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# Climate impact assessment to the groundwater levels based on long time-series analysis in a paddy field area (Piedmont region, NW Italy): preliminary results

## *Valutazione dell'impatto climatico sui livelli delle acque sotterranee basata sull'analisi di lunghe serie temporali in un'area di risaia (Piemonte, Italia occidentale): risultati preliminari*

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### Riassunto

L'analisi delle serie temporali del livello piezometrico delle acque sotterranee è estremamente importante per osservare il comportamento di queste nel tempo e per identificare eventuali situazioni critiche.

L'area in esame consiste di un distretto agricolo caratterizzato da risaie, situato nella parte orientale del Piemonte, al confine con la Lombardia. In quest'area sono state raccolte lunghe serie temporali del livello delle acque sotterranee, a partire dagli anni '60, in 16 pozzi. I dati raccolti hanno una buona completezza, nella maggior parte dei casi >90%.

Per prima cosa è stato studiato il comportamento idrodinamico delle acque sotterranee, basato sui livelli della falda, per evidenziare la risposta delle acque sotterranee alla ricarica. Per fare ciò, è stata eseguita un'analisi statistica di base (media, mediana, deviazione standard, massimi e minimi) grazie alla quale sono stati valutati i trend dei livelli di falda per osservare meglio il comportamento a lungo termine.

Queste analisi hanno permesso di osservare un comportamento idrodinamico delle acque sotterranee caratterizzato da un andamento annuale ripetitivo dei livelli (con un minimo in febbraio/marzo e un massimo in agosto/settembre), in corrispondenza al periodo di irrigazione.

Inoltre, l'analisi dei trend ha evidenziato la presenza sia di pozzi con falda in diminuzione (con un abbassamento massimo di 4,3 m in 60 anni), sia di pozzi con falda in aumento (con innalzamenti massimi di 2,8 m in 35 anni). Inoltre, nella maggior parte dei casi, si può osservare che tutte e tre le tendenze analizzate concordano nell'essere positive o negative.

I futuri approfondimenti del lavoro riguarderanno il confronto di queste serie temporali con i dati meteorologici e l'indagine di altri fattori (ad esempio il prelievo antropico, le variazioni delle pratiche colturali e di irrigazione, la geologia del sottosuolo) per comprendere al meglio le cause delle fluttuazioni e delle tendenze della falda.

### *Abstract*

*The analysis of the time-series of groundwater level are extremely important to observe the behaviours of groundwater over time and to identify any critical situations.*

*The studied area is an agricultural district characterised by paddy fields, located in the eastern part of Piedmont, on the border with Lombardy. In this area long time-series of groundwater level, starting from the 1960s, have been collected in 16 wells.*

*Water table data have a good completeness (in the majority of the cases >90%).*

*Firstly, the groundwater hydrodynamic behaviour, based on water table levels, was investigated to highlight the response of groundwater to the recharge. A basic statistical analysis was performed (mean, median, standard deviation, maximum, minima), and then trends of water table levels were evaluated in order to better observe the long-term behaviour of groundwater.*

*These analyses allowed to observe a groundwater hydrodynamic behaviour characterised by a repeating annual pattern (minimum in February/March and maximum in August/September) in correspondence to the period of irrigation.*

*Moreover, trend analysis highlighted the presence of both wells with a decreasing water table (with maximum lowering of 4.3 m in 60 years) and wells with an increasing water table (with maximum rises of 2.8 m in 35 years). Furthermore, in most cases, it can be observed that all three trends analysed agree on being positive or negative.*

*Future insights will be the comparison of these long time-series with the meteorological data, and the investigation of other factors (e.g. anthropic withdrawal, variations of cultivation practices and irrigation, geology of the subsoil) to better understand the causes of the water table fluctuations and trends.*

## Introduction

Starting from the 20th century groundwater (GW) has become an essential resource to support the constant development of mankind (Alley et al. 2017). However, it is known that GW temperature (GWT) responds to climate variations and this make the aquifers, especially the shallow ones, vulnerable to future climate scenarios (Allen et al. 2004; Alley 2001; Arnell 1998; Bastiancich et al. 2021; Beretta 2021; Colombani et al. 2016; Mastrocicco et al. 2018).

The aim of this paper is to explore how climatic variability in northern Italy could affect groundwater in a paddy field area located in eastern part of the Piedmont Region, at the border with the Lombardy Region. In fact, it has been observed in various parts of the world (Liu C 2022; Liu Y 2022; Wang 2022), and also in the study area (Lasagna et al. 2020b, 2020a; Mancini et al. 2022), that rice cultivation was lately affected by qualitative and quantitative variations in GW, since it uses an agricultural technique that makes heavy use of water resources.

In this study the trends of the phreatic level of the shallow unconfined aquifer were elaborated. More specifically, 16 long time-series of GW level in monitoring wells were collected and analysed. Nine of them consists of more than 60 years of measurements (from the mid-1950s to 2019) and seven of about 40 years of measurements (from the 1980s to 2019).

Moreover, a comparison between GW trend and rainfall data was performed.

## Study area

Piedmont is an Italian region located in the north western Italy. The Piedmont Po plain covers almost the 27% of the territory of the Piedmont region (De Luca et al. 2020) and, due to its size, is considered the greatest reservoir of GW of the region (Castagna et al. 2015; Debernardi et al. 2008).

The study area is located entirely within the boundaries of the Piedmont Region, between the provinces of Novara and Vercelli (Fig. 1). In particular, it covers the area around the city of Novara, part of the Novara plain and a small portion of the city of Vercelli. The area is included within the East Sesia Irrigation and Reclamation Consortium ("Est Sesia – Consorzio di irrigazione e bonifica" 2022). This is Italy's largest irrigation consortium, with 25000 consortium members, and it is responsible for managing and connecting the different paddy field owners in the area between Piedomont and Lomabardy regions.

The geomorphology of the area is predominantly flat, with the massive presence of paddy fields, which has changed the landscape of the territory over last centuries, levelling the ground and making necessary to build a dense irrigation network of canals. The main ones are the Cavour Canal and the Quintino Sella Canal, but there are also other smaller canals that are very important for transporting water from the main river (the Sesia River) to the paddy fields.

