an increase up to 13%. This impact might cause a negative effect on the hydrodynamics of the area, due to soil sealing, decreased soil absorption capacity and increase of the overland flow, leading to a major flooding hazard.

The increase of forested areas in the piedmont sector, instead, has a positive effect on hydrodynamics, counteracting the effect of rainfall, and regulating the overland flow.

The areas covered by arable land have not undergone any change, except for a small reduction due to the presence of new vineyard plants.

Finally, the riparian vegetation is decreased along the Muson river.

Moreover, our data showed that there is a strong correlation between the rainfall and hydrometric levels of the studied area, underlining the influence of rainfall on stream flow.

Rain infiltration depends on the type of vegetation and land use; it increases moving from urban areas, grazing and meadows to forest and arable land. Therefore, urbanization would cause change in the hydrodynamics of the Muson river, increasing the surface water runoff and so the flooding hazard.

The GIS methodology proved useful for improving the monitoring actions and to suggest to decision makers a sustainable land management; indeed, it was possible to manage and edit environmental data, and to understand the transformations occurred in the last twenty years.

These results could be used to address future land use change, in order to avoid further flooding risks and to achieve sustainable land management.

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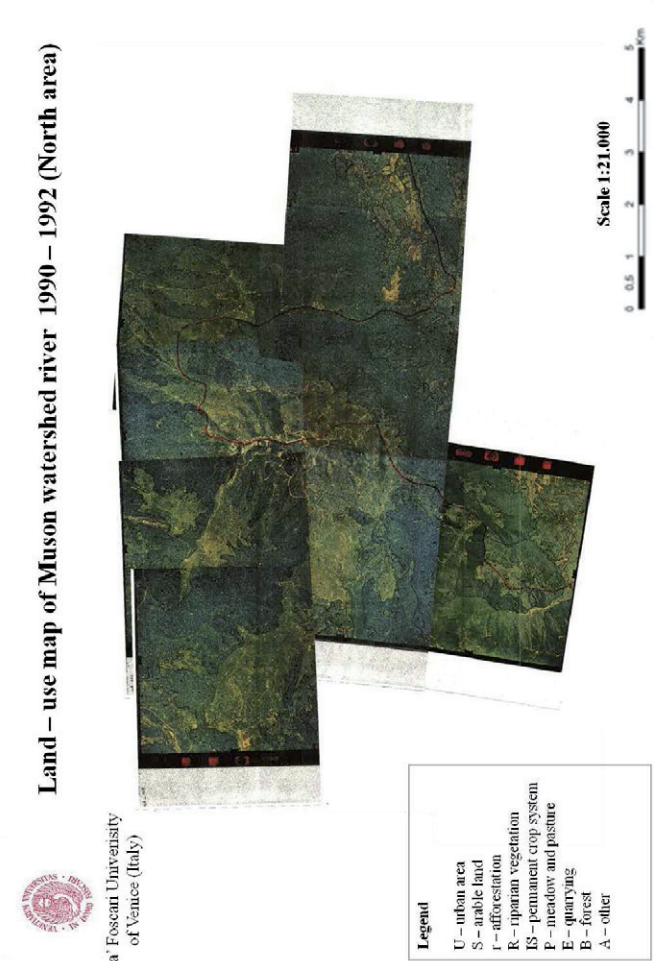
Attachment

Attachment **A**



Attachment B

Land – use map of Muson watershed river 1990 – 1992 (Central area)

Ca' Foscari Univerisity
of Venice (Italy)

