

Chapter 3

Impact of Climatic and Land Use Changes on River Flows in the Southern Alps

Roberto Ranzi, Paolo Caronna, and Massimo Tomirotti

Abstract River flow time series are far from being stationary and always experienced changes in the past, also dramatic in long time horizons. In recent years it seems that both climatic and anthropogenic factors are accelerating the variability of hydrological processes. It is not clear, however, whether climatic or anthropic factors represent the major forcing to the hydrological cycle. Long-term statistics, lasting over 150 years, of annual runoff for the five major Italian rivers in the Central Alps are presented and compared with precipitation, temperature and land use changes. A homogeneous decreasing trend of annual runoff is observed, and the significance of such a trend at the local and regional scale is tested with Mann-Kendall, Sen-Theil and Sen-Adichie statistical tests. It is shown that for some rivers, the increased agricultural water demand and land use changes are a likely major source of non-stationarity, possibly more relevant than meteorological ones. A natural feedback which is being observed also at the global scale is discussed on the basis of land use in the Adige river basin by comparing cadastral maps of the mid-nineteenth century with recent aerial photographs in four sample areas. Results are consistent with the reduced speed of deforestation observed at the global scale and the natural afforestation observed in Europe occurring over the last decades. This process can play a major role in regulating the hydrological cycle and mitigating flood and drought extremes, but also enhancing evapotranspiration losses and thus reducing runoff volumes.

Keywords River flow regime • Runoff • Trends • Climatic change • Anthropogenic changes

3.1 Introduction

In the scientific debate on the recent and projected climate at the global scale (IPCC 2013), a wide consensus is achieved on the fact that the Earth is experiencing a fast climate warming which will affect natural and human systems. Evidences on

R. Ranzi (✉) • P. Caronna • M. Tomirotti
DICATAM, University of Brescia, Via Branze 43, 25123 Brescia, Italy
e-mail: roberto.ranzi@unibs.it; paolo.caronna@unibs.it; massimo.tomirotti@unibs.it

the atmospheric temperature and CO₂ concentration increase, sea level rise and glaciers' retreat were fundamental in convincing 195 countries at the Paris climate conference COP21 to adopt a global action plan with the objective to reduce the global greenhouse gases emissions (UNFCCC 2015). However, in the scientific community, there still exist a few exceptions to this position (Gerhard 2006) and some criticism to the credibility of climate projections for hydrological purposes (Koutsoyiannis et al. 2008; Blöschl and Montanari 2010). In terms of impact on the hydrological cycle, the outcomes of the IPCC 5th Assessment Report (IPCC 2013) and the report by Bates et al. (2008) depict low confidence or unclear scenarios when dealing with soil moisture and mean river runoff. Quoting IPCC (2013) "The most recent and most comprehensive analyses of river runoff do not support the IPCC Fourth Assessment Report (AR4) conclusion that global runoff has increased during the 20th century. New results also indicate that the AR4 conclusions regarding global increasing trends in droughts since the 1970s are no longer supported," and "Projected changes in runoff show decreases in northern Africa, western Australia, southern Europe and southwestern USA and increases larger than the internal variability in northwestern Africa, southern Arabia and southeastern South America associated to the projected changes in precipitation. Owing to the simplified hydrological models in many CMIP5 climate models, the projections of soil moisture and runoff have large model uncertainties."

In spite of these uncertainties on future runoff changes also in the water engineering community, structural and nonstructural adaption measures are being taken to face the problems that could arise from an unbalance between water resources availability and demand in a changing planet (Ranzi et al. 2015). In fact stream flow changes could have relevant feedbacks, in the near future, on the water management policies and engineering design, particularly in those regions which are deeply exploited for hydropower production and where irrigation and domestic water demand are in conflict with industrial uses. The scientific hydrology community is paying more and more attention on several aspects, related to both physical and societal factors, of the changing dynamics of the water cycle in connection with rapidly changing human systems (Montanari et al. 2013). Changes and their reasons are now at the core of research and its technical applications in the water sector, and this chapter aims at contributing to this streamline.

Because of the high regional variability of precipitation projections, it is important to monitor recent changes of river runoff at the regional scale in order to detect changes, if any significant occurs, and to identify the possible natural or anthropogenic reasons for these changes. Several studies at the regional scale report about significant variations on a statistical basis in the twentieth century, which can be linked to temperature changes in a very weak sense (Labat et al. 2004) and are often controversial (Legates et al. 2005). Some statistical analyses indicate a statistically significant decrease of runoff and a temperature and evapotranspiration losses increase, for instance, for the Xiaoxi river close to the sea coast (Zhang et al. 2014), but others, even in a similar geographic context, show a stationary or slightly increasing annual runoff (Liu et al. 2010; Kumar et al. 2009).



Fig. 3.1 The five investigated river basins in the Central Southern Alps: from *left to right*, the Adige, Sarca-Mincio, Oglio, Adda and Ticino rivers. Downstream the Adige river in Trento surface water and groundwater resources are heavily exploited for agricultural uses

In this study we update with more recent and extended data a previous investigation conducted by Ranzi (2012) on runoff in the Central Southern Alps. Annual runoff series with a duration ranging from 62 to 170 years, one starting from year 1845, for five major rivers and six hydrometric stations are analysed to detect trends (Fig. 3.1 and Table 3.1). Because similar patterns of the decreasing trends were observed for the time series of annual runoff of all five basins the null hypothesis they exhibit a common constant trend was tested and results are presented in this chapter together with statistical tests on precipitation and temperature changes in the Adda and Adige basins.

3.2 The Investigated Basins

The first basin investigated is the Adige river, which drains the eastern part of the Central Italian Alps (Fig. 3.1). Because of the lower precipitation and the increase of evapotranspiration losses which are likely to occur also as a consequence of the observed increase of the forested areas due to afforestation (Ranzi et al. 2002), runoff decreased more rapidly than precipitation already in the twentieth century. Focusing on the 1923–2011 period when data are available for two stations of the river (Fig. 3.2), with a mean of 664 mm for the Adige at Trento (with a basin area of 9763 km²), a 163 mm/century decrease of runoff was observed, but a more pronounced decrease (−270 mm/century) was observed at the Adige basin outlet

Table 3.1 Statistics of the annual runoff, precipitation and temperature for the investigated basins

River basin	Station	Area (km ²)	Observation years (N. data)	Mean (mm)	St. dev. (mm)	Trend slope (mm year ⁻¹)	Z _{MK} (-)	Z _{SR} (-)	Theil-Sen slope (mm year ⁻¹)	TS' slope conf. limits (mm year ⁻¹)
			Runoff							
Adige	Boara Pisani	11954	1923–1978, 1980–1986, 1988–2011 (87)	573	145	-2.70 ± 0.28	-4.46	-4.31	-2.39	(-3.45, -1.36)
Adige	Trento	9763	1862–2011 (150)	710	140	-1.42 ± 0.24	-5.54	-5.31	-1.33	(-1.83, -0.90)
Mincio	Monzambano	2380	1950–2011 (62)	709	182	-3.25 ± 1.23	-2.78	-2.52	-3.33	(-5.35, -0.94)
Oglio	Sarnico	1840	1933–2011 (79)	979	227	-1.62 ± 1.11	-0.99	-0.99	-1.16	(-3.28, 0.75)
Adda	Lecco	4508	1845–2014 (170)	1150	237	-0.90 ± 0.36	-2.47	-2.50	-0.90	(-1.64, -0.19)
Ticino	Miorina	6599	1921–2012 (92)	1378	351	-2.02 ± 1.37	-1.11	-1.20	-1.67	(-4.47, 1.36)
Central Alps		25070	1950–2011 (62)	946	201	-1.86 ± 1.42	0.00	-0.03	0.00	(-3.25, 2.39)
Adige + Adda	Trento and Lecco	14271	1862–2011 (150)	843	160	-1.21 ± 0.29	-3.95	-4.02	-1.17	(-1.72, -0.60)
			Precipitation							
Adige	Trento	9763	1864–2011 (148)	890	159	-0.40 ± 0.30	-1.32	-1.27	-0.40	(mm year ⁻¹) (-1.00, 0.20)
Adda	Lecco	4508	1864–2009 (146)	1240	264	-0.95 ± 0.51	-1.99	-1.95	-0.92	(-1.84, -0.02)
Adige + Adda	Trento and Lecco	14271	1864–2009 (146)	1000	185	-0.61 ± 0.36	-1.70	-1.69	-0.58	(-1.31, 0.10)
			Temperature							
Adige	Trento	9763	1862–2011 (150)	2.4	0.7 °C	+0.10 ± 0.1			+0.11	(0.08, 0.13)

