Deliverable 4.3: MONITORING AND IMPLEMENTATION STATUS AND INDICATORS

Author(s): Timothy Foster, Matthew Lees, *University of Manchester*

With contributions from: Hadi Jaafar, Lara Sujud *American University of Beirut;* V. Potharaju, Dinesh Kumar *Institute for Resource Analysis and Policy;* Héctor Macian-Sorribes, *Universitat Politècnica de València;* Cinzia Alessandrini, Rodica Tomozeiu *Agenzia Regionale per la Prevenzione, L'Ambiente e L'Energia Dell'Emilia-Romagna.;* Tania Santos, Gustavo Ayala *Stockholm Environment Institute;* Marinos Kritsotakis KRITI *-Region of Crete;* Robert Blaško *Slovenska Agentura Zivotneho Prostredia.;* Maggie Kossida, I. Tsoukalas *SEVEN Engineering Consultants OE;*. C. Dionisio Pérez-Blanco, Haniyeh Salmani, Osama Hassan, Giammauro Soriano *Universidad de Salamanca* (internal review).

Version	Changes	Date	By
v1	Original submission	28/02/2024	Timothy Foster, Matthew Lees, *University of Manchester*
v2	1. Table of contents for figures and tables added 2. Formatting issues and typos addressed 3. Broken links fixed 4. Figures 12, 13 and 14 edited	17/10/2024	Timothy Foster, Matthew Lees, *University of Manchester;* Héctor González-López, *Universidad de Salamanca*

Title	MONITORING AND IMPLEMENTATION STATUS AND INDICATORS
Author(s)	TIMOTHY FOSTER, MATTHEW LEES
Organization(s)	UNIVERSITY OF MANCHESTER
Reviewer(s)	HADI JAAFAR, C. DIONISIO PEREZ-BLANCO, HANIYEH SALMANI, OSAMA HASSAN, CIAMMAURO SORIANO
Deliverable number	4.3
Submission date	28/02/2024

Prepared under contract from the European Commission

Grant Agreement no. 101084110

Start of the project: 01/01/2023

Duration: 48 months

Project coordinator organization: Universidad de Salamanca

Related Work Package: WP4

Type of Deliverable: Report/Database

Due date of deliverable: Month 12

Actual submission date: February 28th, 2024 (month 14)

Dissemination level

☒ PU = Public, fully open, e.g. web

☐ CO = Confidential, restricted under conditions set out in Model Grant Agreement

☐ CI = Classified, information as referred to in Commission Decision 2001/844/EC.

The TRANSCEND Project has received funding from the European Union's Horizon Europe Research and Innovation Programme under the Grant Agreement 101084110

Executive summary

Effective, sustainable, and equitable basin-scale water management is predicated on monitoring of water use and availability. Yet, many river basins around the world lack intelligence or data about key natural and human components of the water cycle, such as agricultural abstractions or groundwater storage, and how these are evolving over time and space. As part of WP4 of TRANSCEND, a key goal is to identify and address systematic gaps in monitoring of water use and water availability across each of the project's seven living labs. The goal is to build transferable monitoring tools that can support the design, evaluation, and implementation of transformational adaptation policies in these seven basins, and other catchments globally. Towards that goal, this report summarises the current status of water use and water availability monitoring in each of the seven TRANSCEND living labs, and identifies common monitoring gaps and deficiencies that should be addressed to support adaptation to water scarcity. This information was gathered through a survey distributed in October 2023 to living lab leads for each of TRANSCEND's seven case study river basins, supplemented through bi-lateral dialogue with living lab lead organisations and desk research. Our analysis shows that monitoring status across the seven labs is heterogeneous, but there are a number of common monitoring and data gaps across multiple basins which are also consistent with global monitoring deficiencies and trends. For water availability, groundwater monitoring was significantly less well developed in comparison with surface water monitoring. Even those labs (e.g. Jucar) which already have extensive hydrogeological monitoring networks lack detailed information about spatial aquifer dynamics or responses to human pressures, while in other lab (e.g. Mahanadi, CMD) knowledge of groundwater storage dynamics is limited or insufficient despite the significant importance of this water resource base. Across all TRANSCEND's living labs, agriculture is the main land use and water user in some or at least part of each basin. Monitoring of water abstractions and land use by agriculture is universally limited, often at aggregated spatially or for single snapshots in time that are insufficient to support policy design and implementation, and anecdotal evidence from local partners and wider experience suggests the prevalence of significant unregulated water abstractions. More broadly, we find little evidence of attempts in any labs to quantify or account for uncertainties in monitoring data, in particular when using regional or global secondary data products (e.g. gridded hydrometeorological data) to full in-situ data gaps. The information collated in this report will be used as the basis for prioritising and targeting monitoring tool development in WP4 of TRANSCEND, while also providing an important shared knowledge base of catchment conditions and data availability to support modelling and capacity development activities within TRANSCEND.

.

Contents

1 Introduction 7
2 Background information for each living lab 8
2.1 Jucar River Basin (Spain)....8
2.2. Reno River Basin (Italy)....9
2.3. Nitra River Basin (Slovakia) 10
2.4. Tympaki River Basin (Greece)....11
2.5. Orontes River Basin (Lebanon) 13
2.6. Mahanadi River Basin (India) 14
2.7. Caplina-Mauri-Desaguadero System (Peru, Bolivia, Chile) 15
3 Existing monitoring 16
3.1. Jucar River Basin 17
3.2. Reno River Basin 19
3.3. Nitra River Basin....21
3.4. Tympaki River Basin 24
3.5. Orontes River Basin 25
3.6. Mahanadi River Basin 26
3.7. Caplina-Mauri-Desaguadero System....28
4. Synthesis of monitoring and implementation status 31
5. Monitoring gaps by living lab. 34
5.1. Jucar River Basin 34
5.2. Reno River Basin 34
5.3. Nitra River Basin....34
5.4. Tympaki River Basin 35
5.5. Orontes River Basin 35
5.6. Mahanadi River Basin 36
5.7. Caplina-Mauri-Desaguadero System....37
Summary 37
References 39
Annex I 41
Annex II....49

List of Figures

Figure 1 a) Map showing the topography and major rivers b) Map of the Jucar basin showing the Köppen climate zones........ 8
Figure 2 a) Map showing the topography of the Reno basin and the course of the Reno river b) Map of the Reno basin showing the Köppen climate zones 9
Figure 3 a) Map showing the topography and major rivers of the Nitra basin. b) Map of the Nitra basin showing the Köppen climate zones........ 11
Figure 4 a) Topographic map of the Tympaki basin b) Map of the Tympaki basin showing the Köppen climate zones 12
Figure 5 a) Topographic map of the Orontes basin, b) Map of the Orontes basin showing the Köppen climate zones 13
Figure 6 a) Topographic map of the Mahanadi basin, b) Map of the Mahanadi basin showing the Köppen climate zones........ 14
Figure 7 a) Topographic map of the Caplina-Mauri-Desaguadero basin, shown by the green-black outline. b) Map of the Caplina-Mauri-Desaguadero basin showing the Köppen climate zones 16
Figure 8 Map of the precipitation and streamflow/river gauge monitoring stations in the Jucar basin. 18
Figure 9 Spatial distribution of annual potential evapotranspiration in the Jucar basin, in mm/year, for the 1980-2018 period........ 19
Figure 10 Location of rain gauges within the Reno basin. (Source: Image provided in survey response) 20
Figure 11 Locations of hydrometers in the Reno basin. Source: survey response. 21
Figure 12 Map showing the network of groundwater monitoring stations in the Nitra basin.. 23
Figure 13 Map of the Mahanadi river basin 27
Figure 14 Screengrab of WRIS application 28
Figure 15 Illustration of the gridded temperature data products across the basin 29
Figure 16 The potential evapotranspiration map provided in the survey response 30
Figure 17 Grouped bar-chart showing resulting of comparative analysis for water availability across the basins. 32
Figure 18 Grouped bar-chart showing resulting of comparative analysis for water use across the basins.... 33

1 Introduction

Effective basin-scale water management requires monitoring of water use and availability. Within the TRANSCEND project, identifying and addressing gaps in monitoring is a key focus, in particular the development of novel satellite-based approaches which can support design and implementation of transformational adaptation policies (TAP) to deliver sustainable, equitable, and efficient water management. Towards that goal, this report provides a succinct introduction to the hydrology of each of the seven TRANSCEND living labs and describes the current status of monitoring – and any monitoring gaps – in each. The main use of this report will be as an input to monitoring tool development work within Work Package 4 (WP4) of TRANSCEND. The report has three specific objectives:

1. **To provide background information about each of the seven living labs**, giving a summary of the hydrology, climate, water and land use in each.
2. **To describe how, and by whom, water use and availability are currently being monitored in each living lab**. Specifically, we consider monitoring of the following variables/parameters:
    - Climatological: Precipitation, temperature, evapotranspiration
    - Surface water: Rivers/stream flows and levels; reservoir discharges and levels; mapping of lakes, rivers and streams
    - Groundwater: Aquifer characterisation (type, extent, hydrogeologic parameters), groundwater levels
    - Land cover/use
    - Water use: use by source, use by sector (agricultural, domestic, industry)
    - Other: Snow/ice where relevant, agricultural productivity, natural/ecosystem monitoring
3. **To identify water use and availability monitoring gaps in each basin**. The focus is on aspects of the hydrologic system that are of high significance in each basin, and particularly those aspects of water use and availability where remote sensing technologies could feasibly be used to improve monitoring.

The first section of this report gives background information about each living lab (objective 1). In the second section, each living lab is considered in turn and the existing state of monitoring is described. At the end of this section, we identify key cross-cutting themes and trends across the living labs (objective 2). In section three, we identify lab-specific monitoring gaps (objective 3). In the conclusion, we discuss common monitoring gaps across the basins, relate the status of monitoring in the living labs to the global trends, and discuss how the contents of this report will inform future TRANSCEND activities, especially as part of WP4 (monitoring). The primary source for this report is the responses to a survey distributed in October 2023 to living lab leads for each of TRANSCEND's seven case study river basins. A template of the survey is attached as Annex I. Information obtained from the survey was supplemented through bi-lateral dialogue with living lab lead organisations and by referencing external reports/studies, which are cited where they have been used.