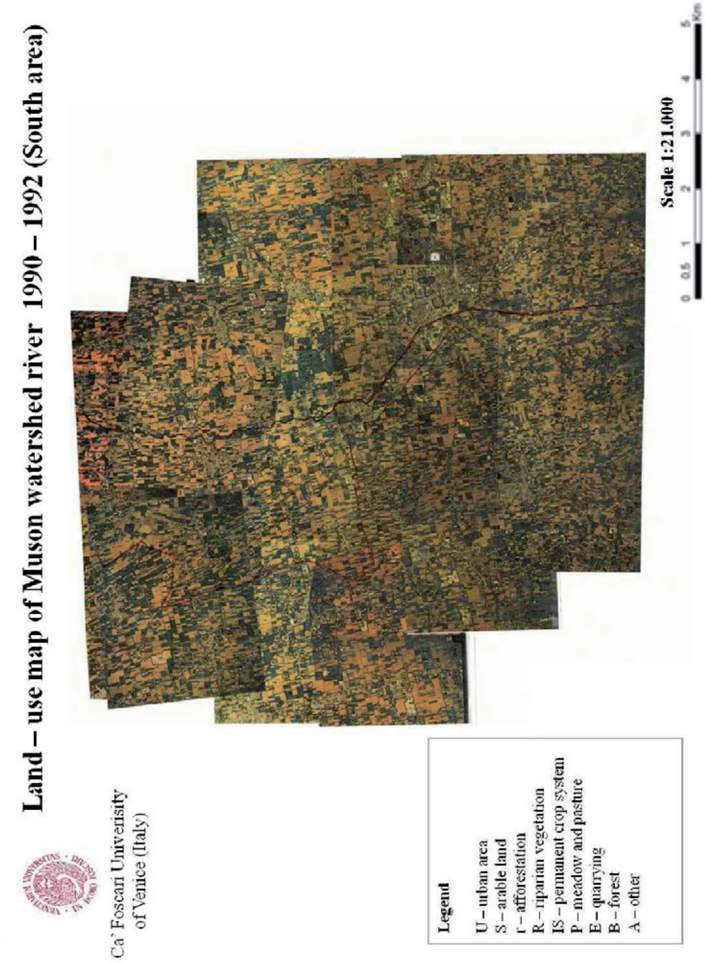
Legend

U – urban area
S – arable land
r – afforestation
R – riparian vegetation
IS – permanent crop system
P – meadow and pasture
E – quarrying
B – forest
A – other

Scale 1:21.000

0 0.5 1 2 3 4 5 Km

Attachment C



Attachment D

Land – use map of Muson watershed river 1990 - 1992 (Study area)

Ca' Foscari Univerisity
of Venice (Italy)

Legend

U – urban area
S – arable land
r – afforestation
R – riparian vegetation
IS – permanent crop system
P – meadow and pasture
E – quarrying
B – forest
A – other