Results of Mann-Kendall (MK), Spearman (SR), Theil-Sen (TS) slope tests and parameters of linear regression line trend (slope and its standard deviation) for the considered stations. In bold statistics of time series with negative trends at 5 % significance level

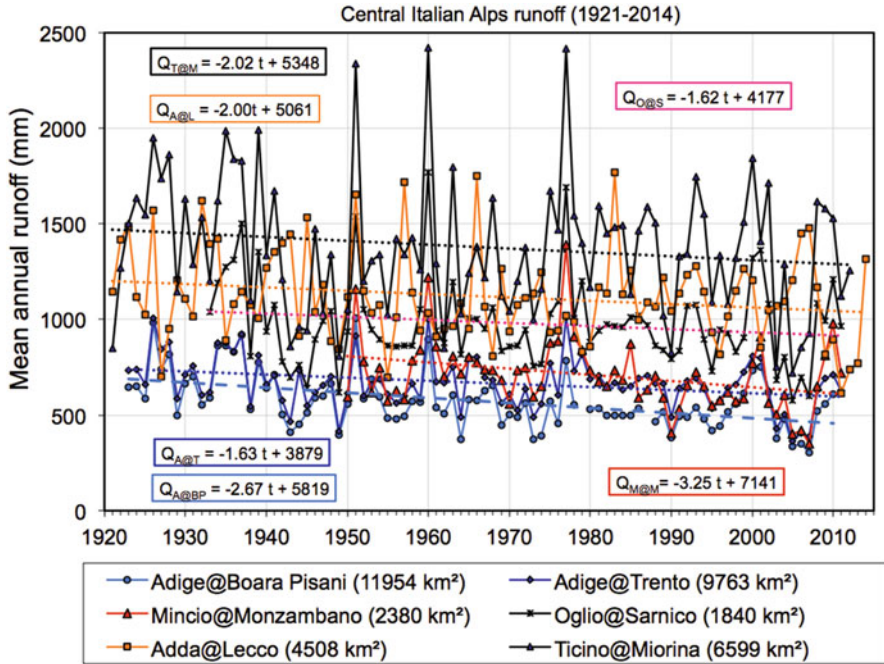


Fig. 3.2 Time series of annual runoff for four major river basins in the Central Southern Alps

into the Adriatic sea, close to the Boara Pisani station which gauges a basin area of 11 964 km². It is worth noting that runoff measured in the mountain part of the catchment gauged at Trento was quite close to that measured at the outlet of Boara Pisani until 1950 (697 vs. 655). After that period, runoff at the downstream station of Boara Pisani, accounting for 536 mm in the 1950–2011 period (with the exception of the years 1979 and 1987 when the missing daily runoff data were more than 10%), was much lower than that measured at Trento, averaging 650 mm. Considering a longer time period of 150 years from 1862 to 2011, the mean annual runoff of the Adige river reached 710 mm ± 140 mm, and the slope of the linear regression trend line decreases to −142 mm/century. It has to be mentioned that data for the Adige river in Trento for the 1943 to 1950 period were reconstructed as described in Zolezzi et al. (2009) through a linear regression with the downstream stations of Serravalle and Boara Pisani.

A possible explanation of the specific runoff decrease in the downstream part of the river in the second half of the last century is the increase of water pumped from the river and the surrounding groundwater for irrigation purposes in the downstream agricultural areas and increased evapotranspiration losses. Because the exploitation of water resources increased significantly in the second half of the century, this anthropogenic factor is a likely reason of the runoff decrease in the downstream areas, more than climate change. Another factor of minor importance is the diversion

of a maximum discharge of 500 m³/s from the Adige river to the Garda lake and the Mincio river which occurred during about ten flood events starting with the year 1960 when a by-pass gallery was constructed.

A marked decrease of mean annual runoff (−325 mm/century) is observed also for the shortest time series investigated, the one of the Mincio river at Monzambano (709 mm is the mean value of annual runoff over the years 1950–2011), at the outlet of the Garda lake and for the Oglio at Sarnico (see Figs. 3.1 and 3.2 and Table 3.1), accounting for a mean annual runoff of 979 mm. A new time series lasting for 170 years and spanning the 1845–2014 period was investigated here. It is the series of annual outflow of the Adda river from the Como lake at Lecco, which was previously investigated by Moisello and Vullo (2009) for the trends in annual maxima. Also the Adda river exhibits a less pronounced but statistically significant decreasing trend of 90 mm/century over the 1845–2014 period, when the mean annual runoff is 1150 ± 237 mm. For the Ticino river at Miorina, at the outlet of the Maggiore lake, a 202 mm/century runoff decrease of the lake's inflow is observed over the 1921–2012 period, when the mean annual runoff is 1378 ± 351 mm. It has to be pointed out that trend lines are very sensitive to anomalies in the time series. For instance, an increasing trend of 69 mm/century was previously observed for the Ticino river over the 1943–2012 period, characterised by a dry decade in the 1940s, possibly because of the recent precipitation increase observed in the NW Alps and the retreat of glacierised areas, which accelerated in the last decades.

3.3 Statistical Tests on Trends

In order to test the significance level of trends in the time series, several statistical tests are available in the literature (e.g. McCuen 2003); among them, Mann-Kendall (MK), Spearman's rho (SR) and run tests are widely used. These tests are nonparametric, one of their primary merits being that they do not assume that the data under analysis were drawn from a given distribution. MK (Mann 1945; Kendall 1970) and SR (Spearman 1904) tests were selected for our analysis since they have been extensively used in hydrology; on the other hand, their performances are almost identical in terms of power (Yue et al. 2002).

Both MK and SR tests are based on the null hypothesis that a sample of data $\{x_1, \dots, x_n\}$ is independent and identically distributed, which means that there is no trend or serial correlation among the data. The alternative hypothesis of the two-sided tests is that the distributions of x_j and x_k are not identical for all $k, j \leq n$ and $k \neq j$. The tests can be used to detect a monotonically increasing or decreasing trend according to the sign of the test statistic Z_{MK} or Z_{SR} (positive for an increasing trend, negative for a decreasing one), which we computed as in Appendix A in Yue et al. (2002) (thus taking into account the so-called correction for continuity for Z_{MK}). The trend is significant if the null hypothesis cannot be accepted for the given significance level α . The results obtained by MK and SR tests for the considered gauging stations selecting a significance level $\alpha = 0.05$ are shown in

Table 3.1. Since both Z_{MK} and Z_{SR} for large sample size (>10 for Z_{MK} , >20 for Z_{SR}) can be considered distributed according to a standard normal distribution (Kendall 1970), setting $Z = Z_{MK}$ or Z_{SR} , the acceptance region of MK and SR tests is given by the interval $-1.96 \leq Z \leq 1.96$, while the rejection region is given by $Z < -1.96$ (significant decreasing trend) and $Z > 1.96$ (significant increasing trend). It is worth noting that the values obtained for Z_{MK} and Z_{SR} are very close together and the conclusions about the significance of the trends are in agreement for all the series, except for the annual precipitation over the Adda river basin; however, in this case the values of Z_{MK} and Z_{SR} are very close to the boundary of the non-rejection region.