2 Background information for each living lab

2.1 Jucar River Basin (Spain)

The Jucar basin is located in the east of Spain, as seen in *Köppen climate* zones, with climate zones from Beck et al. (2023). In both maps, the basin boundary is represented by the green-and-black line. In the legend for b), Med. is shorthand for Mediterranean

a, which shows the basin's physical geography and location within Spain. The western two thirds of the basin have upland character, either mountains or plateau, and there is a smaller, low-lying coastal plain in the east. An important geographic sub-domain, shown in *Köppen climate* zones, with climate zones from Beck et al. (2023). In both maps, the basin boundary is represented by the green-and-black line. In the legend for b), Med. is shorthand for Mediterranean

a, is the Mancha Oriental area, a plateau named for the hydrologically important Mancha Oriental aquifer where significant agricultural activity occurs. The basin's Köppen climate zones are shown in *Köppen climate* zones, with climate zones from Beck et al. (2023). In both maps, the basin boundary is represented by the green-and-black line. In the legend for b), Med. is shorthand for Mediterranean

b. Most of the basin has a semi-arid climate, with the upland areas primarily classed as "cold semi-arid" and the coastal plain as "hot semi-arid". There is a small zone of Mediterranean climate in the northern mountains, which receives greater rainfall. The "cold semi-arid" climate of the uplands is characterised by mild mean annual temperatures between 9 and 14 degrees (Estrela et al., 2004) and, although it is cooler in the mountains, snow does not play a significant role in the hydrology of the Jucar basin. Across the basin, the summer is mostly dry, with precipitation concentrated in the autumn and winter months.

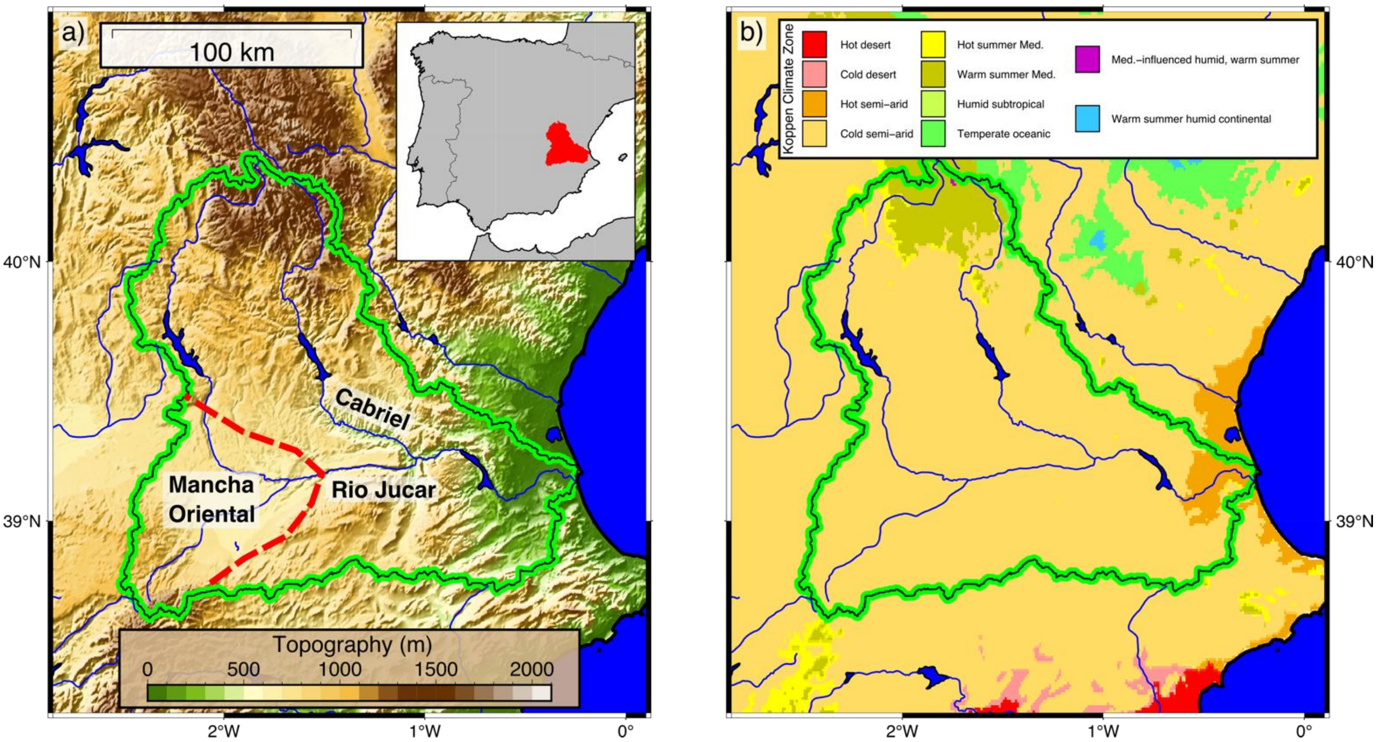

Figure 1 a) Map showing the topography and major rivers (blue lines) of the Jucar basin. The Mancha Oriental sub-domain is shown with red dashes. The inset shows the location of the Jucar basin (red shading) within Spain. b) Map of the Jucar basin showing the Köppen climate zones, with climate zones from Beck et al. (2023). In both maps, the basin boundary is represented by the green-and-black line. In the legend for b), Med. is shorthand for Mediterranean

The largest land use categories in the Jucar basin are forested/seminatural (49%) and agricultural land (48%), with the remaining land comprised of artificial surfaces, lakes or wetlands (Estrela et al., 2004). The agricultural land can be further divided into tree crops, which are mainly grown in the coastal plain, and row crops, which are mainly grown in the Mancha Oriental. Most crops are irrigated but there is some drylands farming in the Mancha Oriental. Agriculture is the major water user, alongside minor domestic use, and groundwater and surface water are both used. The extent, distribution, and type of agriculture has remained largely unchanged since at least the 1990s, but there has been a transition from row to tree crops in some areas. Compared to 1991, the area covered by irrigated citrus crops has slightly reduced, and that covered by irrigated vegetables and corn has almost halved. In contrast, the area of irrigated vineyards, olive groves and winter cereals have all doubled. There has been a very minor increase in the total area covered by irrigated crops.

2.2. Reno River Basin (Italy)

The Reno basin is located in the north of Italy and forms the watershed for the Reno river (see *Figure 2*a for a map of the physical geography of the basin and its location within Italy). The Reno rises in the Apennines mountain range in the southern part of the basin, flows north through a low-lying plain, and discharges into the Adriatic sea. The basin's Köppen climate zones are shown in *Figure 2*b. The low-lying plain has a humid subtropical climate, characterised by hot summers, whereas the climate in the mountains tends to be cooler. Precipitation occurs throughout the year, although the summer is the driest season, especially in the mountains where there are small zones of Mediterranean climate. During winter months, snow accumulates in the mountains and constitutes an important part of the hydrologic cycle, although in recent years, winter snow cover has reduced and therefore its contribution to the water cycle has fallen.

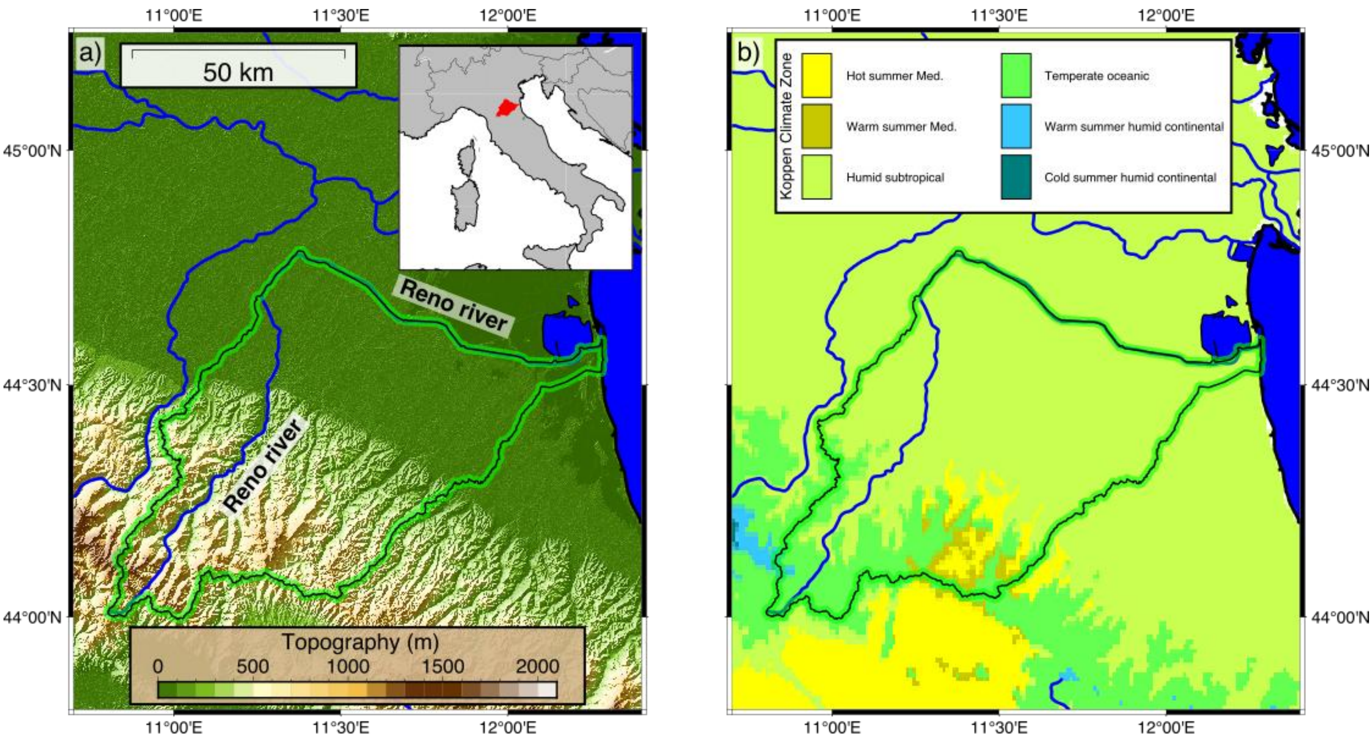

Figure 2 a) Map showing the topography of the Reno basin and the course of the Reno river (note that the river flows along the basin's northern boundary). The red shading in the inset shows its location within Italy. b) Map of the Reno basin showing the