The whole study area is characterised by a meteorological pattern that shows a summer maximum (mainly in July) and a winter minimum (mainly in January) ("Accesso ai dati - Annali meteorologici ed idrologici - Banca dati meteorologica" 2021; Arpa Piemonte 2021; Lasagna et al. 2020b).

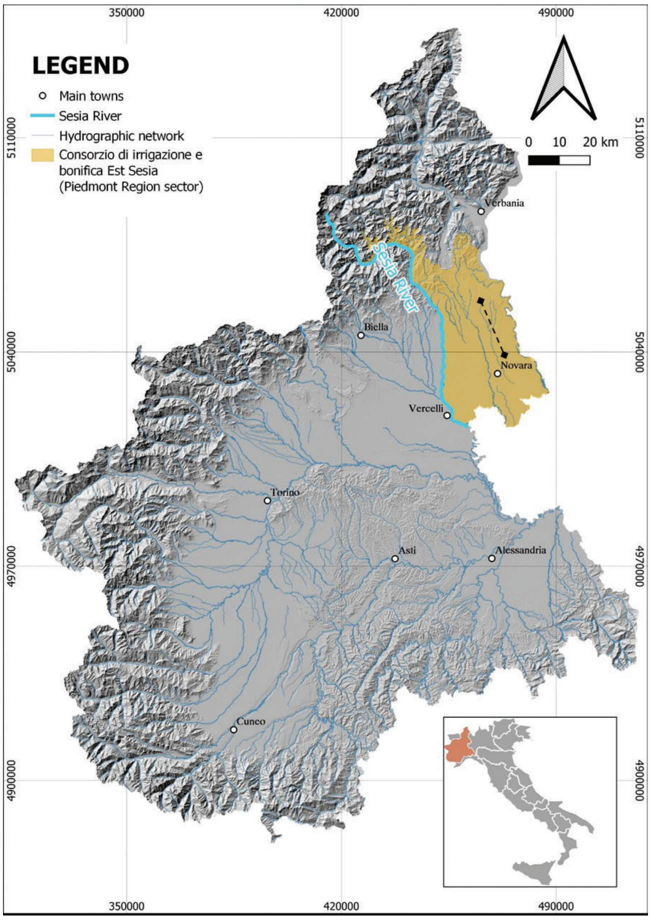

*Fig. 1 - Study area. The figure shows the Piedmont Region (hillshade) and the study area located in the NW sector of the Region is highlighted in orange. The black dashed line indicates the cross-section in Figure 2.*

Fig. 1 - Area di studio. In figura è raffigurata la Regione Piemonte (*hillshade*) ed è evidenziata in arancio l'area di studio che si trova nel settore NW della Regione. La linea nera tratteggiata indica la cross-section della Figura 2.

The 16 monitoring wells are located in the shallow unconfined aquifer of the region constituted by alluvial deposits (coarse gravels and sands of fluvial or fluvioglacial origin, with some intercalations of silty clay) with a thickness varying between 20 and 50 metres, an hydraulic conductivity between 5 e10$^{-4}$ to 5 e10$^{-3}$ m/s and a water table depth between 0 and 20 metres (De Luca et al. 2020). Separation from underlying deposits is represented by the presence of local thick and continuous layers of silt and/or clay rich deposits (Irace et al. 2009). Under this aquifer there are the Villafranchiano transitional deposits and then the Pliocenic marine deposits (Fig. 2).

## Material and methods

The time series of phreatic level were collected in 16 monitoring wells. According to the start date of data collection, the monitoring points can be divided into two

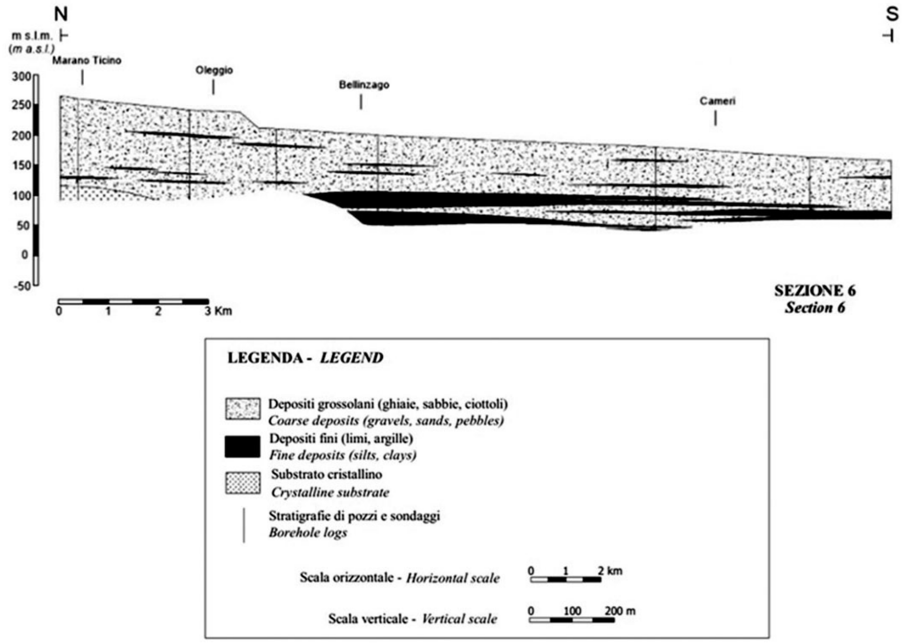

*Fig. 2 - Typical cross-section of hydrogeological complexes in the study area (modified from De Luca et al. 2020). The cross-section trace shown in figure is presented as a dashed black line in Figure 1.*

Fig. 2 - Sezione trasversale tipica dei complessi idrogeologici dell'area di studio (modficata da De Luca et al., 2020). La traccia della cross-section rappresentata in figura è presente in Figura 1 come linea nera tratteggiata.

categories (Fig. 3):

1. type I: 9 time series, starting from the late 1950s / early 1960s;
2. type II: 7 time series, starting from the early 1980s.