The trend slopes indicated in Table 3.1 were obtained by linear regression. To this purpose, the nonparametric Theil-Sen estimator (TS in the following) was used as described in Appendix A, while the corresponding confidence interval was obtained according to Appendix B. With respect to the traditional (parametric) least squares approach, there are several important advantages in using TS estimator (e.g. Wilcox 2010). First, it is more robust in the presence of outliers. On the other hand, while it is substantially comparable with least squares estimator in the presence of both normality and homoscedasticity of the response variable Y (where least squares method exhibits the best behaviour), it is superior in terms of standard error even preserving normality hypothesis, if only homoscedasticity condition is removed.

In addition to the tests for trend detection of single series, a test of homogeneity of trends at regional scale was performed. To test the hypothesis that the runoff and precipitation series exhibit a common trend slope, the Sen-Adichie test (SA in the following) for the parallelism of regression lines was performed as described in Appendix C. The test was applied to three sets of series. First, the null hypothesis was that the $k = 5$ regression lines for the annual runoff time series $Y(x)$ of Adige at Trento, Mincio, Oglio, Adda and Ticino have a common, unspecified β slope, i.e. they are parallel. The above hypothesis was tested both on the full extension of the available data and on the 1950–2011 period, which was monitored more homogeneously. Finally it was assumed that the overall moisture fluxes in the region, including both the five runoff time series and the annual precipitation averaged over the Adige and Adda river basins, exhibit a long-term trend with the same slope (in this case the number of regression lines is $k = 6$).

As anticipated, the test was performed first assuming, as null hypothesis, that the five time series of the runoff data have the common slope β_A . The pooled least squares SA estimator (C.2) of trend provided the value $\beta_A = -1.26 \text{ mm year}^{-1}$ for the long-term Adige, Mincio, Oglio, Adda and Ticino runoff time series. As for the V statistic (C.6) that resulted $V = 3.05$ and the upper tail chi-square limit $\chi^2_{4,0.05} = 9.49$, the null hypothesis of a common slope is not rejected.

The observation period of the series is not homogeneous, and therefore the test was repeated for the same time series but selecting a common time interval lasting from the year 1950 until the year 2011, for which the time series are complete. In this case the pooled least square estimator resulted $\beta_B = -2.00 \text{ mm year}^{-1}$ and the SA statistic $V = 5.43$, well below the same chi-square limit $\chi^2_{4,0.05} = 9.49$. The region of non-rejection of the null hypothesis is wider, also because of the minor size of the data sample.

Finally, the hypothesis was tested that also the rainfall time series has the same trend slope of the runoff series, assuming that the moisture fluxes in the whole hydrosphere exhibit a common decrease. The annual rainfall averaged spatially over the Adige and Adda river basins for the 1864–2009 time period was added to the five complete runoff time series. In this case the pooled least square slope, because of the milder decreasing trend of rainfall, results $\beta_C = -1.10 \text{ mm year}^{-1}$. The null hypothesis of this value for a unique slope is not rejected as the V statistics is 6.02 and $\chi^2_{5,0.05} = 11.1$.

3.4 Climate, Anthropogenic and Land Use Changes

In order to infer the possible factors influencing runoff trends in the Central Southern Alps, the major changes that occurred in that area over the last 150 years which we consider as more relevant are the following:

- Precipitation changes
- Temperature changes
- Land use changes including afforestation and urbanisation
- Retreat of glacierised areas

In this chapter some of these factors were investigated, starting from temperature, precipitation and land use changes in the Adige basin. From the analyses described in the following, some conjectures on the factors influencing runoff changes in the investigated area can be drawn.

3.4.1 Climatic Changes in the Adige Basin

The uncertainty on the response of precipitation to a climate warming is confirmed by recent climatological analyses in the Alps (Auer et al. 2007). A tendency to an increase of precipitation in the NW part of the Alps and to a decrease in the SE part is observed, but only the former trend was considered as statistically significant by Brunetti et al. (2009), with an 11 % increase over the 1901–2000 period. In the Adige river basin gauged at the Trento station, mean annual precipitation, estimated as 832 mm in the 1923–1996 period using a network of 14 stations, showed a decrease of 105 mm/century, a tendency which is consistent with the precipitation decrease in the southeastern Alps (Ranzi and Barontini 2010). Extending the observation period to the years 1864–2011 based on the HISTALP database (Auer et al. 2007), a mean annual precipitation of 890 mm at the catchment scale was estimated.

The observed -40 mm/century linear trend slope, a value which was consistent with the estimate using the Theil-Sen slope, as shown in Table 3.1, is not statistically significant at the 5 % significance level. This result is consistent with the statistics

of mean areal precipitation estimated over the Adda basin and the combinations of the Adige and Adda basins, where annual precipitation decreases with a rate of 95 and 61 mm/century, respectively, a value which, however, is not sufficient to reject the null hypothesis of no trend, at the 5 % significance level.

As it has been pointed out by Auer et al. (2007), the whole Alpine region is characterised by uniform trends of temperature. Over the 1886–2005 time period, in this area the rate of increase of mean annual temperature was 1.4 ± 0.1 °C/century (Brunetti et al. 2009) with significance higher than 99 % with Mann-Kendall test, thus confirming the global trend to a fastening warming. In the second half of the twentieth century, trends are higher than those observed in the same regions in the first half of the century. This is a possible reason why the temperature change for the Adige basin estimated on the HISTALP data base depicts a slower decrease of -1 °C/century over the 1862–2011 period. These values are, however, being investigated more in detail to complete the series with more stations, and comments of results are under preparation.

The impact of the combined effect of increased temperature and enhanced precipitation on runoff is not trivial although the runoff trend analysis is consistent with the above-mentioned “dipole” effect of precipitation changes over the Alps. An area-weighted sum of runoff in the five rivers, considering only the Trento station for the Adige river, provides a time series of runoff in a fictitious station draining an overall area of 25 070 km². Because of the short time series for the Oglio river at Sarnico, corresponding to the inflow in the Iseo Lake, the fictitious station data covers a 62-year period only, and the resulting mean runoff of 946 mm shows a negative trend of -186 mm/century which is, however, not significant at 5 % level. Therefore, for the Central Southern Alps, the null hypothesis of the existence of no trend cannot be rejected at 5 % significance level. This conclusion changes when a smaller hydrological region is investigated, including only the Adige and Adda basins, but with a time series 150 years long (Fig. 3.3). Although the runoff decrease is less marked, because of the availability of more data, the null hypothesis of no trend cannot be rejected with the same significance level (Table 3.1). In Fig. 3.3 annual runoff is compared with annual precipitation which exhibits a milder negative slope of 61 mm/century which confirms that precipitation decrease rate is less marked than that of runoff and is not statistically significant.

3.4.2 *Land Use Changes in the Adige Basin*

To explain the runoff decrease, land use changes for the Adige basin were investigated. A land use change which can be partially ascribed to anthropogenic factors is the increase of the forested areas in Europe, including Italy, in the last decades, as reported in the official reports by FAO (2011). Forests have a positive effect on the hydrological cycle by mitigating runoff extremes and storing moisture in soils and in the canopy, but they enhance evapotranspiration losses and therefore they have impact on runoff as well.