Köppen climate zones, with climate zones from Beck et al. (2023). In both a and b, the basin boundary is represented by the green-and-black line. In the legend for b), Med. is shorthand for Mediterranean

Approximately 55% of the Reno basin, by area, is agricultural land, concentrated in the low-lying plain. Of that land, ~ 60% is irrigated, with the irrigated land primarily in the plain and the non-irrigated croplands in the hills and mountains. The main irrigated crops are: maize, sorghum, rapeseed, onion, potatoes, soy, grapevines (vineyards), several seed crops and orchards. In general, both the amount and type of agriculture has remained constant for at least the past 30 years. The most substantial changes in land use, as measured between 1994 and 2020, have been a decline in orchards (- 90%) and an increase in vineyards (+ 30%). Besides agriculture, the other main land uses are wooded (30%) and wetland/water habitat (15%). Irrigation accounts for 80% of the water use in the Reno basin, of which 80% comes from surface water and 20% from groundwater. Other water uses are industry, which accounts for 12% of total use (20% from surface water, 80% from groundwater), and domestic, which accounts for 8% of total use (20% from surface water, 80% from groundwater).

2.3. Nitra River Basin (Slovakia)

The Nitra basin is located in the west of Slovakia and forms the watershed for the Nitra river, which rises in the mountains in the north of the basin, flows through a broad valley and discharges into the Váh in a flat plain in the south of the basin (see *Figure 3*a for a map of the physical geography of the basin and its location within Slovakia). Upstream parts of the basin are characterised by forest and grasslands, and agricultural land is concentrated in the southern and central lowland plains. Unlike the other TRANSCEND living labs, agriculture does not constitute a major water use in the Nitra basin: use is approximately equal between the industrial (mainly mining) and domestic sectors. Partly due to mining activity, which has created surface depressions, there are numerous wetland areas throughout the basin, and there is growing interest in the ecologic function of these wetlands. For all uses in the basin, abstractions are from a mix of surface water and groundwater.

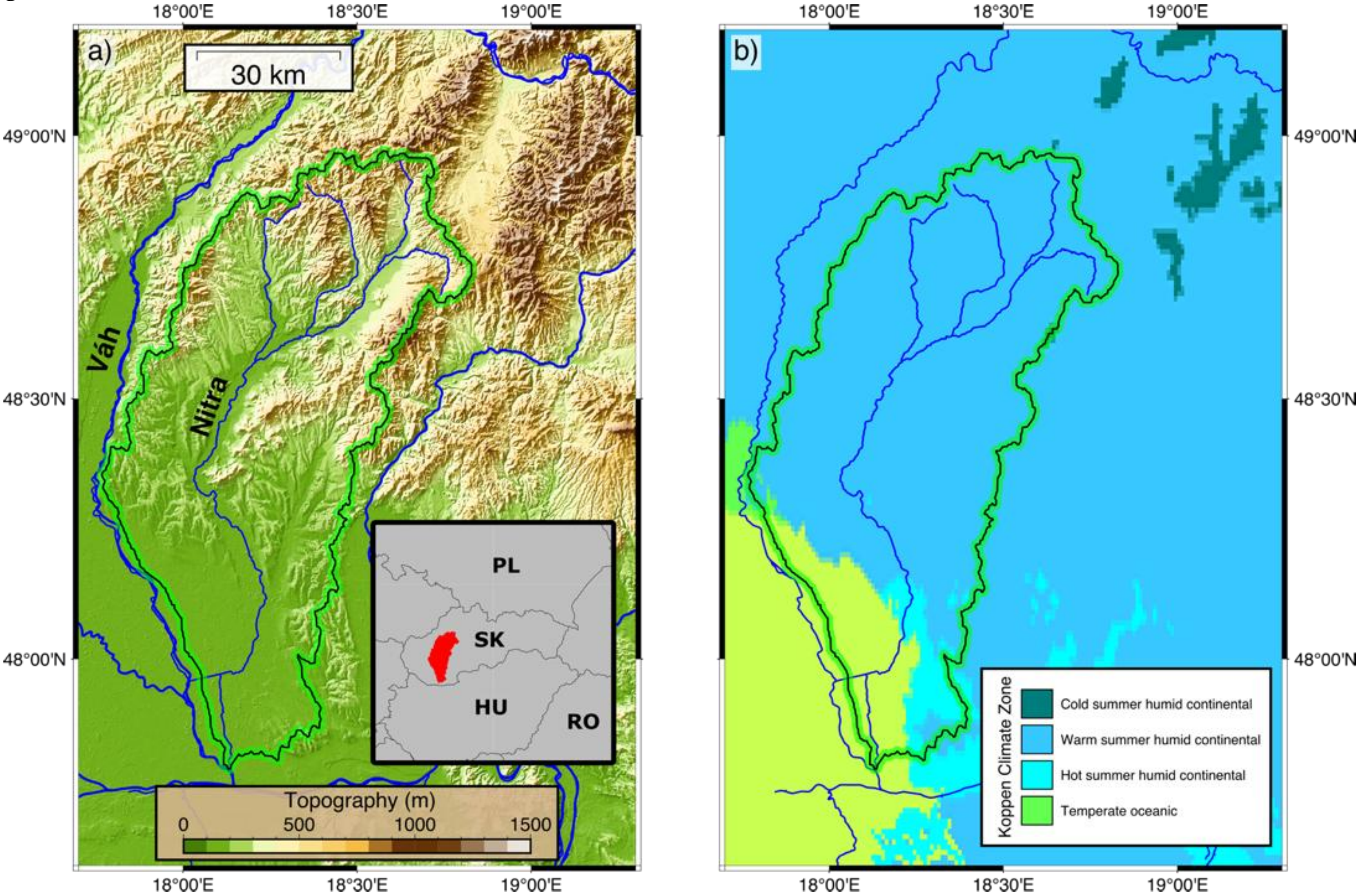

Figure 3 a) Map showing the topography and major rivers of the Nitra basin. The red shading in the inset shows its location within Slovakia, with Poland, Hungary and Romania also marked. b) Map of the Nitra basin showing the Köppen climate zones, with climate zones from Beck et al. (2023). In both maps, the basin boundary is represented by the green-and-black line

The basin's Köppen climate zones are shown in *Figure* 3b. The north of the basin has a "warm summer humid continental" climate, which is characterised by four distinct seasons, including a cold winter. There is a "temperate oceanic climate" in the south-west corner of the basin, where the winters are less intense. Precipitation occurs throughout the year, and snow accumulates during winter months, especially at higher elevations of the surrounding mountains. Snow is an important part of the hydrological cycle and any shifts in the snow patterns due to climate change will have implications for the hydrology of the basin.

2.4. Tympaki River Basin (Greece)

The Tympaki basin, located in Crete island, Greece, is the smallest of the living labs. The major rivers and streams are the Geropotamos river and its major tributary, the Koutsoulidis stream (see *Figure* 4a for a map of the physical geography of the basin and its location within Greece and Crete). There are also extensive groundwater resources in the basin. The basin's topography transitions from a rugged and mountainous north to a lower-lying region in the south. These lowlands are the westernmost part of the wider Messara plain, the main agricultural productive area of Crete. There is one major surface water body in the basin, the Faneromeni reservoir, which is located on the mid-reaches of the Koutsoulidis stream. The basin's Köppen climate zones are shown in *Figure* 4b, and most of the basin has a "hot summer Mediterranean" climate, characterised by hot, dry summers and relatively wetter and cooler winters. The mountains see somewhat cooler climates, with higher precipitation totals and occasional snow during winter months.