For both categories, the available preatic levels data are manually measured every 3 to 5 days, for a total of about 5 to 7 data per month. For this reason, data were elaborated to calculate a mean monthly GW level, to have comparable data throughout the entire time series.

The data of the rainfall time series were picked from the MeteoWeb database of the Arpa Piemonte ("Accesso ai dati - Annali meteorologici ed idrologici - Banca dati meteorologica" 2021) and refer to the only weather station of this database in the study area, located in Cameri (see Fig. 3). These data are daily measurements of the cumulated rainfall expressed in mm, and, to facilitate the comparison with the GW level data, it has been chosen to observe the monthly cumulated rainfall.

For these data, the monitored time interval available was found to be from the late 1980s to 2020 and, for this reason, the comparison between the rainfall data and the phreatic levels data has been done only for this time interval.

Phreatic levels were plotted vs. time to observe the hydrodynamic behaviour of groundwater.

Then the same data were studied with basic statistical analyses (mean, maximumphrea, minimum). Moreover, trends and slopes of the data series were calculated with the ProUCL software (Singh et al. 2007) using the non-parametrical Mann-Kendall (Kendall 1955; Mann 1945) and the Theil-Sen (Sen 1968) methods, as also performed in previous similar works (Franzke et al. 2022; Helsel et al. 2020; Mancini et al. 2022; Yue and Wang 2002).

In this investigation, the Mann-Kendall test was used to identify statistically significant positive or negative monotonic

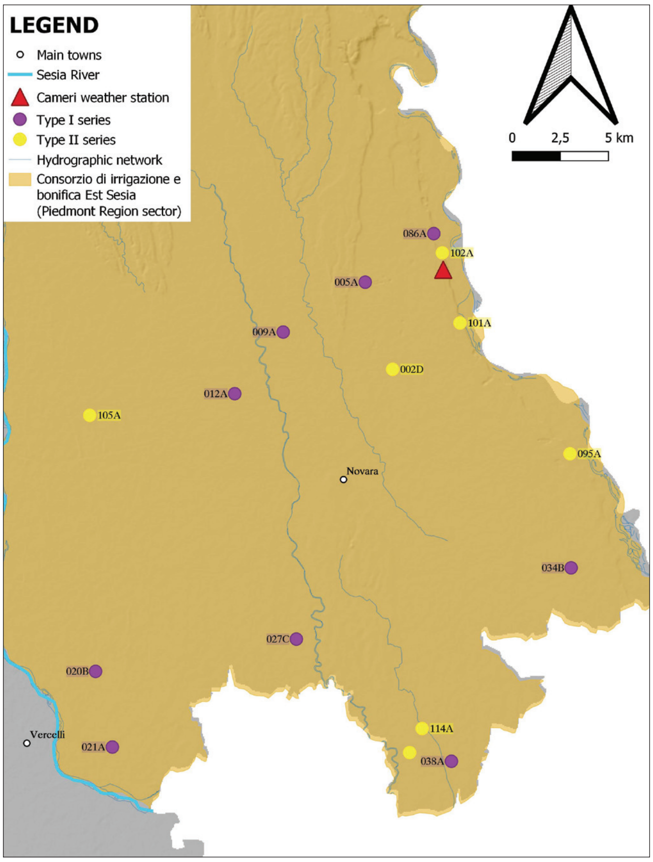

*Fig. 3 - Detail of the study area with location of monitoring wells divided into the two categories. Purple shows Type I wells (historical series beginning in the late 1950s/early 1960s); yellow shows Type II wells (historical series beginning in the early 1980s). Also highlighted with the red triangle is the weather station that was used for groundwater and precipitation comparisons.*

Fig. 3 - Dettaglio dell'area di studio con localizzazione dei pozzi di monitoraggio suddivisi nelle due categorie. In viola i pozzi di tipo I (serie storica che inizia alla fine degli anni 50/inizio anni 60); in giallo i pozzi di tipo II (serie storica che inizia all'inizio degli anni 80). Inoltre viene evidenziata con il triangolo rosso la stazione meteo che è stata utilizzata per i confronti tra acque sotterranee e precipitazioni.

trends in the time series of GW phreatic levels and the slope estimator of the Theil-Sen permitted us to examine the magnitude of the trends.

First the Mann-Kendall test statistic (S) was calculated according to:

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn\left(X_j - X_k\right) \qquad t = 1 \ldots T$$

with $$sgn(X) = \begin{cases} 1\ if\ X > 0 \\ 0\ if\ X = 0 \\ -1\ if\ X < 0 \end{cases} \qquad \text{and} \qquad X = X_j - X_k$$

Where $X_j$ and $X_k$ are equivalent to the data values at times j and k (with j > k), respectively.

With a value of S>0 there is a positive trend; with a value of S<0 (very low) there is a negative trend. When the $H_0$ (null hypothesis) value is rejected at a level of significance $\alpha$ (0.05) is possible to affirm that data have a statistically significant trend.

After, if it is present a linear trend, to evaluate the magnitude of the slope of the trend line, the Sen's slope estimator ($Q_i$) is used:

$$Q_i = \frac{X_j - X_k}{j - k} \qquad \text{for } i = 1, 2, 3, \ldots n$$

The T-value was defined at a significance level of 5%, and trends were only considered statistically significant for p-values≤0.05.

The same investigations were made for the rainfall time series.

Finally, a comparison between phreatic levels and rainfall was performed using the average annual value. These analyses were performed using rainfall data from the weather station in the area and phreatic levels of two monitoring wells representative of the entire study area: one well is located in the northern part (002D) and one in the southern part (117A). Because of the data from the weather station are measured from the 1980s onwards, the two wells belong to the category of data starting from the 1980s (Type II in Fig. 3).

## Results and discussion

Regarding the basic statistics carried out for the analysis of phreatic levels of monitoring wells, the results are shown in Table 1.

Phreatic levels show a repeating annual pattern, with a minimum in February/March and a maximum in August/September. This hydrodynamic behaviour is very different from other areas of the region (Lasagna et al., 2020b), were the minimum phreatic level is in July-August and the maximum in March-April.