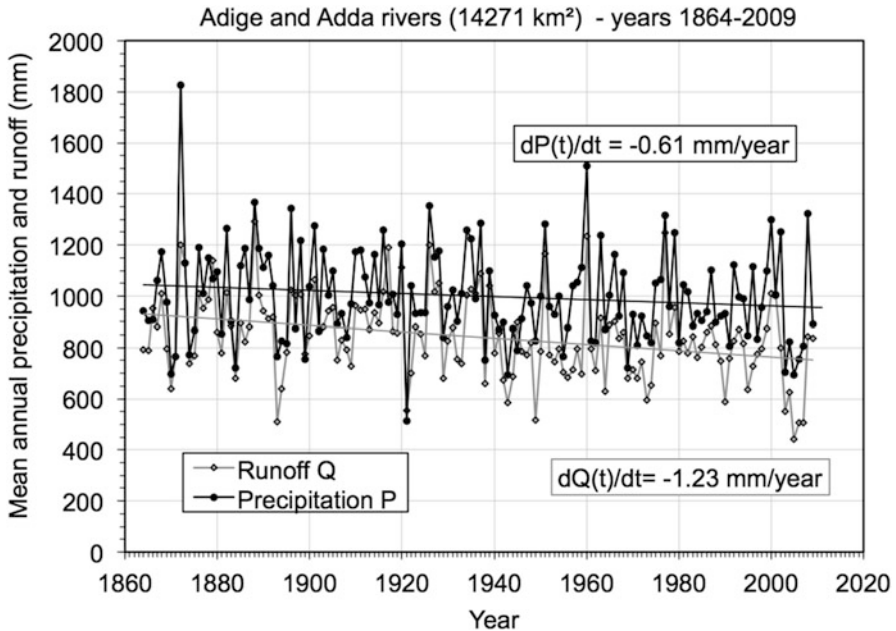


Fig. 3.3 The area-weighted runoff for a fictitious river basin in the Central Southern Alps draining an area of 14,271 km² including the Adige at Trento and Adda at Lecco river basins observed over the 1864–2009 period when precipitation data are available as well

Because of the combined effect of natural afforestation due to the decreased use of wood as a source of energy and the abandoning of agricultural areas (see, for instance, Ranzi et al. 2002 who described the effect of these land use changes on floods) and good management practices including protection of forests for the conservation of biodiversity and forests plantations, forested areas are growing in Europe, in the Russian Federation, North America and East Asia and in other subregions of our planet.

A study focused on four different areas of the Adige watershed (Fig. 3.4) was conducted to investigate the land use variations in order to link them with the runoff changes in the same time period.

The Adige River sources in Italy at an altitude of 1586 m a.s.l near the Resia Lake, close to the borders with Austria and Switzerland, 410 km in length, it is the second longest river in Italy after the Po River and it flows into the Adriatic Sea. The watershed is included in the Italian provinces of Bolzano and Trento, and, in the Veneto Region, it flows in the province of Verona and (for a small part) in the province of Vicenza. A small portion of the basin is located in Switzerland (Canton of Grisons). The valley bottom ranges from 1300 to 1500 m a.s.l. in the northern part of the watershed, while the river flows at an altitude of 240 m a.s.l. in the Bolzano plain and 190 m a.s.l. near Trento. In Fig. 3.4 the Adige catchment with the Trento's outlet is represented: this drainage area has an extension of 9763 km².

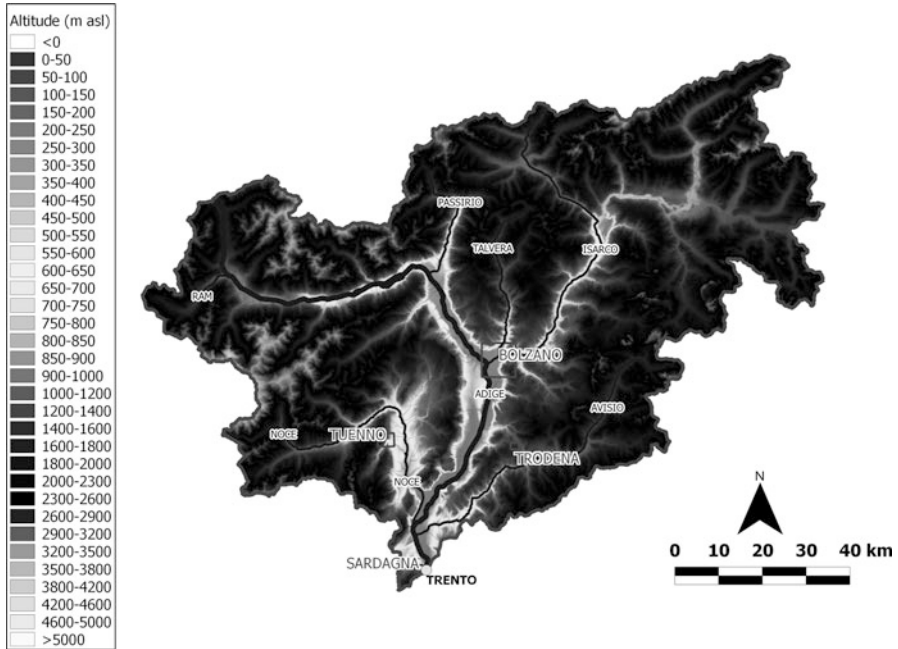


Fig. 3.4 Adige Watershed (digital elevation model), main hydrographic network and investigated areas (Tuenno, Bolzano, Sardagna, Trodena) (Image created with Quantum GIS Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>)

The land use changes that occurred between mid-nineteenth century and present days were analysed on the basis of up-to-date GIS techniques. One of the most evident findings in this investigation was the strong increase of forest extension in the basin. This fact is not surprising since the increase of amount of land covered in forest is well known in Europe. FAO (2011) reports that this increase accounts for more than 15,000 thousands of ha out of 989,000 thousands estimated in 1990. Considering the global situation, FAO (2015) stated that planted forest area has increased by over 110 million ha since 1990 (7% of the world's forest area), with peak growing rates from 2000 to 2010. FAO observations started in 1990, but such a change is observed also in the investigated area, where land use close to Trento and Bolzano in the Adige river basin is compared considering the cadastral maps of the mid-nineteenth century with recent aerial photographs in a sample area and the Corine Land Cover 2006 maps. The comparison between natural and planted forests is an interesting topic and matter of debate among many stakeholders (natural forests play an important role in maintaining biodiversity; planted forests are important for wood production and environmental protection purposes), but the data available for the study were not sufficient to point out this demarcation.

The analysis was based on three main sources: the mid-nineteenth-century land use maps were obtained from the Province of Trento cadastral office and from the web GIS service of the Autonomous Province of Bolzano (South Tyrol), <http://>

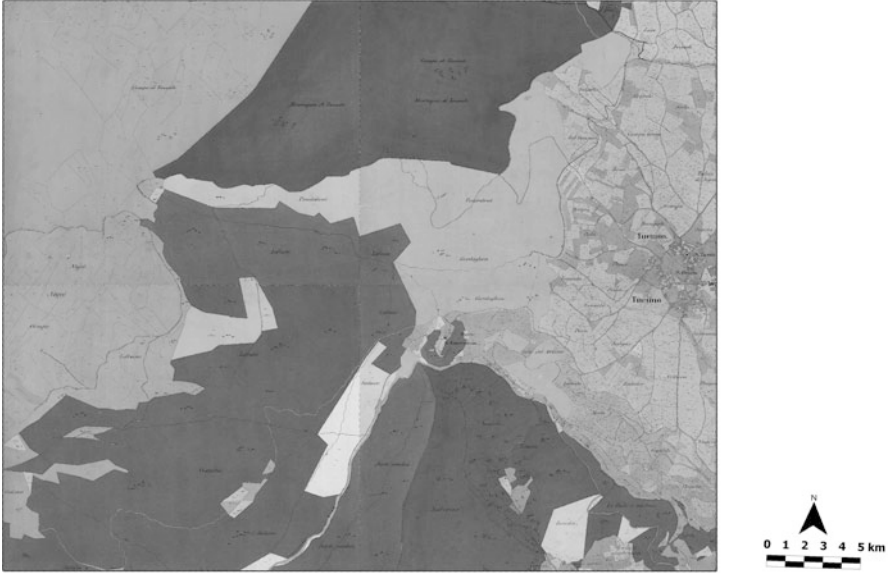


Fig. 3.5 Mid-nineteenth-century cadastral map of the area close to Tuenno (Courtesy of Ufficio Catasto of Provincia Autonoma di Trento)

gis2.provinz.bz.it/geobrowser/. The current land use maps were generated from aerial photographs provided by Google Earth (Image Landsat, © 2009 GeoBasis - DE/BKG, © 2015 Google). To complete the current observable information, the Corine Land Cover 2006 map was used. All the mentioned sources were imported in the Quantum GIS open-source software, redrawn and transformed from the original format to vector polygonal files. Hence, for each watershed subregion, it was possible to create the past and present land use maps and overlap them to precisely quantify the land use variation in more than 150 years. In Figs. 3.5, 3.6, 3.7 and 3.8, the start and end points of this process are shown. The Tuenno area (1150 ha) is represented as drawn in the digitalised cadastral map in Fig. 3.5. In Fig. 3.6 the same area is shown, illustrating the present-day situation. Both images were then manually converted into vector shape files: Figs. 3.7 and 3.8 can be observed to appreciate this transformation. The same colours were used for identical land uses in the two ages, to appreciate the similarities and the changes occurred.