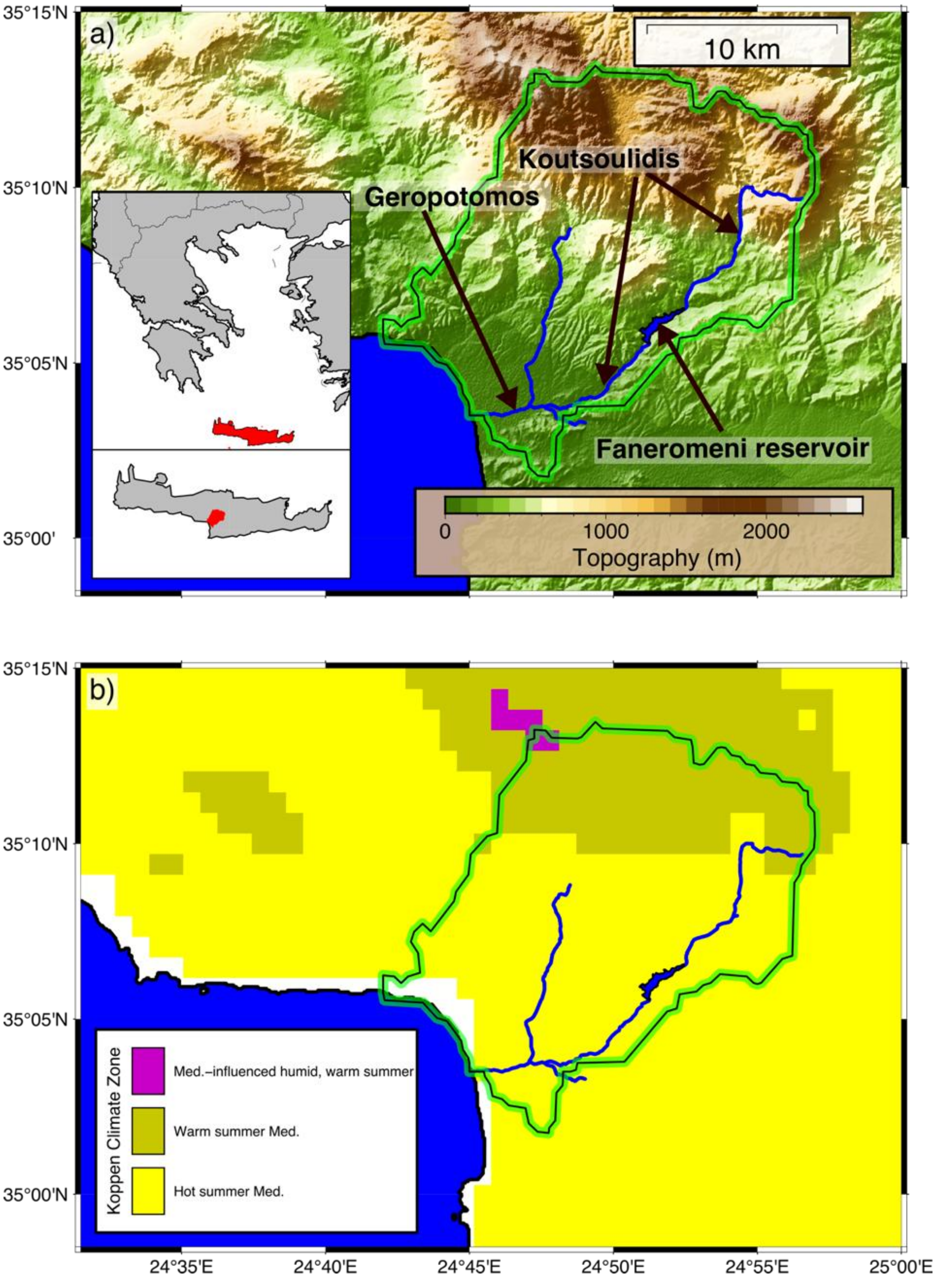

Figure 4 a) Topographic map of the Tympaki basin, shown by the green-and-black outline. Its location within Crete is shown by the red shading in the bottom part of the inset, and the location of Crete within Greece is likewise shown in the top part of the inset. b) Map of the Tympaki basin showing the Köppen climate zones, with climate zones from Beck et al. (2023). "Med." in the legend is shorthand for Mediterranean

Approximately 90% of the basin's land area is used for agriculture, with 40% dedicated to crops and 50% used as pasture. About half of the cropland is irrigated, and the most numerous crop types are olive groves, greenhouses with fruits and vegetables, and fruit trees. Since at least 2000, there have not been any major changes to the distribution or nature of agriculture, other than the construction in 2005 of the Faneromeni reservoir, which provides surface water for irrigation. The main water use in the basin is for irrigation (95%), and there is also minor urban use (4.5 %). The basin contains six groundwater bodies, and about 85% of the water used is derived from groundwater, including all urban water. The remaining 15% of water use comes from surface water through the Faneromeni reservoir. Most years, there is unmet water demand due to irrigation requiring more water than is available.

2.5. Orontes River Basin (Lebanon)

The Orontes basin is a transboundary basin, mainly located within Syria with smaller portions in Lebanon (upstream) and Turkey (downstream), which forms the watershed for the Orontes (also known as the Assi) river. *Figure 5*a provides a map of the physical geography of the basin and, in the inset, its location with regards Turkey, Syria and Lebanon. The basin is fringed by mountains, the highest of which are in the upstream areas, and there is a broad plain/valley surrounding the river in the basin's central and northern portions. The basin's Köppen climate zones are shown in *Figure 5*b. Most of the basin has a "hot summer Mediterranean" climate, characterised by mild, wet winters and hot, dry summers. There are parts of the south and east of the basin with semi-arid climate, whereas colder climates are seen in the mountains in the far south. These mountains receive winter snow, and the spring/summer snowmelt is thought to contribute significantly to groundwater recharge which, by feeding spring discharge, has an important role in surface water hydrology. In the southern and central regions of the basin (Lebanon and parts of Syria), an extensive and complex system of karst aquifers supply multiple springs, which maintain a stable flow throughout the year, and the flows of these springs provide the major surface flow of the Orontes Basin in Lebanon (Zwahlen et al., 2016).

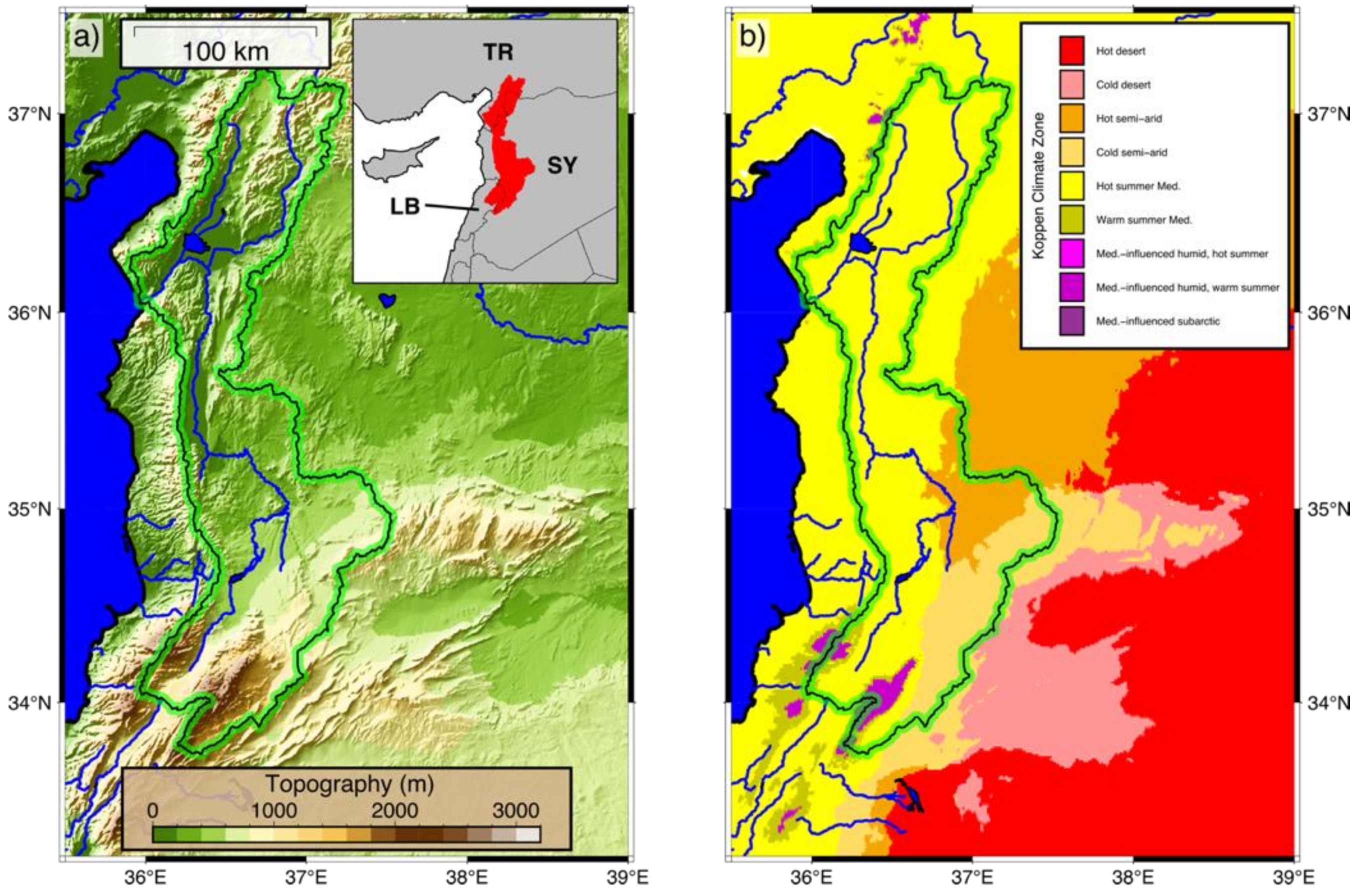

Figure 5 a) Topographic map of the Orontes basin, shown by the red outline. Its location within Syria (SY), Turkey (TR) and Lebanon (LB) is shown by the red shading in the inset, with borders shown as solid black lines and marked with dashes where the *aquifer crosses them. b) Map of the Orontes basin showing the Köppen climate zones, with climate zones from Beck et al. (2023). In both maps, the basin boundary is represented by the green-and-black line.*

Approximately 25% of the land use in the Orontes basin is agricultural, concentrated in the river valley and particularly in Syria, with about two thirds of this being field crops and the remainder tree crops. The other land cover is mostly grassland or bare. Although there are only basic data on changing agricultural patterns over time, the study of Mhanna et al. (2023) suggested that, since the beginning of the Syrian conflict in 2011, there has been a shift from grasslands to croplands in the upstream parts of the basin. There is also anecdotal evidence that more trees (olives and almonds) are now being cultivated in the basin.

Much of the agriculture in the basin is irrigated. In the Syrian portion of the basin, it has been estimated that there are 300,000 hectares of irrigated land (Myriam et al., 2018), while it is estimated that, out of a total of 26,000 hectares of cropped area in the upper/Lebanese portion of the basin, 14,000 hectares are irrigated (Jaafar et al., 2016). An important consideration in the Orontes basin is the complex political situation regarding water use in Lebanon and Syria, which is governed by a 1994 agreement signed by both countries (Fanack Water, 2022).

2.6. Mahanadi River Basin (India)

The Mahanadi basin is located in eastern India and forms the watershed for the Mahanadi river, which rises in the Eastern Ghats (mountains) in the west of the basin and flows into the Bay of Bengal in the east. *Figure 6*a shows the main physiographic features of the basin as well as its location within India. The basin is ringed by mountainous areas in the north, south and west, but most of the land is flat. The basin's Köppen climate zones are shown in *Figure 6*b, and most of the basin has a "tropical wet and dry" climate, characterised by a wet monsoon period from June to September; the far north of the basin has a "humid subtropical" climate. There is never snow in the basin, even in the mountains.