The hydrodynamic behaviour in the study area is clearly linked to the phases of the irrigation process of the paddy fields ("Est Sesia – Consorzio di irrigazione e bonifica" 2022). The water used for agricultural purposes is obtained from rivers in the northern part of the study area and then it is distributed through a network of channels managed by local irrigation authorities (Consorzio d'Irrigazione e bonifica Est Sesia). Flooding starts in early April, and the submersion lasts until August, which is when the paddies are left to gradually dry (Romani,

2008). An example representative of the entire study area is reported in Figure 4.

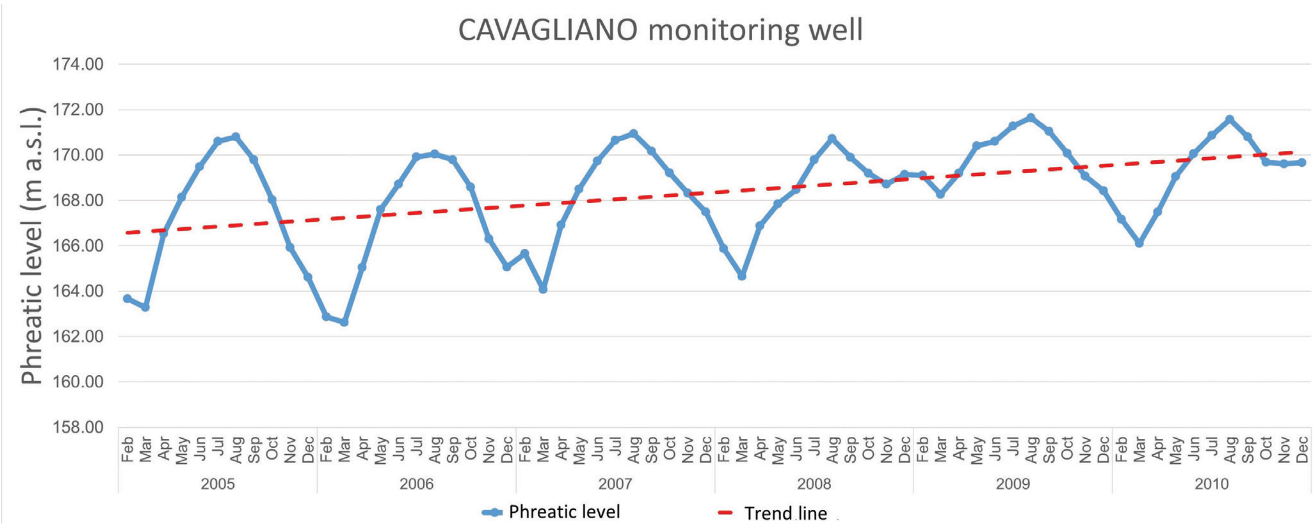

*Fig. 4 - Example of the annual pattern of phreatic level in an analysed monitoring well. Note how the minimum value is reached in February/March and the maximum value is in August/September. The dashed red line represents the trend line of the observed series.*

Fig. 4 - Esempio del pattern annuale del livello freatico in un pozzo di monitoraggio analizzato. Si noti come il valore minimo si raggiunge nei mesi di febbraio/marzo e il valore massimo si ha nei mesi di agosto/settembre. La linea rossa tratteggiata rappresenta la linea di tendenza della serie osservata.

*Tab. 1 - Descriptive statistics of groundwater levels time series in monitoring wells.*

Tab. 1 - Statistiche descrittive delle serie temporali dei livelli delle acque sotterranee nei pozzi di monitoraggio.

| Code | Location | UTM_x | UTM_y | Observed period (yyyy/mm/dd) | Number of years of observation (including partial years) | Annual mean (m) | Annual maximum (m) | Annual minimum (m) |
|---|---|---|---|---|---|---|---|---|
| 002D | Cameri | 473469 | 5038703 | 1981/4/2 - 2017/2/5 | 36.03 | 155.62 | 160.10 | 152.40 |
| 005A | Cavagliano | 472045 | 5043228 | 1956/10/2 - 2015/7/27 | 58.85 | 168.17 | 174.80 | 160.97 |
| 009A | Calatignaga | 467783 | 5040638 | 1960/4/2 - 2019/3/18 | 59.00 | 174.64 | 178.44 | 173.84 |
| 012A | Nibbia | 465265 | 5037437 | 1956/10/2 - 2015/7/25 | 58.85 | 168.00 | 174.80 | 160.90 |
| 020B | Borgo Vercelli | 458037 | 5023018 | 1960/4/2 - 2019/3/18 | 59.00 | 174.64 | 177.00 | 172.10 |
| 021A | Torrione Savarda | 458910 | 5019089 | 1954/2/2 - 2016/12/28 | 62.95 | 119.46 | 120.80 | 118.33 |
| 027C | Monticello | 468467 | 5024693 | 1962/3/2 - 2019/2/12 | 56.99 | 127.57 | 134.08 | 126.59 |
| 034B | Cerano | 482740 | 5028394 | 1959/4/2 - 2019/10/18 | 60.59 | 121.96 | 126.68 | 117.33 |
| 038A | Borgo Levazzaro | 476522 | 5018349 | 1962/3/2 - 2019/2/12 | 56.99 | 126.54 | 132.00 | 124.33 |
| 086A | Molinetto | 475606 | 5045750 | 1962/2/2 - 2011/12/28 | 49.93 | 147.19 | 148.57 | 143.57 |
| 095A | Torre Mandelli | 482681 | 5034319 | 1981/1/5 - 2019/5/18 | 38.39 | 118.88 | 119.21 | 115.90 |
| 101A | Cascina Galdina | 476970 | 5041111 | 1981/1/5 - 2019/9/25 | 38.75 | 133.13 | 133.76 | 132.72 |
| 102A | Molinetto Sud | 476050 | 5044750 | 1981/1/5 - 2011/12/28 | 30.99 | 133.12 | 134.10 | 131.90 |
| 105A | Vicolungo scuole | 457734 | 5036315 | 1980/6/25 - 2019/7/28 | 39.12 | 167.97 | 168.74 | 167.45 |
| 114A | Vespolate | 475000 | 5020050 | 1981/11/2 - 2019/12/12 | 38.13 | 118.31 | 119.48 | 117.18 |
| 117A | Borgo Lazzero | 474350 | 5018800 | 1981/11/2 - 2019/12/8 | 38.12 | 115.50 | 117.05 | 114.15 |