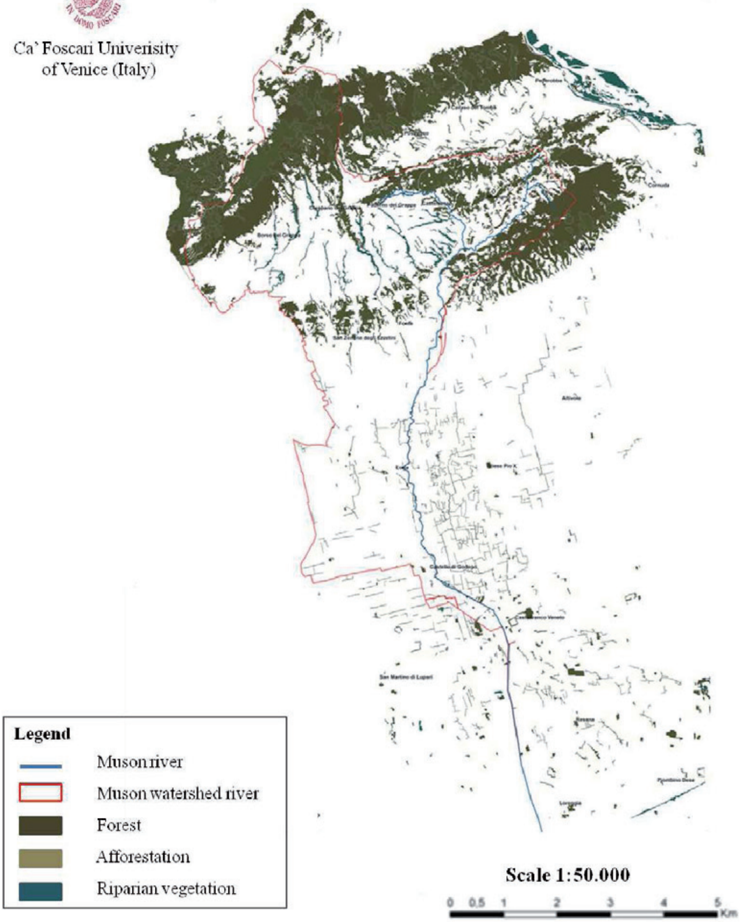
Scale 1:21.000

0 0.5 1 2 3 4 5 Km

Attachment **E**

Ca' Foscari Univerisity of Venice (Italy)

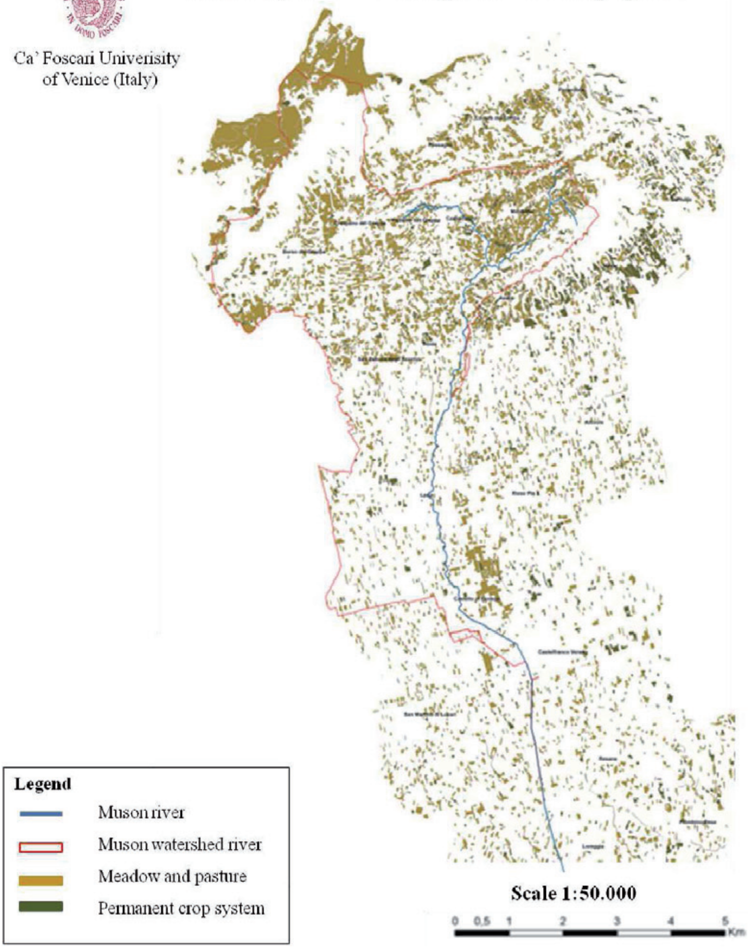
Forest, afforestation and riparian vegetation



Attachment F

Ca' Foscari Univerisity
of Venice (Italy)