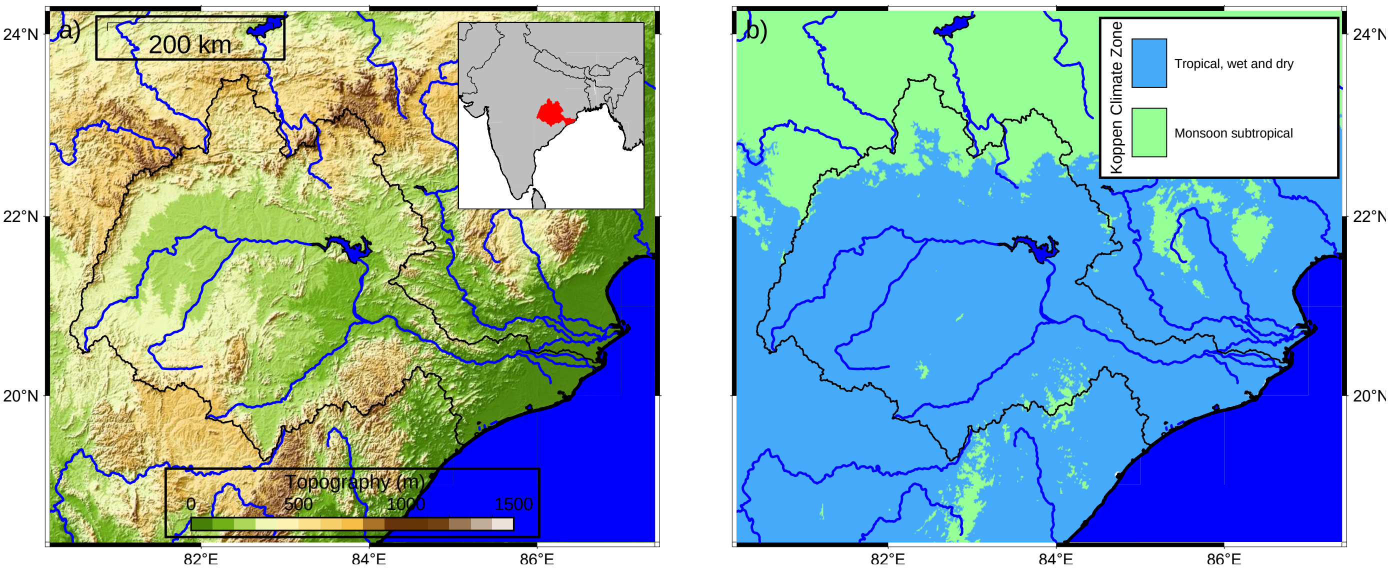

Figure 6 a) Topographic map of the Mahanadi basin, shown by the green and black outline. Its location within India is shown by the red shading in the inset, with borders shown as solid black lines. b) Map of the Mahanadi basin showing the Köppen climate zones, with climate zones from Beck et al. (2023).

The basin is predominantly agricultural (land use breakdown: 50% agricultural, 30% forested, 20% urban, barren or water), with a mix of commercial and subsistence farming dominated by rice cultivation. There are extensive irrigation networks (canals, reservoirs, etc.), and, in 2004, it was estimated that approximately 30% of croplands were under irrigation; of these, 30% were being irrigated by groundwater and the remainder using surface water (Amarasinghe et al., 2005). The irrigated lands are more common in eastern parts of the basin (Odisha state), while Kharif-style farming is more common in the western half of the basin (Chhattisgarh state). Summary land use statistics from 2005 and 2020 do not provide evidence of major changes in the amount of land dedicated to agriculture over that period. Since groundwater use is not monitored, detailed information on abstractions is not known, and this reflects the distributed, small-scale nature of irrigated agriculture in the Mahanadi basin and wider South Asian region.

2.7. Caplina-Mauri-Desaguadero System (Peru, Bolivia, Chile)

The Caplina-Mauri-Desaguadero basin is a transboundary system of basins located in Bolivia, Chile and Peru (inset, *Figure 7*a), comprised of the Mauri, Desaguadero and Caplina river basins. Although no river connects the Mauri and Desaguadero basins with the Caplina, the Kovire tunnel carries water from the Mauri basin into the Caplina basin, so the three basins can be treated as one hydrologic system which is referred to as the Caplina-Mauri-Desaguadero basin in this report. The basin's topography is shown in *Figure 7*a, revealing that the predominant feature is a large high-altitude plateau – with elevation over 3000 m – in the south and east of the basin, bordered by mountains, some of which exceed 6000 masl. This plateau contains two large lakes: Lake Titicaca and Lake Poopó. To the west, the mountains drop away to the Pacific Ocean, where the basin's outlet is found. The basin's Köppen climate zones are shown in *Figure 7*b. The south portion of the upland area has a "cold semi-arid" climate, whereas the north has an alpine tundra climate. Neither see large precipitation totals, but around Lake Titicaca and in some of the higher mountains, temperate climates are found, and these areas are important as they receive the highest rainfall. In the lowlands near the Pacific Ocean, there is a desert climate (this is the northernmost extent of the Atacama desert), which transitions from hot to cold with increasing elevation. Snow falls in the higher mountains, where there are glaciers which serve hydrologically important functions.

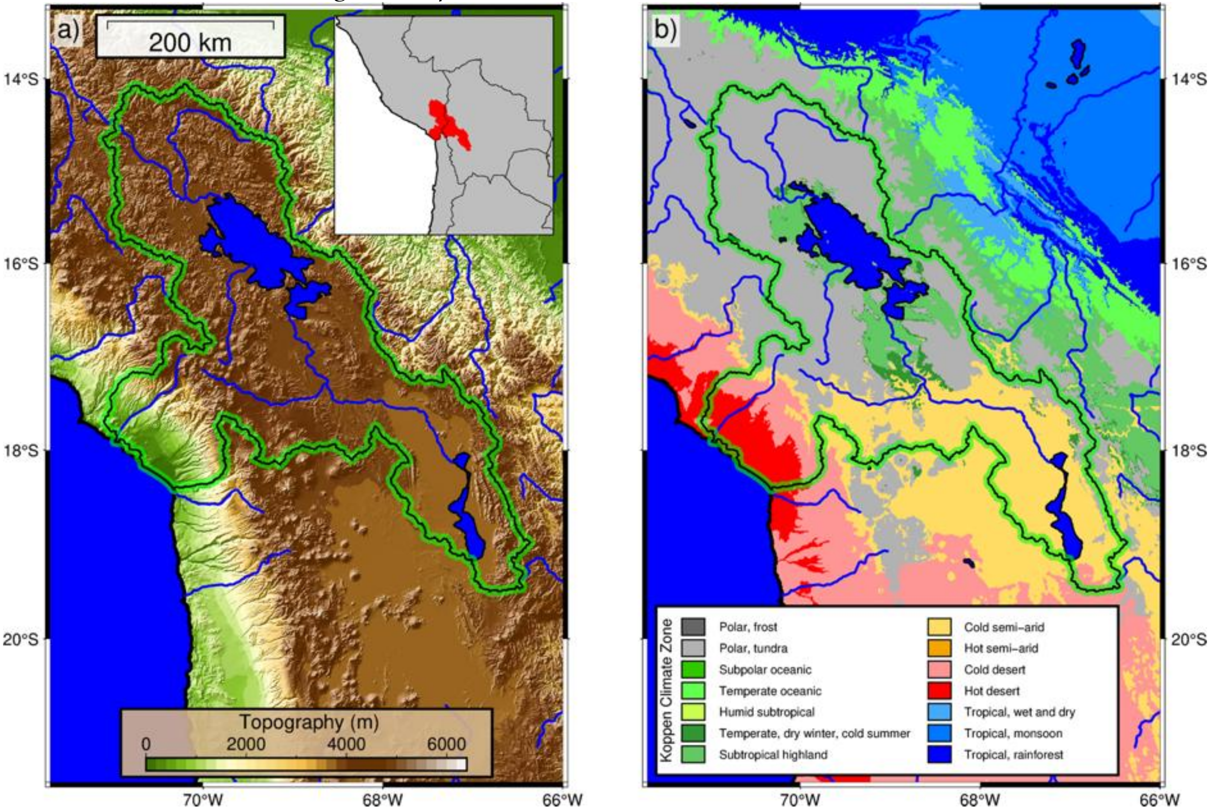

Figure 7 a) Topographic map of the Caplina-Mauri-Desaguadero basin, shown by the green-black outline. Its location within Bolivia, Peru and Chile is shown by the red shading in the inset, with borders shown as solid black lines and marked with dashes where the aquifer crosses them. b) Map of the Caplina-Mauri-Desaguadero basin showing the Köppen climate zones, with climate zones from Beck et al. (2023).

Approximately 10% of the land in the Caplina-Mauri-Desaguadero basin is croplands, with the majority of that under irrigation. The main crops grown are quinoa, potato, barley, maize, and alfalfa. Another 40% of the land is pasture, typically used for grazing of camelids, and 25% is forest or shrubland, mostly in the north-eastern mountains where precipitation is higher. Due to the large lakes, almost 10% of the basin's area is water. Between 1992 and 2015, there have been some changes in land use, particularly a growth in urban area (36% growth), agricultural land (10% growth) and wetlands (5% growth), with decreasing amounts of bare land (17% reduction) and shrubland (11% reduction). Most water use in the basin is for agriculture, and both surface and groundwater are used.

3 Existing monitoring

In this section, we describe the existing status of monitoring in each living lab, with three parts for each. The first part, "*who is monitoring?*", contains a summary of which bodies/agencies are leading the monitoring; in the second, "*water availability*", the status of water availability monitoring is presented; and in the third, "*water use*", the status of water use monitoring is described. At the end of this section is a synthesis/summary, where we compare the status of monitoring between the living labs to identify key cross-cutting themes and trends.

3.1. Jucar River Basin

Who is monitoring?

In the Jucar basin, a combination of local and national/international organisations monitor water use and availability. Locally, the Jucar River Basin Agency (JRBA) monitors stream gauges, groundwater levels, reservoir levels, reservoir releases, domestic water abstractions and agricultural water extractions. At the national/international level, a number of agencies are involved in monitoring: the Geological Survey of Spain (groundwater characterisation), the national meteorological agency (precipitation and temperature), the Geographical Institute of Spain (land cover/use), the European Environment Agency (land cover/use), and the Ministry of Agriculture, Fisheries and Food (agricultural productivity and land use).