Trend analysis for phreatic levels were conducted using a level of significance of 0.05 for the Mann-Kendall method. The results highlighted the presence of a positive trend in 3 wells (with a maximum increase of 2.8 m in 35 years – 102A, 101A, 002D) and a negative trend in 5 wells (with a maximum decrease of 4.3 m in 60 years – 009A, 095A, 034B, 020B, 021A). In addition, half (9 out of 16 monitoring wells) of the wells observed do not show a statistically significant trend (086A, 005A, 012A, 105A, 027C, 114A, 117A, 038A) (Fig. 5).

More specifically, the only three wells that show a negative trend are located in the southern part of the study area and relate to the longest time series (020B, 021A, 034B).

However, observing the location of the monitoring wells and their evolution time, it was not possible to understand the factors that cause phreatic levels to behave so differently in a relatively small area, even if they are close to each other. Moreover, also the division into the two categories due to the length of the time series is not useful to describe the results.

With regard to rainfall data from the weather station, the

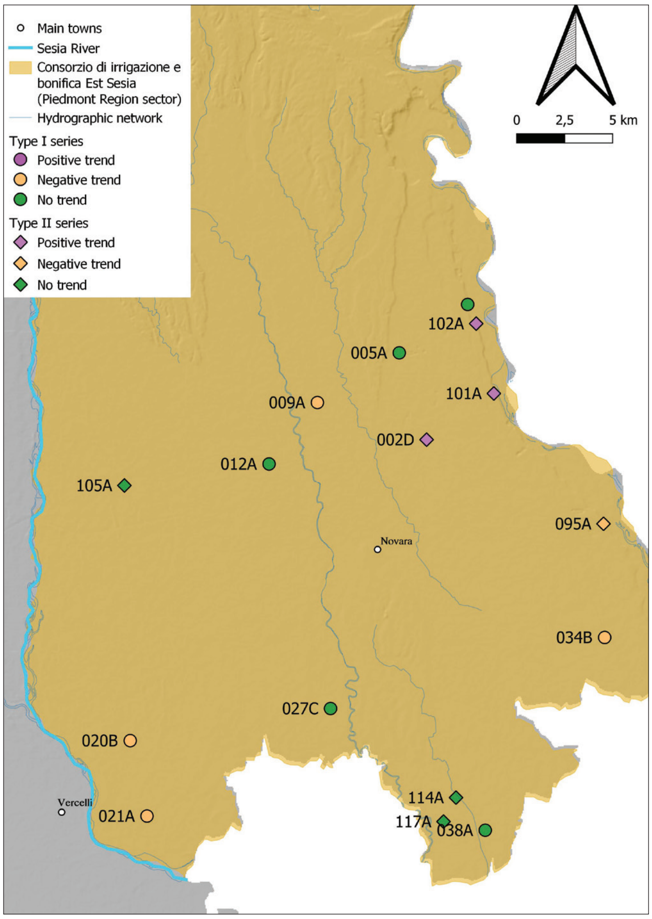

*Fig. 5 - Detail of data on trends in phreatic level trends in the observed monitoring wells. Circle symbol indicates Type I wells and rhombus symbol indicates Type 2 wells.*

Fig. 5 - Dettaglio dei dati relativi agli andamenti dei trend del livello freatico nei pozzi di monitoraggio osservati. Con il simbolo del cerchio sono indicati i pozzi di tipo I e con il simbolo del rombo quelli di tipo 2.

average annual cumulative rainfall is 900 mm/year and they don't show a significantly statistical trend using the Mann-Kendall and Theil-Sen methods on the program ProUCL. From 1988 to 2000, the annual rainfall was always below 1400 mm/year. Subsequently, in the years 2000, 2002, 2008 and 2010, annual rainfall values above 1400 mm/year were recorded, and in 2014, they reached 1695 mm/year (Fig. 6).

The monthly rainfall presents two peaks in correspondence with the spring and autumn seasons, a characteristic common to the entire Piedmont Region (Arpa Piemonte 2021).

At last, a comparison was made between rainfall and phreatic levels. To do this, two monitoring wells were chosen based on their geographical location in the study area. Well 002D was chosen for the northern part, and well 114A was chosen for the southern part (see figure Fig. 3).

Annual comparisons between the two parameters were performed analysing and comparing data at specific interval and in particular every 5 years from 1990 to 2015, and using the monthly mean value for the phreatic level and the cumulative monthly rainfall (Fig. 7 and Fig. 8)

In both monitoring wells, the pattern of the phreatic levels starts to change between 2005 and 2010. In fact, it can be observed, especially with regard to the south well (Fig. 8), that the phreatic level in 2005 has the classic maximum peak in August and the minimum in March, whereas in 2010 this has a different pattern that is more influenced by rainfall.

In fact, it is possible to observe how that the phreatic level become more influenced by the precipitations having the same peaks of the rainfall. This behavior is also observed in the northern well, but is less evident.