Considering the Tuenno area, which covers more than 1150 ha, forested areas changed from 45.52 to 60.67 %. The most part of the gained area derived from the abandoned pastures that totally disappeared during the considered period. The percentage increase of urbanised area was significant but negligible in absolute terms considering the whole extent. The grasslands halved, one part contributing to the crops' increase and the other part to the forest's increase. Also the noncultivated areas are more than doubled. The past and present uses of the land in percentage, together with the land use migrations, are shown in Table 3.2. In the second column,



Fig. 3.6 Current aerial photograph of the area close to Tuenno (Trento, Italy). The territory included in the *light grey box* corresponds to the same area in Fig. 3.5. © 2015 Cnes/Spot Image, © 2009 GeoBasis – DE/BKG, © 2015 Google

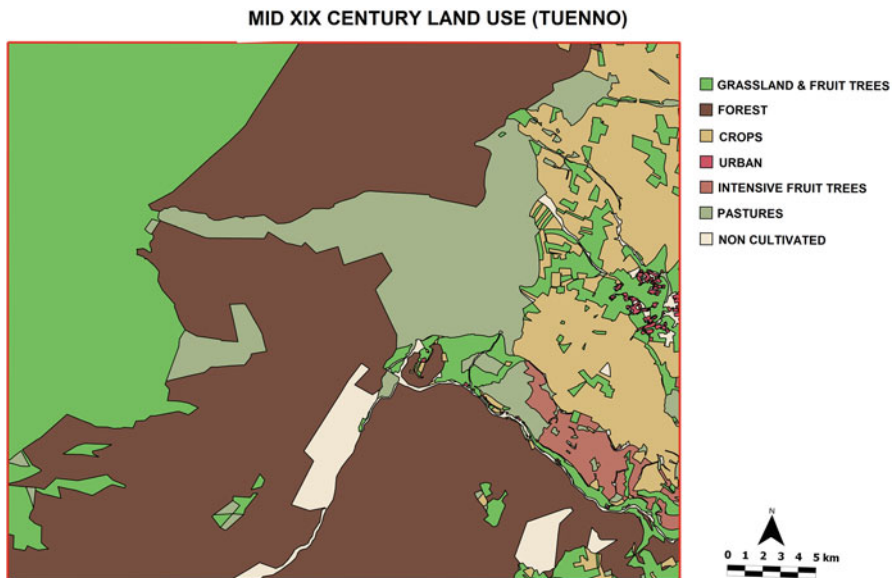


Fig. 3.7 Mid-nineteenth-century cadastral map of the area close to Tuenno (Trento, Italy) converted in a polygonal vector file (Image created with Quantum GIS (Quantum GIS Development Team, 2015). Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>)

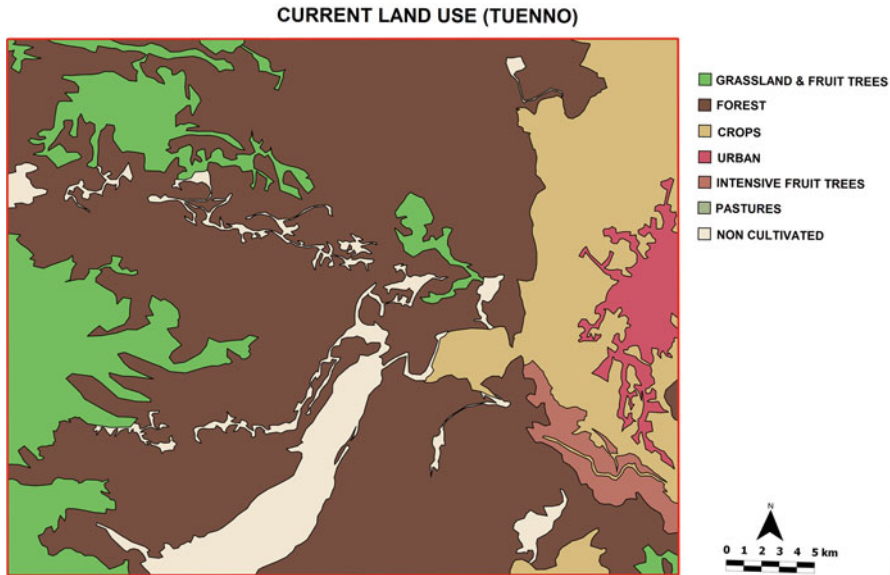


Fig. 3.8 Current aerial photograph of the area close to Tuenno (Trento, Italy) converted in a polygonal vector file (Image created with Quantum GIS (Quantum GIS Development Team 2015). Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>)

the mid-nineteenth-century land use is listed; in the second row, the current land use is represented. In the mid-cells, each variation is quantified. In the last column and row, the total lost and gained extents for each land use category are shown. For example, in the mid-nineteenth century, forests covered 45.52 % of the total area. Reading the corresponding row, we can see that 0.16 % of the total area is now occupied by crops, 2.23 % by grassland (with minor presence of fruit trees) and 4.20 % by noncultivated lands; current urbanised (and, obviously, pasture) areas didn't gain territories from the forests. On the other hand, we can observe the column corresponding to the current extension of the forests (60.67 %) observing that 0.03 % was gained from previously urbanised areas, 0.15 % from crops, 11.67 % from grassland (with minor presence of fruit trees), 0.06 % from intensive cultivation of fruit trees, 9.14 % from pastures and 0.79 from noncultivated areas. The comparison between past and present land use is shown in the chart of Fig. 3.9.

The same analysis was conducted in three other sample areas representative of different geographical conditions. The land use alterations for the area close to Sardagna are shown in Fig. 3.10. Here the percentage land use changes over the past 150 year are computed for a mountain area of 256 ha (with altitude ranging between 600 and 1200 m a.s.l.): it is evident how significant was the land use change from grassland, agricultural and fruit crops to forests. Forested areas increased from 52.07 % in the mid-nineteenth century to the present 77.80 %, with a growth of urbanised area from 1.02 to 10.95 % and a reduction of agricultural crops from 19.89 to 9.46 %.

Table 3.2 Percentage land use changes in the area close to Tuenno (Trento, Italy)

		Present land use (% out of 11.50 km ²)										
		2.85	14.14	13.33	60.67	1.92	0.00	7.10				
		Urban	Crops	Grass-land & fruit trees	Forest	Intensive fruit trees	Pastures	Non cultivated	Lost area (%)			
Mid nineteenth century land use (% out 11.50 km ²)	Total area 100 %	0.23	0.00	0.00	0.03	0.00	0.00	0.00	0.03			
	Urban	-	0.00	0.00	0.03	0.00	0.00	0.00	0.03			
	Crops	1.46	-	0.03	0.15	0.14	0.00	0.03	0.03			
	Grass-land & fruit trees	0.88	3.25	-	11.67	0.38	0.00	0.49	16.67			
	Forest	0.00	0.16	2.23	-	0.00	0.00	4.20	6.59			
	Intensive fruit trees	0.00	0.37	0.00	0.06	-	0.00	0.00	0.43			
	Pastures	0.03	0.77	1.12	9.14	0.16	-	0.71	11.93			
	Non cultivated	0.27	0.23	0.00	0.79	0.03	0.00	-	1.32			
	Gained area (%)		2.64	4.77	3.38	21.84	0.71	0.00	5.43			