Water availability monitoring

Precipitation and temperature are monitored at in-situ meteorological stations across the basin. These stations collect hourly data and, at a subset of the stations, climate normals describing the average conditions are calculated. To illustrate the spatial coverage of meteorological stations, the locations of the stations used for monitoring precipitation are shown in *Figure 8*. There are two national-level products of gridded temperature and precipitation available which cover the Jucar basin: the Spain02 dataset, available at ~ 10 km spatial resolution with daily temporal resolution for the period 1951-2015 (Herrera et al., 2016; Piña-Rey et al., 2020); and the ROCIO_IBEB dataset, available at 5 km spatial resolution with daily temporal resolution for the period 1951-2022 (AEMET, 2024; Peral García et al., 2017). Both products were created through interpolation between observations.

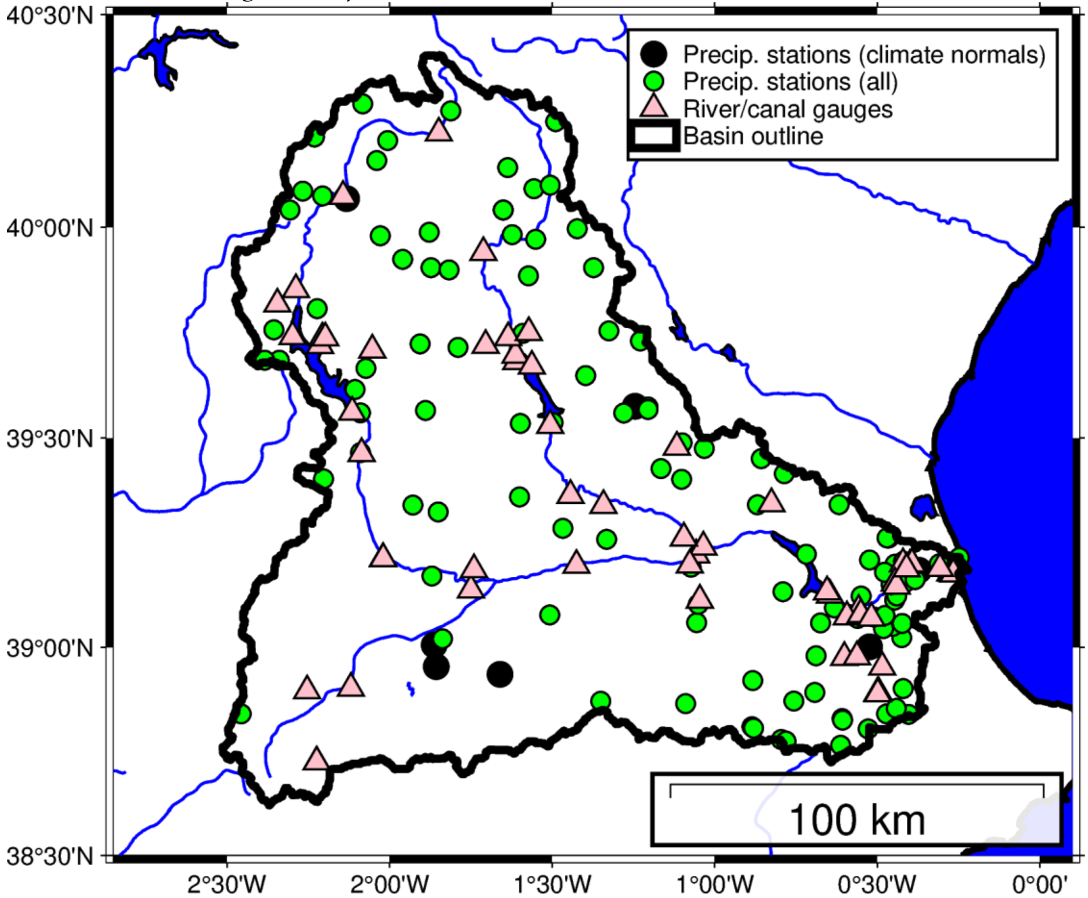

Figure 8 Map of the precipitation and streamflow/river gauge monitoring stations in the Jucar basin. Black circles are the subset of precipitation stations where climate normals are calculated. Data from AEMET (https://opendata.aemet.es/centrodedescargas/productosAEMET) and the JRBA website.

Streamflow and river level measurements are made at a network of 59 stations covering the Jucar and its main tributaries – the locations of these stations are shown in *Figure 8*. Note that not all stations are currently active, but for active stations, the whole time series of measurements are available at the daily scale, and the most recent measurements are available with 5-minute sampling frequency. Streamflow information is also estimated using the PATRICAL model, a distributed conceptual model that takes meteorological observations from weather stations and physical characteristics such as terrain type, slope, and land cover, and uses these to parameterise and solve, at 1 km cell-size, a water balance equation, from which streamflow is an output flux estimate (Pérez-Martín et al., 2014). This information is particularly useful for ungauged streams. For all reservoirs with active use, there are monthly records of outflow and stored volume, obtained using gauge data, in addition to records of inflow which are estimated using a water balance. Flows through canals are also monitored. Groundwater is monitored through a network of 1523 piezometric wells (active and inactive) where water levels are measured with a monthly-to-quarterly frequency. There is substantial information on aquifer characteristics in the basin, including aquifer permeability, sediment/soil type, estimated recharge rates and usable resource.

Water use monitoring

Satellite and in-situ data are combined, using the Penman-Monteith equation and crop coefficients, to calculate potential evapotranspiration across the basin, resulting in maps such as the one shown in *Figure 9*. Land cover/use is monitored using the European-wide CORINE Land Cover data product with 250 x 250 m resolution and/or the Spanish-specific land cover map, SIOSE, which has higher resolution, nominally as good at 5 m. SIOSE has been produced in 2005, 2009, 2011, 2014, 2017 and CORINE in 1990, 2000, 2006, 2012 and 2018. To monitor agricultural productivity, a survey of crop areas and yields has been carried out annually since 1990, called ESYRCE, from which province-level crop yields are estimated. Certain local and regional agencies, such as municipalities or regional governments, also hold "CAP" data, which is self-reported data from farmers on land use. So far as direct monitoring of water use is concerned, water abstraction rights/permits are documented by the JRBA, abstraction from canals is gauged, and farmers in overexploited areas self-declare their volumetric groundwater use. In addition to this, an estimate of consumptive use in the Mancha Oriental area is made using remote sensing to estimate the amount of irrigated area and then multiplying it by a water consumption ratio based on the existing crops.

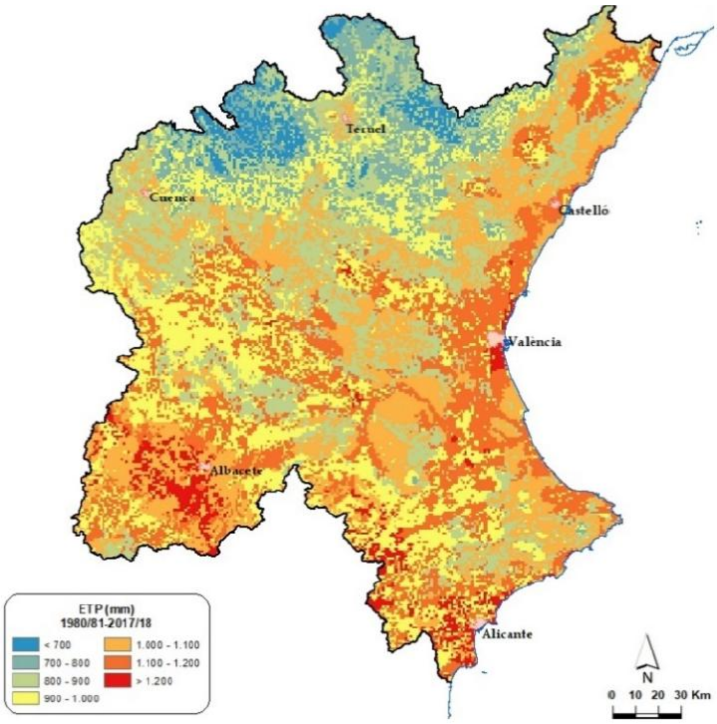

Figure 9 Spatial distribution of annual potential evapotranspiration in the Jucar basin, in mm/year, for the 1980-2018 period. Source: Jucar River Basin Management Plan (Confederación Hidrográfica del Júcar, 2023).

3.2. Reno River Basin

Who is monitoring?

Monitoring of water use and availability in the Reno basin is done by regional-level organisations. The Agency for Environmental Protection and Energy of Emilia-Romagna (ARPAE) leads all monitoring, with two exceptions. These exceptions are land use monitoring, which is overseen by the Emilia-Romagna Region Department on Digital Innovation, Data, Technology and Central Archives; and agricultural productivity, which is monitored by the Emilia-Romagna Department of Agriculture, Hunting and Fishing.

Water availability monitoring

Precipitation is measured hourly at approximately 80 rain gauges located throughout the basin (see *Figure 10* for the spatial distribution of those gauges), and temperature is monitored through a network of approximately 20 meteorological stations. In addition to these in-situ data, there is the ERG5 data product, which contains grids of daily – and, in some cases, hourly - precipitation and temperature data, with ~5 km resolution, based on interpolation between a subset of the in-situ data which are screened for quality prior to interpolation (Antolini et al., 2016). Currently, the periods covered by ERG5 are 1991-2022 for hourly resolution and 1961-2022 for daily resolution. This gridded dataset is used to estimate climate normals in the Reno basin.