This different hydrodynamic behavior between 2005 and 2010 is probably due to introduction of new techniques in the rice cultivation. Indeed recently, the dry direct-seeded rice

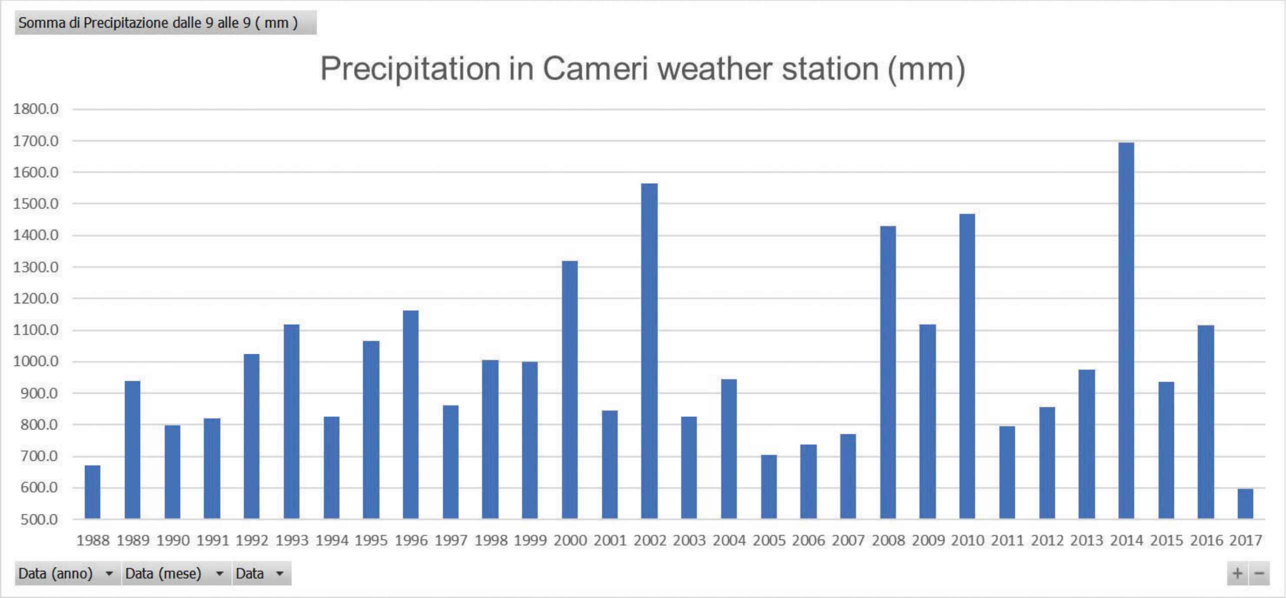

*Fig. 6 - Trend of annual cumulative rainfall recorded by the Cameri meteorological station.*

Fig. 6 - Andamento delle precipitazioni cumulate annue registrate dalla stazione meteoreologica di Cameri.

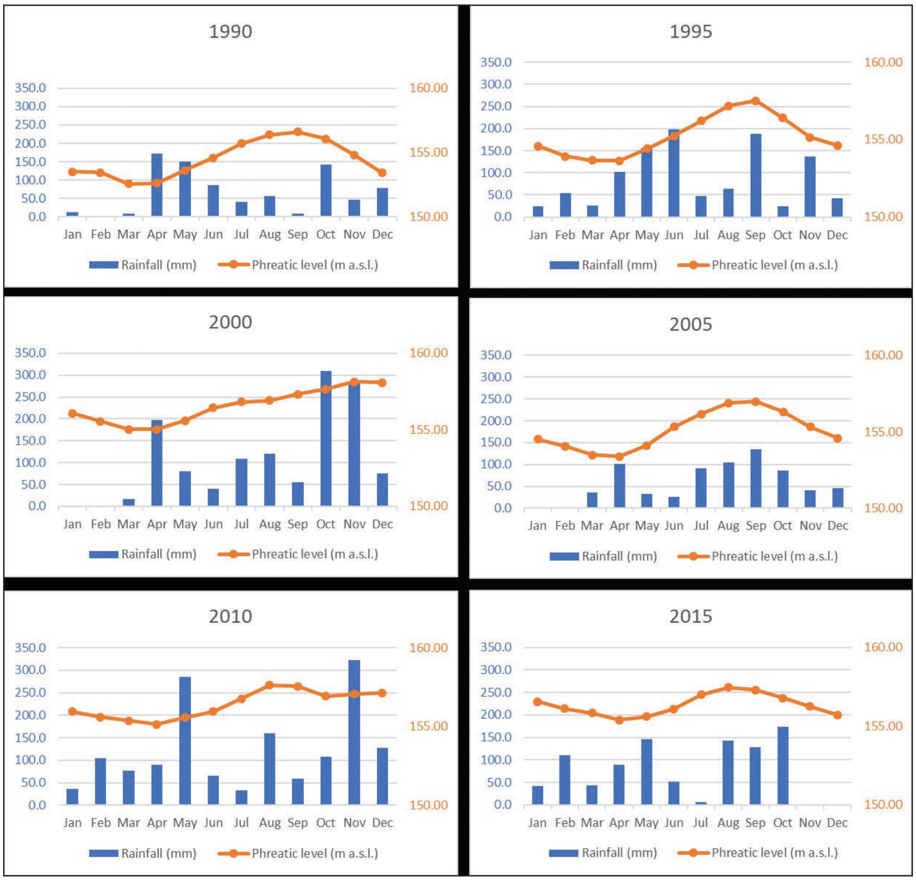

*Fig. 7 - Comparison of monthly average phreatic level trend of monitoring well 002D (north) and monthly cumulative rainfall value. In orange the phreatic level and in blue the precipitation.*

Fig. 7 - Confronto tra l'andamento del livello freatico medio mensile del pozzo di monitoraggio 002D (a nord) e il valore cumulato mensile delle precipitazioni. In arancione il livello freatico e in blu le precipitazioni.