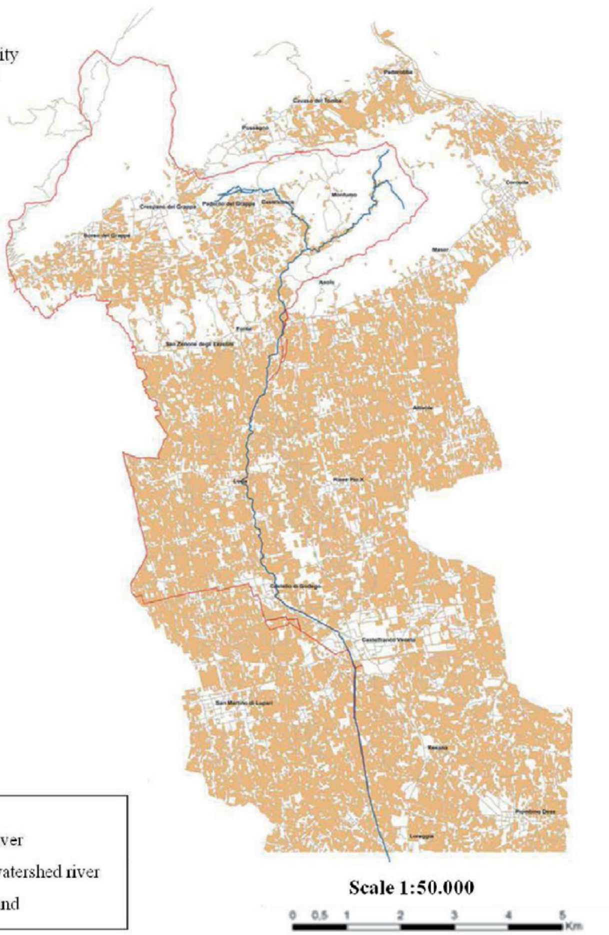
Pasture, meadow and permanet crop system



Attachment G

Ca' Foscari Univerisity
of Venice (Italy)

Arable land



Legend

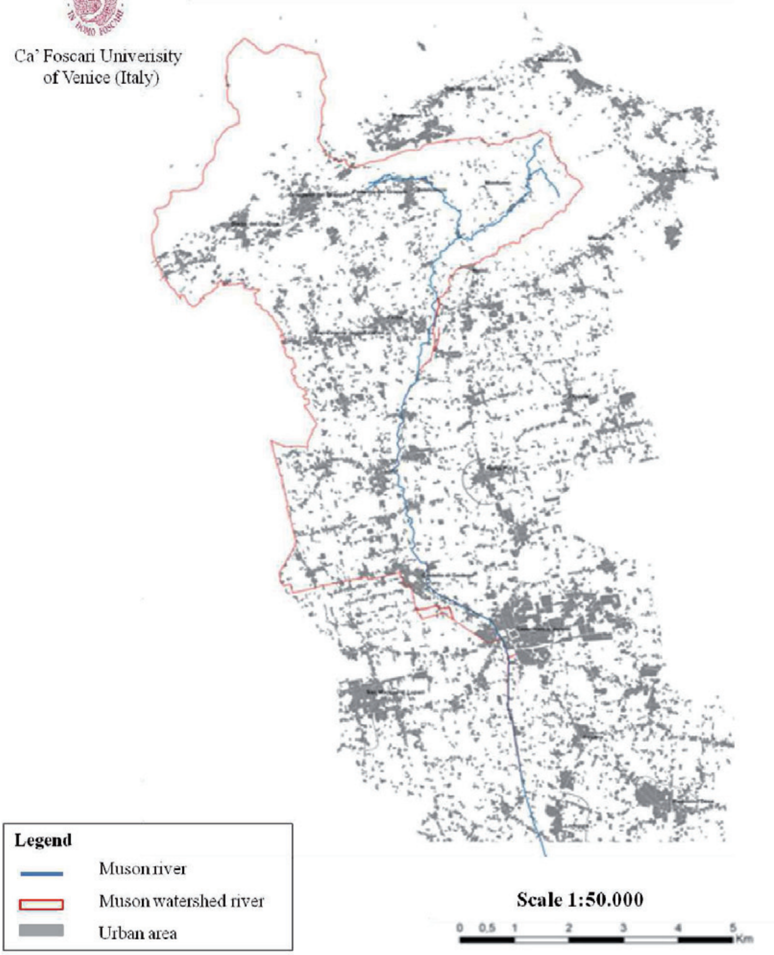
- Muson river
- Muson watershed river
- Arable land

Scale 1:50.000

Attachment H

Ca' Foscari Univerisity
of Venice (Italy)

Urban area



Attachment I