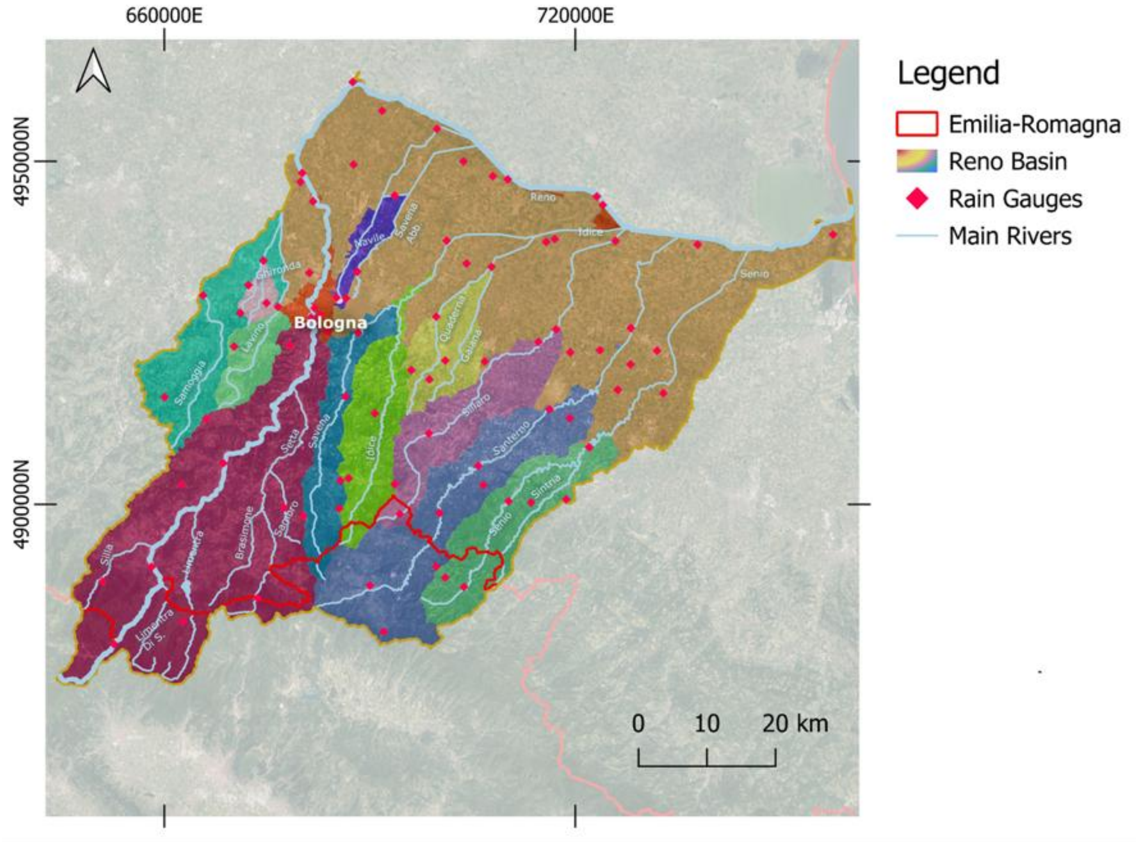

Figure 10 Location of rain gauges within the Reno basin. (Source: Image provided in survey response)

There are approximately 30 hydrometers (locations shown in *Figure 11*) at which streamflow of the Reno and its main tributaries are measured. Measurement frequency is approximately three times annually, although not every station is monitored every year and additional measurements may be made during high or low flow periods. These streamflow data are used to develop stage-discharge relations which are then applied to estimate discharge at a subset of the basin's 80-120 river gauges. River level measurements are made at these gauges every 10 minutes. Groundwater is monitored through ~ 150 groundwater monitoring points at springs and wells, including several automatic stations. In most cases, measurements at wells are made twice per year, and records are published in reports by ARPAE. General groundwater characteristics (aquifer thickness, type, extent, etc.) are also known in significant detail. Soil moisture and snow water equivalent products are generated using remote sensing.

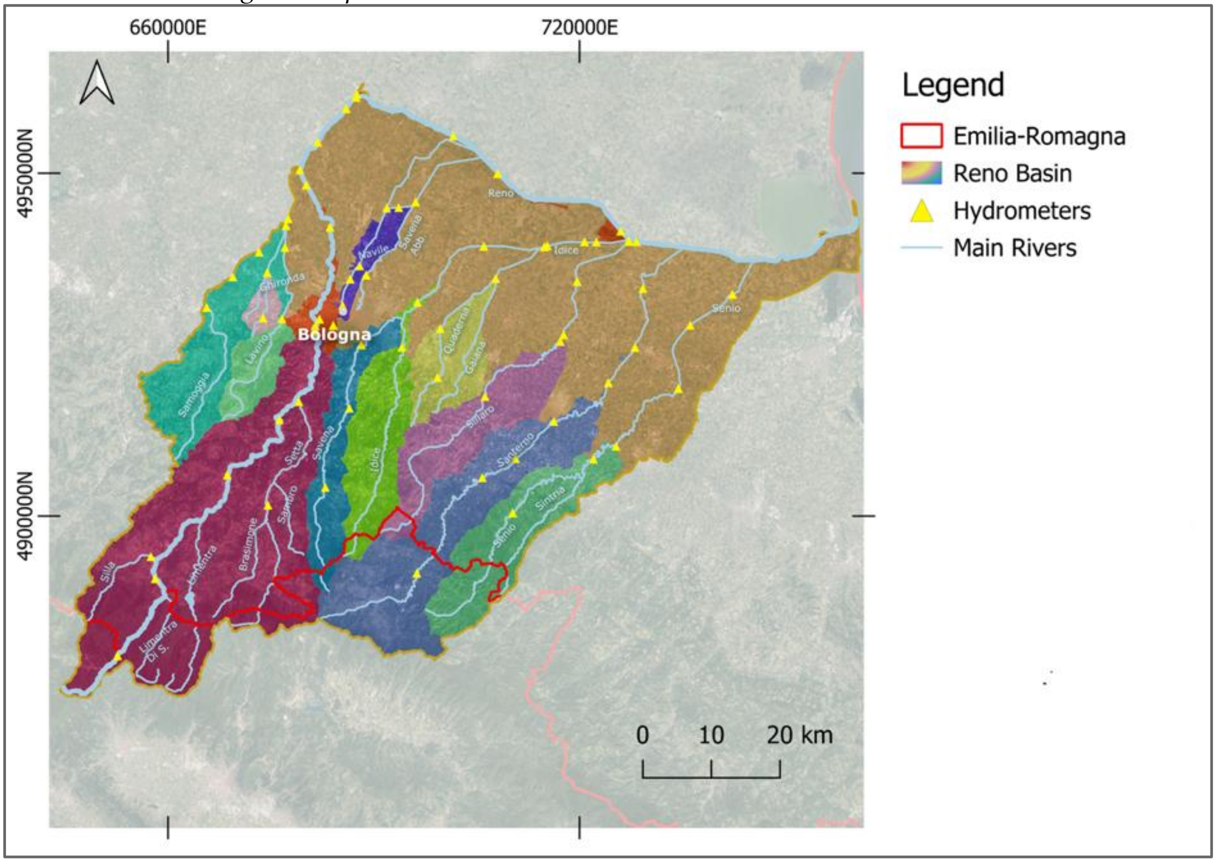

Figure 11 Locations of hydrometers in the Reno basin. Source: survey response.

Water use monitoring

An agro-hydrological model is used to estimate evapotranspiration at a resolution of 5 x 5 km. There is a record of land use/cover in the basin, based on photogrammetry surveys from 1976, 1994, 2003, 2008, 2011, 2014, 2017 and 2020. The resolution of the 1976 land use map is 0.375 hectares (approx. 60 x 60 m pixels) and the subsequent maps all have 0.16 hectares resolution (approx. 40 x 40 m pixels). There is an additional map of 1854 land cover, which is of lower quality reflecting the historical records it is based on. ARPAE maintains information on water abstraction permits for both surface and groundwater, covering industrial and agricultural use, while permitting for domestic use is not required. At the province level, water abstractions are estimated as part of the six-yearly water Management Plan updates. These estimates, which are for a sub-period within the six years and not the whole six year period, include a breakdown of abstractions by source (groundwater and surface water) as well as use (irrigation agriculture, livestock agriculture, aquaculture, domestic, industrial). Note that the province level is an administrative division larger than the Reno basin, and finer-scale estimates of abstractions are not available.

3.3. Nitra River Basin

Who is monitoring?

The monitoring of water use and availability in the Nitra basin is mostly performed by two national-level organisations: the Slovak Hydrometeorological Institute (SMHU) and the Slovenský Vodohospodársky Podnik (SVP).

Water availability monitoring

In the Nitra basin, there are around 10 locations where precipitation is measured, and one weather station where temperature measurements are made. All measurements are automated to be recorded hourly, with additional manual temperature measurements made three time per day. There are four hydrologic stations on the Nitra river at which measurements of streamflow are made approximately six times per year, and these measurements are used to develop stage-discharge relations. River levels are monitored at a larger network of stations, and daily data from these stations for the period 2001-present are available online, with recent data available at 15-minute intervals. There are five boreholes in the upstream part of the Nitra basin equipped with automated measuring equipment at which groundwater levels in the shallow, alluvial aquifers are monitored, and further groundwater level monitoring occurs in the downstream part of the basin. The mining company monitors groundwater levels in deeper layers, although these data are not publicly available. In addition, discharge and temperature of the spring source of the Nitra River are measured. The locations of the five boreholes in the upstream part of the basin are shown in *Figure 12*, as is the spring source station. Reservoirs are monitored by SVP through measurements of reservoir levels (elevation) and flows.