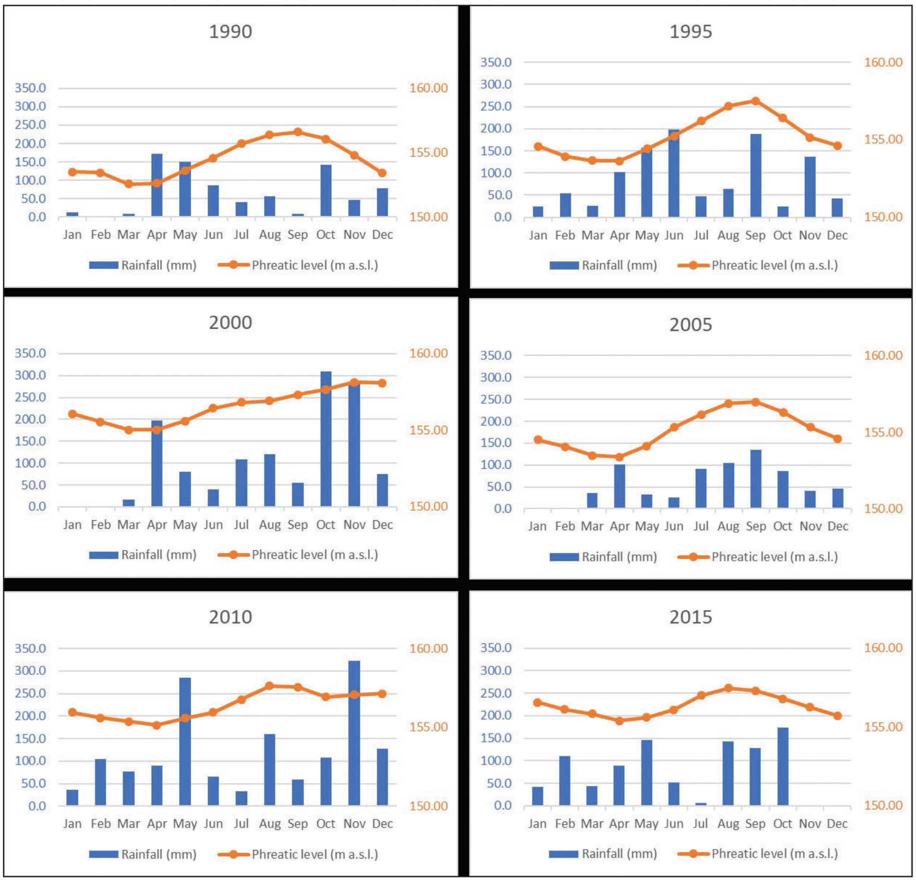

*Fig. 8 - Comparison of monthly average phreatic level trend of monitoring well 114A (south) and precipitation. In orange the phreatic level and in blue the precipitation.*

Fig. 8 - Confronto tra l'andamento del livello freatico medio mensile del pozzo di monitoraggio 114A (a sud) e le delle precipitazioni. In arancione il livello freatico e in blu le precipitazioni.

technique with delayed flooding has replaced the traditional technique in some areas of the Piedmont Plain (Lasagna et al. 2020b). Dry direct-seeded rice is an alternative cropping technique that avoids three basic operations, namely, puddling (a process where soil is compacted to reduce water seepage), transplanting and maintaining standing water (Joshi et al. 2013). Therefore, the technique requires less water and work than classical transplanted-flooded rice (Liu et al. 2015). In particular, the dry direct-seeded rice technique has developed in more than 30–40% of the rice paddies in the low Vercelli Plain ("risoitaliano.eu" 2022). In the dry direct-seeded rice technique, water is introduced when the seedlings have already grown, which is almost one month later (May) than in the traditional technique. The flooding of the rice fields takes place for a shorter period, causing a corresponding reduced period of raised piezometric level.

The year 2000 showed anomalous data about the phreatic levels that show a peak in correspondence of the fall season. This is due to a big flood that occurred in Piedmont during the month of October 2000 (Cassardo et al. 2000) that led, as can be seen in Figures 7 and 8, to a significant alteration of the phreatic levels.

## Conclusion

Data analyses of phreatic level and rainfall in the eastern Piedmont Plain showed an evident link between these parameters. However, the trend analyses for phreatic level showed the presence of very different situations in a relatively small area, with positive trends, negative trends and no statistically significant trend.

The analyses of the comparison between rainfall and phreatic level performed analysing the data every 5 years showed that, starting from 2010, an important change took over. The different hydrodynamic behavior between 1995 and 2010 was attributed to introduction of new techniques in the rice cultivation (i.e., the dry direct-seeded rice technique) in some parts of the study area and for the year 2000, the phreatic oscillation was probably influenced by the flood event that occurred in October 2000.

This highlighted how the analysis of the land use, together with meteorological parameters (rainfall), is a very important change driver, that should be considered and analysed to have a clear conceptual model of the hydrodynamic behaviour of groundwater.

Further insights will require the collection of new data about flow rates and how they are distributed and data about land use and agricultural techniques to better understand the agricultural practices of each paddy field of the study area. Moreover, it will be essential the investigation of the anthropic withdrawals in the area and a more detailed analysis of the permeability of unsaturated zone and aquifer.

In this way, it will be possible to better describe and explain the hydrodynamic behaviour of groundwater, in order to enhance a more sustainable management of GW in the study area

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### Competing interest

The authors declare no competing interest.

### Author contributions

Collection of data, Egidio E, Lasagna M, Mancini S; data processing, Egidio E; interpretation of results, all authors; writing-original draft preparation, Egidio E; writing-review and editing, Lasagna M, Mancini S, De Luca DA; graphical editing, Egidio E; supervision, Lasagna M, De Luca DA. All authors have read and agreed to the published version of the manuscript.

### Additional information

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## REFERENCES

Accesso ai dati “Annali meteorologici ed idrologici” Banca dati meteorologica [WWW Document], 2021. URL https://www.arpa.piemonte.it/rischinaturali/accesso-ai-dati/annali_meteoidrologici/annali-meteo-idro/banca-dati-meteorologica.html (last accessed 6.14.21).

Allen DM, Mackie DC, Wei M (2004) Groundwater and climate change: a sensitivity analysis for the Grand Forks aquifer, southern British Columbia, Canada. Hydrogeol. J. 21.

Alley W, Furey S, Klingbeil R, Shivakoti BR, Kabede S, Hirata R (2017) The UN-SDGs for 2030: Essential Indicators For Groundwater 8 pages.

Alley WM (2001) Ground Water and Climate. Ground Water 39, 161.

Arnell NW (1998) Climate Change and Water Resources in Britain. Clim Chang 39, 83–110.

Arpa Piemonte (2021) Arpa Piemonte - Home Page [WWW Document]. URL http://rsaonline.arpa.piemonte.it/meteoclima50/clima_ed_indicatori.htm (accessed 7.7.21).