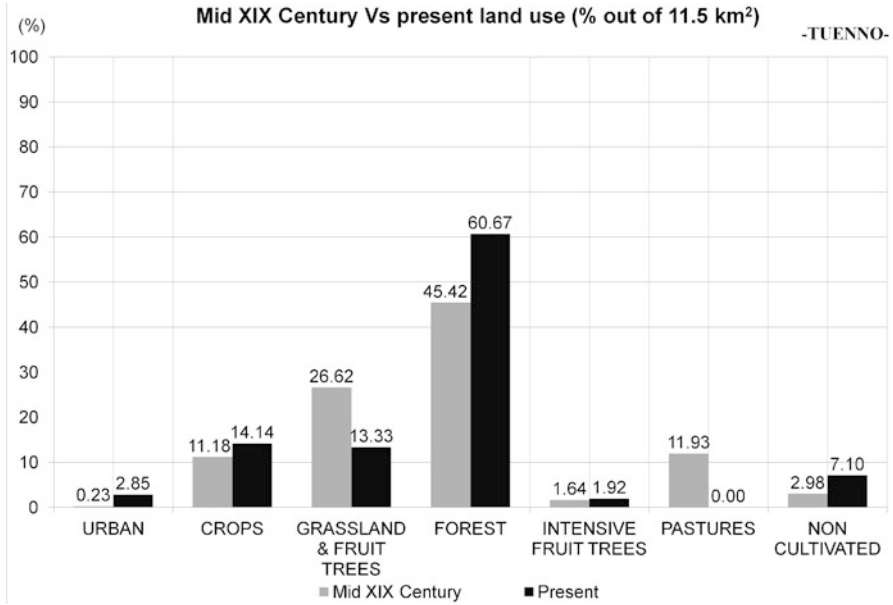


Fig. 3.9 Comparison between the mid-nineteenth century and the present land use in the area close to Tuenno (Trento, Italy)

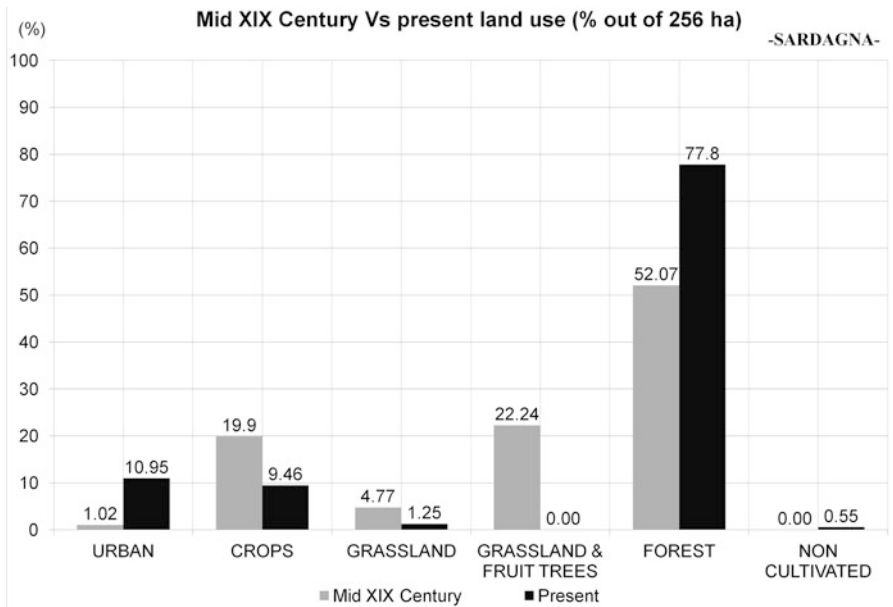


Fig. 3.10 Comparison between the mid-nineteenth century and the present land use in the area close to Sardagna (Trento, Italy)

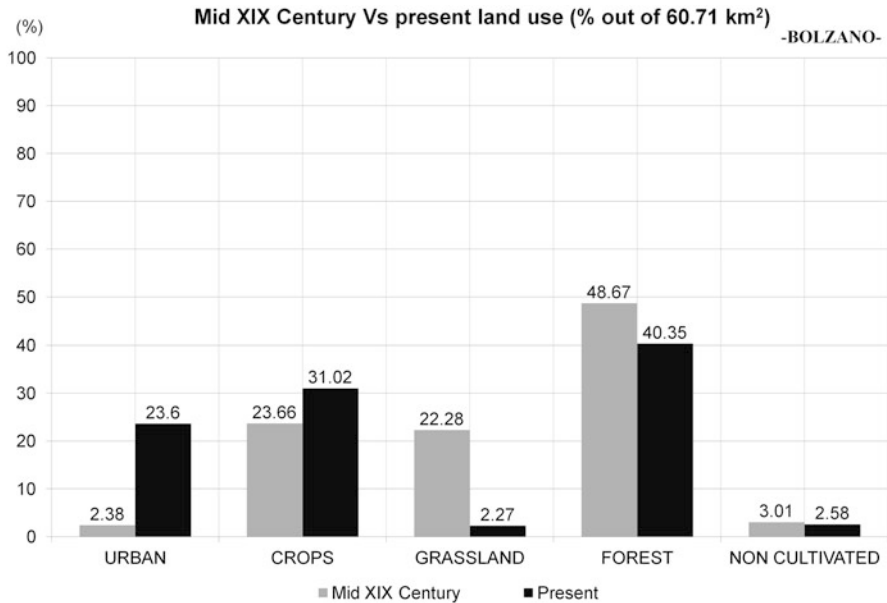


Fig. 3.11 Comparison between the mid-nineteenth century and the present land use in the area close to Bolzano (Italy)

Considering an old rural district, now transformed into a medium-size city (Bolzano), forested areas only changed from 48.67 % in the mid-nineteenth century to the present 40.35 %. The increase of urbanised area was substantial, instead: from 2.38 to 23.60 %. The agricultural crops increased from 23.66 to 31.02 % in the analysed area, while grasslands and pastures strongly decreased (see Fig. 3.11).

The land use in the mid-nineteenth-century cadastral maps was then compared with the present situation in the mid-mountain area of the Adige river basin close to Trodena (see Fig. 3.12). Here forested areas changed radically from 11.50 % in the mid-nineteenth century to a surprising current value of 86.90 %.

On the basis of the analysis conducted over the Adige watershed, the forest expansion occurring in the last decades in Europe can be confirmed. Under the hydrologic point of view, the resulting increase of evapotranspiration and interception losses from forests is one of the possible reasons of the runoff decrease.

3.5 Closing Remarks

Time series of annual runoff for the five major river basins in the Central Italian Alps were collected and analysed for trend detection applying three statistical tests. Trend analyses show a decreasing trend of mean annual runoff for all the investigated basins, significant at 5 % level according to a Mann-Kendall test for some of the

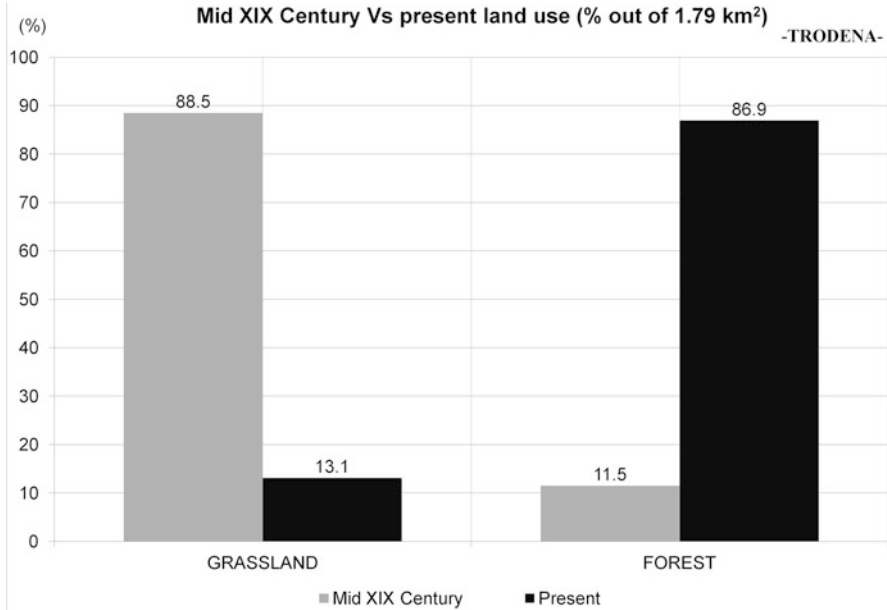


Fig. 3.12 Comparison between the mid-nineteenth century and the present land use in the area close to Trodena (Bolzano, Italy)

basins only. As the pattern of runoff decrease is similar for the Adige, Mincio, Oglio, Adda and Ticino rivers, the null hypothesis that a constant decreasing trend of $\beta = -1.26 \text{ mm year}^{-1}$ is exhibited by all the series was tested with the Sen-Adichie test. The hypothesis is not rejected with a 5 % significance level and the confidence limits of $\beta_1 = -1.79 \text{ mm year}^{-1}$ to $\beta_2 = -0.84 \text{ mm year}^{-1}$ were estimated. To look for possible reasons of such a decrease of runoff, the climatology of precipitation and temperature was analysed resulting in a slight, not statistically significant decrease of precipitation in the Adige and Adda river basins and a $+1 \text{ }^\circ\text{C/century}$ increase of air temperature over the 1862–2011 period, which can be a reason of major evapotranspiration losses.

These losses can be enhanced also by the afforestation of areas previously dedicated to agriculture and pasture. An example of the analysis conducted on four representative areas with different altitudes and levels of urbanisation was presented. Considering the mountain area near Trodena, forested areas changed from 11.50 % in the mid-nineteenth century to a surprising current value of 86.90 %, with grassland having an opposite land use change. In other mid-altitude areas, the pattern is similar. In another area with altitude ranging between 600 and 1200 m.a.s.l., forested areas changed from 52.07 % in the mid-nineteenth century to the present 77.80 %, with an increase of urbanised area from 1.02 to 10.95 % and a reduction of agricultural crops from 19.89 to 9.46 % of the analysed area. The

resulting increase of evapotranspiration and interception losses from forests is one of the possible reasons of the runoff decrease observed in the Adige basin and in the other investigated basins as well.

Thus anthropogenic effects, as land use changes, are factors to be included in both analyses of trends and development of adaptation and mitigation measures to climate change.

Appendices

Appendix A: Estimation of the Regression Line

According to Theil-Sen estimator (Theil 1950a, b, c; Sen 1968; Hollander et al. 2014), trend slope can be computed as

$$\widehat{\beta} = \text{median} (S_{ij}, 1 \leq i < j \leq n), \quad (\text{A.1})$$

where S_{ij} denote the $N = n(n-1)$ individual slopes between values Y_i and Y_j of the series, corresponding to time positions x_i and x_j :

$$S_{ij} = \frac{Y_j - Y_i}{x_j - x_i}. \quad (\text{A.2})$$

To calculate (A.1) the sample slopes S_{ij} are ranked in ascending order $S^{(1)} \leq \dots \leq S^{(N)}$; then

$$\widehat{\beta} = S^{(k+1)}, \quad N \text{ odd} \quad (N = 2k + 1) \quad (\text{A.3})$$

$$\widehat{\beta} = \frac{S^{(k)} + S^{(k+1)}}{2}, \quad N \text{ even} \quad (N = 2k). \quad (\text{A.4})$$

Accordingly, the intercept of the regression line can be estimated as (Hollander et al. 2014)

$$\widehat{\alpha} = \text{median} (A_1, \dots, A_n), \quad A_i = Y_i - \widehat{\beta}x_i. \quad (\text{A.5})$$

In this way, if $A^{(1)} \leq \dots \leq A^{(n)}$ denote the ordered A_i values,

$$\widehat{\alpha} = A^{(k+1)}, \quad n \text{ odd} \quad (n = 2k + 1) \quad (\text{A.6})$$

$$\widehat{\alpha} = \frac{A^{(k)} + A^{(k+1)}}{2}, \quad n \text{ even} \quad (n = 2k). \quad (\text{A.7})$$

Appendix B: Confidence Interval for the Trend Slope

A symmetric two-sided confidence interval for the trend slope can be obtained in terms of the upper $(\alpha/2)$ th percentile $k_{\alpha/2}$ of the null distribution of the Kendall statistic (Hollander et al. 2014):

$$C = \sum_{i=1}^{n-1} \sum_{j=1+1}^n \text{sign}(D_j - D_i), \quad D_s = Y_s - \widehat{\beta}x_s. \quad (\text{B.1})$$

Setting $C_\alpha = k_{\alpha/2} - 2$ and

$$M = \frac{N - C_\alpha}{2}, \quad Q = \frac{N + C_\alpha}{2} = M + C_\alpha \quad \text{with } N = \frac{n(n-1)}{2} \quad (\text{B.2})$$

the $(1-\alpha)$ confidence interval (β_L, β_U) is given by

$$\beta_L = S^{(M)}, \quad \beta_U = S^{(Q+1)} \quad (\text{B.3})$$

according to the notation of Appendix A.

For large n , the following approximation can be used:

$$C_\alpha \approx z_{\alpha/2} \left[\frac{n(n-1)(2n+5)}{18} \right]^{1/2}, \quad (\text{B.4})$$

where $z_{\alpha/2}$ denotes the upper $(\alpha/2)$ th percentile of the standard normal distribution. In general, Eq. (B.4) provides a noninteger value; in this case the integer part of the right-hand side can be used.

Appendix C: Test for the Parallelism of Several Regression Lines

The null hypothesis H_0 is that k regression lines have a common, but unspecified slope β :

$$H_0 : [\beta_1 = \dots = \beta_k = \beta, \quad \text{with } \beta \text{ unspecified}]. \quad (\text{C.1})$$

The first step is to obtain an estimate of the common slope β under the null hypothesis (C.1); to this purpose, the following pooled least squares estimator is used:

$$\bar{\beta} = \frac{\sum_{i=1}^k \sum_{j=1}^{n_i} (x_{ij} - \bar{x}_i) Y_{ij}}{\sum_{i=1}^k \sum_{j=1}^{n_i} (x_{ij} - \bar{x}_i)^2}, \quad \bar{x}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} x_{ij}, \quad (\text{C.2})$$

where Y_{ij} is the value of the i -th response variable Y_i corresponding to the value x_{ij} and the i th independent variable x_i (for $i = 1, \dots, k$).

Then for each of the k regression lines, the aligned observations can be computed as

$$Y_{ij}^* = Y_{ij} - \bar{\beta} x_{ij} \quad i = 1, \dots, k; \quad j = 1, \dots, n_i, \quad (\text{C.3})$$

whose rank in the i th regression sample is denoted by r_{ij}^* .

Setting

$$T_i^* = \frac{\sum_{j=1}^{n_i} (x_{ij} - \bar{x}_i) r_{ij}^*}{n_i + 1}; \quad i = 1, \dots, k \quad (\text{C.4})$$

and

$$C_i^2 = \sum_{j=1}^{n_i} (x_{ij} - \bar{x}_i)^2; \quad i = 1, \dots, k, \quad (\text{C.5})$$

the Sen-Adichie statistic V is given by

$$V = 12 \sum_{i=1}^k \left[\frac{T_i^*}{C_i} \right]^2. \quad (\text{C.6})$$

Under the null hypothesis (C.1), V is asymptotically distributed as a chi-square with $k-1$ Degrees of freedom (Sen 1969). This implies that hypothesis (C.1) versus the alternative

$$H_1 : [\beta_1, \dots, \beta_k \text{ not all equal}] \quad (\text{C.7})$$

has to be rejected at the level of significance α if

$$V \geq \chi_{k-1, \alpha}^2 \quad (\text{C.8})$$

where $\chi_{k-1, \alpha}^2$ is the upper α th percentile of a chi-square distribution with $k-1$ degrees of freedom (Adichie 1976, 1984; Hollander et al. 2014).