Bastiancich L, Lasagna M, Mancini S, Falco M, De Luca DA (2021) Temperature and discharge variations in natural mineral water springs due to climate variability: a case study in the Piedmont Alps (NW Italy). Environ. Geochem. Health. https://doi.org/10.1007/s10653-021-00864-8

Beretta GP (2021) Groundwater and climate change. Acque Sotter. - Ital. J. Groundw. 10, 5–6. https://doi.org/10.7343/as-2021-532

Cassardo C, Cremonini R, Gandini D, Paesano G, Pelosini R, Qian MW (2000) Analysis of the severe flood of 13-16th October 2000 in Piedmont (Italy) 16.

Castagna SED, De Luca DA, Lasagna M (2015) Eutrophication of Piedmont Quarry Lakes (North-Western Italy): Hydrogeological Factors, Evaluation of Trophic Levels and Management Strategies. J. Environ. Assess. Policy Manag. 17, 1550036. https://doi.org/10.1142/S1464333215500362

Colombani N, Giambastiani BMS, Mastrocicco M (2016) Use of shallow groundwater temperature profiles to infer climate and land use change: interpretation and measurement challenges. Hydrol. Process. 30, 2512–2524. https://doi.org/10.1002/hyp.10805

De Luca DA, Lasagna M, Debernardi L (2020) Hydrogeology of the western Po plain (Piedmont, NW Italy). J. Maps 16, 265–273. https://doi.org/10.1080/17445647.2020.1738280

Debernardi L, De Luca DA, Lasagna M (2008) Correlation between nitrate concentration in groundwater and parameters affecting aquifer intrinsic vulnerability. Environ. Geol. 55, 539–558. https://doi.org/10.1007/s00254-007-1006-1

Est Sesia – Consorzio di irrigazione e bonifica *“Irrigation and land reclamation consortium”* (2022) URL https://www.estsesia.it/ (accessed 7.19.22).

Franzke CLE, Ciullo A, Gilmore EA, Matias DM, Nagabhatla N, Orlov A, Paterson SK, Scheffran J, Sillmann J (2022) Perspectives on tipping points in integrated models of the natural and human Earth system: cascading effects and telecoupling. Environ. Res. Lett. 17, 015004. https://doi.org/10.1088/1748-9326/ac42fd

Helsel DR, Hirsch RM, Ryberg KR, Archfield SA, Gilroy EJ (2020) Statistical methods in water resources (Report No. 4-A3), Techniques and Methods. Reston, VA. https://doi.org/10.3133/tm4A3

Irace A, Clemente P, Natalicchio M, Ossella L, Trenkwalder S, De Luca DA, Mosca P, Piana F, Polino R, Violanti D (2009) Geologia e idrostratigrafia profonda della Pianura Padana occidentale (Regione Piemonte) *“Geology and deep hydrostratigraphy of the west Piedmon Plain (Piedmont Region)”*. La NuovaLito.

Joshi E, Kumar D, Lal B, Nepalia V, Gautam P, Vyas AK (2013) Management of direct seeded rice for enhanced resource-use efficiency. Plant Knowledge Journal 2, 119–134.

Kendall MG (1955) Rank Correlation Measures. Charles Griffin, London 202

Lasagna M, Ducci D, Sellerino M, Mancini S, De Luca DA (2020a) Meteorological Variability and Groundwater Quality: Examples in Different Hydrogeological Settings. Water 12, 1297. https://doi.org/10.3390/w12051297

Lasagna M, Mancini S, De Luca DA (2020b) Groundwater hydrodynamic behaviours based on water table levels to identify natural and anthropic controlling factors in the Piedmont Plain (Italy). Sci. Total Environ. 716, 137051. https://doi.org/10.1016/j.scitotenv.2020.137051

Liu C (2022) Traditional agricultural management of Kam Sweet Rice (16.)

Liu H, Hussain S, Zheng M, Peng S, Huang J, Cui K, Nie L (2015) Dry direct-seeded rice as an alternative to transplanted-flooded rice in Central China. Agron. Sustain. Dev. 35, 285–294. https://doi.org/10.1007/s13593-014-0239-0

Liu Y (2022) Effects of climate change on paddy expansion and potential adaption strategies for sustainable agriculture development across Northeast China. Appl. Geogr. 12.

Mancini S, Egidio E, Luca DAD, Lasagna M (2022) Application and comparison of different statistical methods for the analysis of groundwater levels over time: Response to rainfall and resource evolution in the Piedmont Plain (NW Italy). Sci. Total Environ. 157479. https://doi.org/10.1016/j.scitotenv.2022.157479

Mann HB (1945) Nonparametric Tests Against Trend. Econometrica 13, 245. https://doi.org/10.2307/1907187

Mastrocicco M, Busico G, Colombani N (2018) Groundwater Temperature Trend as a Proxy for Climate Variability. Proceedings 2, 630. https://doi.org/10.3390/proceedings2110630

risoitaliano.eu [WWW Document] (2022) RisoItaliano Il Portale Riso. URL https://www.risoitaliano.eu/ (accessed 5.25.22).

Romani M (2008) Romani, M. (2008). Tecnica colturale. In ART Servizi Editoriali S.r.l. (Eds.), Il riso (pp. 298–323). Bayer CropScience. http://www.colturaecultura.it/content/tecnica-colturale-3

Sen PK (1968) Estimates of the regression coefficient based on Kendall’s tau. Journal of American Statistical Association 39, 1379–1389.

Singh A, Maichle R, Singh AK, Lee SE, Armbya N (2007) Proucl Version 4.00. 02 User Guide.

Wang H (2022) Effects of free-air temperature increase on grain yield and greenhouse gas emissions in a double rice cropping system. Field Crops Res. 9.

Yue S, Wang CY (2002) Applicability of prewhitening to eliminate the influence of serial correlation on the Mann-Kendall test: Technical Note. Water Resour. Res. 38, 4-1-4–7. https://doi.org/10.1029/2001WR000861