References

- Adichie JN (1976) Testing parallelism of regression lines against ordered alternatives. *Commun Stat Theory Methods* 5(11):985–997
- Adichie JN (1984) Rank tests in linear model. In: Krishnaiah PR, Sen PK (eds) *Handbook of statistics 4: nonparametric methods*. North Holland, Amsterdam, pp 229–257
- Auer I, Böhm R, Jurkovic A, Lipa W, Orlik A, Potzmann R, Schoener W, Ungersboeck M, Matulla C, Briffa K, Jones P, Efthymiadis D, Brunetti M, Nanni T, Maugeri M, Mercalli L, Mestre O, Moisselin J-M, Begert M, Mueller-Westermeier G, Kveton V, Bochnicek O, Stastny P, Lapin M, Szalai S, Szentimrey T, Cegnar T, Dolinar M, Gajic-Capka M, Zaninovic K, Majstorovic Z, Nieplova E (2007) HISTALP – historical instrumental climatological surface time series of the Greater Alpine Region. *Int J Climatol* 27:17–46. doi:10.1002/joc.1377
- Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (eds) (2008) *Climate change and water*. Technical paper VI of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva
- Blöschl G, Montanari A (2010) Climate change impacts: throwing the dice? *Hydrol Process* 24(3):374–381, 6693. doi: 10.1002/hyp.7574
- Brunetti M, Lentini G, Maugeri M, Nanni T, Auer I, Böhm R, Schöner W (2009) Climate variability and change in the Greater Alpine Region over the last two centuries based on multi-variable analysis. *Int J Climatol* 29(15):2197–2225. doi:10.1002/joc.1857
- FAO (2011) *State of the world's forests, 2011*. Food and Agriculture Organization of the United Nations, Rome (available at <http://www.fao.org/docrep/013/i2000e/i2000e00.htm>)
- FAO (2015) *Global forest resources assessment 2015: how are the world's forests changing?* Food and Agriculture Organization of the United Nations, Rome (available at <http://www.fao.org/3/a-i4793e.pdf>)
- Gerhard LC (2006) Climate change: conflict of observational science, theory, and politics: reply. *AAPG Bull* 90(3):409–412. doi:10.1306/11030505107
- Hollander M, Wolfe DA, Chicken E (2014) *Nonparametric statistical methods*, 3rd edn. Wiley & Sons, New York
- IPCC (2013) *Climate change 2013: the physical science basis*. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK/New York, 1535 pp
- Kendall MG (1970) *Rank correlation methods*, 4th edn. Griffin, London
- Koutsoyiannis D, Efstratiadis A, Mamassis N, Christofides A (2008) On the credibility of climate predictions. *Hydrol Sci J* 53(4):671–684. doi:10.1623/hysj.53.4.671
- Kumar S, Merwade V, Kam J, Thurner K (2009) Streamflow trends in Indiana: effects of long term persistence, precipitation and subsurface drains. *J Hydrol* 374:171–183. doi:10.1016/j.jhydrol.2009.06.012
- Labat D, Godderis Y, Probst J, Guyot J (2004) Evidence for global runoff increase related to climate warming. *Adv Water Resour* 27(6):631–642. doi:10.1016/j.advwatres.2004.02.020
- Legates DR, Lins HF, McCabe GJ (2005) Comments on “Evidence for global runoff increase related to climate warming”. *Adv Water Resour* 28:1310–1315. doi:10.1016/j.advwatres.2005.04.006
- Liu D, Chen X, Lian Y, Liu Z (2010) Impacts of climate change and human activities on surface runoff in the Dongjiang River basin of China. *Hydrol Process* 24:1487–1495. doi:10.1002/hyp.7609
- Mann HB (1945) Nonparametric tests against trend. *Econometrica* 13(3):245–259
- McCuen RH (2003) *Modeling hydrologic change*. Lewis Publishers, Boca Raton
- Moisello U, Vullo F (2009) I massimi di portata dell'Adda a Lecco. *L'Acqua* 6:9–27
- Montanari A, Young G, Savenije HHG, Hughes D, Wagener T, Ren LL, Koutsoyiannis D, Cudennec C, Toth E, Grimaldi S, Blöschl G, Sivapalan M, Beven K, Gupta H, Hipsev M, Schaeffli B, Arheimer B, Boegh E, Schymanski SJ, Di Baldassarre G, Yu B, Hubert P, Huang Y, Schumann A, Post DA, Srinivasan V, Harman C, Thompson S, Rogger M, Viglione A,

- McMillan H, Characklis G, Pang Z, Belyaev V (2013) “Panta Rhei—Everything Flows”: change in hydrology and society—The IAHS Scientific Decade 2013–2022. *Hydrol Sci J* 58(6):1256–1275. doi:[10.1080/02626667.2013.809088](https://doi.org/10.1080/02626667.2013.809088)
- Ranzi R (2012) Climate and anthropogenic change impact on the hydrological cycle, water management and engineering. In: Proceedings of 4th International Conference on Estuaries and Coasts, Hanoi, 8–11 October 2012, Science and Technics Publishing House, Hanoi (Vietnam), vol 2, pp. 439–446
- Ranzi R, Barontini S (2010) Are there evidences of the impacts of global warming on runoff regimes in the Southern Alps. In: Proceedings of the international workshop on impacts of global warming from hydrological and hydraulics issues, Kyoto, 16 March 2010, pp 1–6
- Ranzi R, Bochicchio M, Bacchi B (2002) Effects on floods of recent afforestation and urbanisation in the Mella River (Italian Alps). *Hydrol Earth Syst Sci* 6(2):239–253
- Ranzi R, Nalder G, Abdalla AA, Ball J, De Costa GS, Galvão C, Jia Y, Kim YO, Kolokytha E, Lee SI, Nakakita E, Nguyen VTV, Paquier A, Patel PL, Peviani MA, Teegavarapu R (2015) Summary of recommendations for policymakers on adaption to climate change in water engineering. *Hydrolink* 3:93–95
- Sen PK (1968) Estimates of the regression coefficient based on Kendall’s tau. *J Am Stat Assoc* 63(324):1379–1389
- Sen PK (1969) On a class of rank order tests for the parallelism of several regression lines. *Ann Math Stat* 40(5):1668–1683
- Spearman C (1904) The proof and measurement of association between two things. *Am J Psychol* 15(1):72–101
- Theil H (1950a) A rank-invariant method of linear and polynomial regression analysis, I. Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen Series A 53:386–392
- Theil H (1950b) A rank-invariant method of linear and polynomial regression analysis, II. Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen Series A 53:521–525
- Theil H (1950c) A rank-invariant method of linear and polynomial regression analysis, III. Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen Series A 53:1397–1412
- UNFCCC–United Nations Framework Convention on Climate Change (2015) Adoption of the Paris Agreement. <http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf>, 32 pp
- Wilcox RR (2010) Fundamentals of modern statistical methods, 2nd edn. Springer, New York
- Yue S, Pilon P, Cavadias G (2002) Power of the Mann-Kendall and Spearman’s rho tests for detecting monotonic trends in hydrological series. *J Hydrol* 259(1–4):254–271. doi:[10.1016/S0022-1694\(01\)00594-7](https://doi.org/10.1016/S0022-1694(01)00594-7)
- Zhang C, Zhang B, Li W, Liu M (2014) Response of streamflow to climate change and human activity in Xiaoxi river basin in China. *Hydrol Process* 28:43–50. doi:[10.1002/hyp.9539](https://doi.org/10.1002/hyp.9539)
- Zolezzi G, Bellin A, Bruno MC, Maiolini B, Siviglia A (2009) Assessing hydrological alterations at multiple temporal scales: Adige River, Italy. *Water Resour Res* 45(12): W12421-1–W12421-15. doi: [10.1029/2008WR007266](https://doi.org/10.1029/2008WR007266)