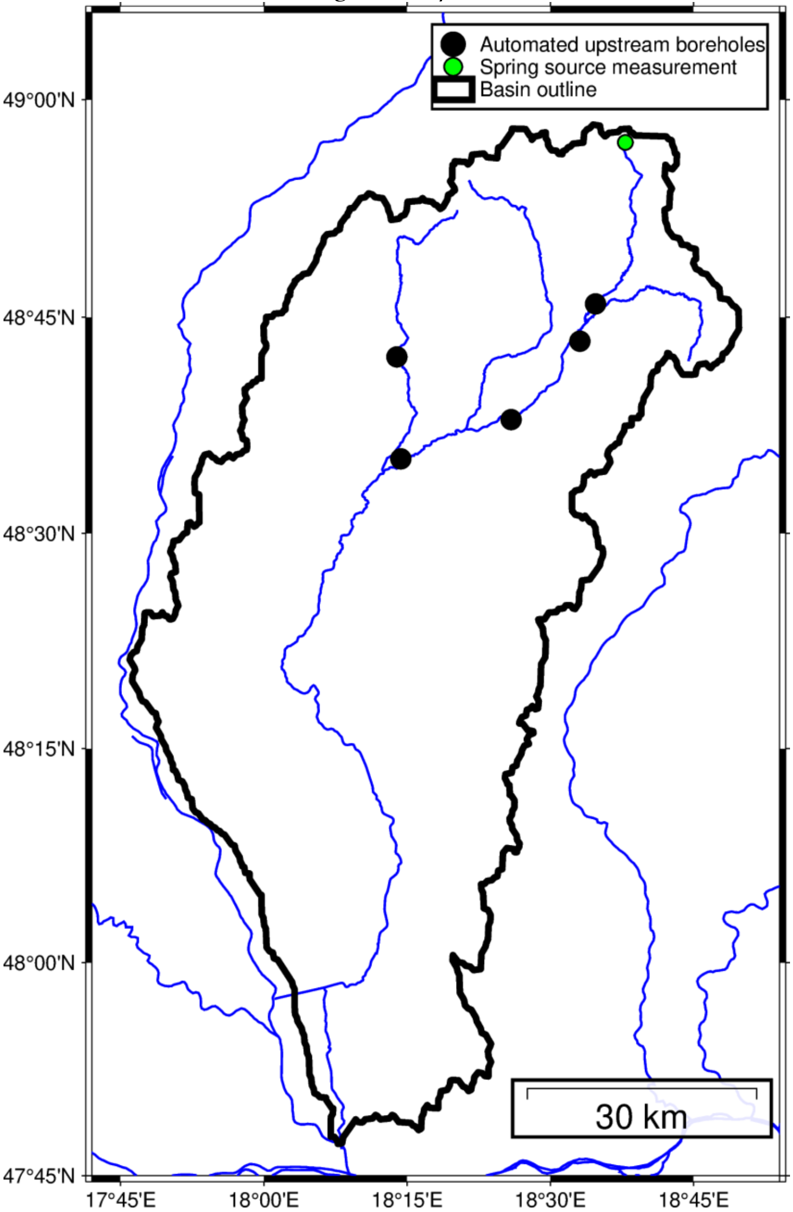

Figure 12 Map showing the network of groundwater monitoring stations in the upper part of the Nitra basin. Boreholes are shown as the black circles, and the green circle is the spring source measurement. Source: map data from SMHU.

Water use monitoring

Although data required to estimate potential evapotranspiration are collected at the weather station in the basin, it is not certain whether that estimate is actually made. Land cover/use is monitored through off-the-shelf products such as CORINE. Local authorities grant permits for water abstraction rights/permits in consultation with SVP, while no permits are required for abstractions < 15 000 m^3 annually (or < 1250 m^3 monthly). Permits and historic permit records are held by local authorities, and there are plans to create a central registry. Water users self-report both surface and groundwater abstractions and these are then collated by various organisations to create annual abstraction and water balance reports.

3.4. Tympaki River Basin

Who is monitoring?

Monitoring of water use and availability in the Tympaki basin is undertaken by a mixture of national, regional and local organisations. The bulk of monitoring is coordinated by regional groups, primarily through two main organisations: the Region of Crete governmental/public authority, which operated monitoring stations until 2010 (streamflow, stream gauges, groundwater levels, groundwater storage, precipitation and temperature, actual evapotranspiration, land use/cover, reservoir levels), and the Water Directorate of the Decentralized Administration of Crete (WDC), which has operated automatic telemetric stations since 2015 (precipitation and temperature, actual evapotranspiration, streamflow, stream gauges, groundwater levels, groundwater storage, precipitation and temperature, actual evapotranspiration, reservoir inflow and storage, water rights, groundwater abstractions). Additionally, there are three national-level organisations that contribute: the Hellenic Survey of Mineral and Geological Exploration (EAGME), which monitors groundwater quality; the National Observatory of Athens (NOA), which monitors precipitation, temperature and other meteorological parameters; and the Hellenic Statistical Authority (HSA) that provides monitoring of agricultural land use and productivity. Finally, the Municipal Water Supply and Sewage Company in Faistos (DEYA Faistou) monitors industrial and domestic water use, while the Local Land Reclamation Organisation ("TOEV Zone A' of Messara") office is involved in the monitoring of agricultural abstractions, agricultural productivity, and land use. Some additional monitoring information is obtained by the Technical University of Crete and/or through academic or other external papers/reports. Web portals to facilitate data display and/or download are provided by the Region of Crete, the HSA, the World Wildlife Fund Greece, and others.

Water availability monitoring

There are nine traditional meteorological stations[1] in the basin, which provide comprehensive spatial coverage. These stations have records of daily precipitation and temperature for the period 1974-2010 (manual monitoring). Since 2015 two automatic meteorological stations have operated in the basin, providing hourly records. There is a 5-year monitoring gap between 2010 and 2015. At one site in the basin, there are in-situ gauge measurements of streamflow, where daily data have been gathered since 2005 (and monthly in the period 1969-1997), and at further sites there are gauges that measure the river stage only. Where only river stage is measured, streamflow is estimated using stage-discharge relations. There are also groundwater wells where measurements of water levels were taken every six months until 2010, and several automated stations have provided hourly data since 2015, accessible in real-time. The aquifers in the basin have been extensively described in terms of their size, extent and physical parameters such as storage, transmissivity, etc. Daily and monthly inflows and storage values have been collected at the Faneromeni dam since 2015.

Water use monitoring

There are literature/scientific reports which have modelled potential evapotranspiration in the Tympaki basin, and reference evapotranspiration information is calculated using the Penman-Monteith method at the meteorological stations at the basin, with daily records from 1974-2010 (manual monitoring) and hourly records from 2015-present (automated monitoring). Land use/cover has been monitored using the EU-wide CORINE dataset (available for: 2000, 2012, 2018; resolution = 250 x 250 m) as well as 1987 and 2007 datasets

[1] The stations are the following: Tympakion, Lagolio, Vorizia, Zarros, Gergeri, Gortyna, Pmopia, Pitsidia, Moroni

produced through collaboration between the World Wildlife Fund Greece and the Aristotle University of Thessaloniki (resolution = 250 x 250 m). Agricultural productivity is monitored using field surveys, with annual data available from 2000-present. There are comprehensive data on abstractions, which are available at the annual level from 2000-present. Groundwater pumping is monitored through water meters, and surface water abstractions data are also available.

3.5. Orontes River Basin

Who is monitoring?

The Orontes Basin is a transboundary basin experiencing ongoing geopolitical instability caused by regional war (Syrian civil war) and natural disaster (2023 Turkey-Syria earthquakes). Therefore, the data and practice regarding monitoring of water use and availability varies significantly across borders. The majority of the monitoring described in this report occurs in the Lebanese portion of the basin, where Lebanese agencies such as the Lebanese Meteorological Service operate. The Assi River Basin, which is essentially the Lebanese portion of the basin, was the subject of a EU MADAD-funded project (ACTED et al., 2023) and has had significant associated monitoring. Furthermore, there was a USAID project from 2012-2016 called "Development of a Water Supply and Wastewater Systems Master Plan Within The Service Area of the Bekaa Water Establishment" that resulted in additional monitoring within the Lebanon part of the basin, which is reported in Dai/Kredo (2015). The Food and Agriculture Organization of the United Nations has developed a product to monitor evapotranspiration in part of the Orontes basin. In Turkey, Meteoroloji Genel Müdürlüğü (or the Turkish State Meteorological Service) provides data on precipitation and temperature, while in Syria, General Organization for Space and Ministry of Water resources (known as Ministry of Irrigation pre-2012) provides meteorological data. Other data from the Turkish and Syrian portions of the basin are likely available but are not reported on here.

Water availability monitoring

Four weather stations monitor precipitation and temperature in the Lebanese part of the Orontes basin, and a fifth station just outside provides data that informs understanding of these variables in the mountainous source area. There are also meteorological data collected in Syria and Turkey. It is unclear how many river gauges and streamflow monitoring stations there are in the Orontes basin. There has been irregular monitoring of river flow at multiple springs in the upstream parts of the basin during the period 2012-2022. The general characteristics of the aquifers in the Assi River Basin were described in the Assi River Basin report of ACTED et al. (2023), including estimates of natural groundwater recharge and discharge rates to/from rivers and springs. Some groundwater levels were measured in these aquifers in 1970, and well owners have information of more recent water depths. In the Lebanese part of the basin, the capacity and condition (i.e., whether in need of repair or not) of reservoirs is known but there is no further monitoring and public reporting (e.g. of storage dynamics). A few of the basin's reservoirs have storage and outflow monitoring, and some canal flows are monitored although these data are scattered across various reports.

Water use monitoring

Evapotranspiration is monitored by using the Water Productivity Open-access portal (WAPOR) product, a remote-sensing approach that provides estimation of reference evapotranspiration in the Lebanese and

Syrian parts of the basin at 100 m resolution; the WAPOR dataset does not extend into Turkey at present. In Lebanon and Syria, the data are available for annual, monthly or dekadal (10-daily) periods from 2018 to near-present, with approximately five-daily latency for dekade-scale data. Land cover/use has been monitored across the whole basin by Mhanna et al. (2023), who used a remote sensing and machine learning method to classify land into 10 categories with temporal frequency of twice per year, spanning 2004 to 2022 and with a spatial resolution of 40 m. Estimations of water use for the Assi River Basin were made in the report of ACTED et al. (2023), with domestic use estimated at the village-scale using simple water-demand calculations, and groundwater abstractions estimated at the well-scale, with private wells grouped together by village, using a groundwater model. Very precise values for the annual domestic abstractions from springs and the annual domestic abstractions from groundwater wells were included in the report, but the methodology used to generate these values was not clear. Different estimates of water demand in the Assi River Basin (Upper Orontes) were made using remote sensing approaches by Jaafar et al. (2016).

3.6. Mahanadi River Basin

Who is monitoring?

Monitoring of water use and availability in the Mahanadi basin is done by several agencies, mostly national but also state agencies (the Mahanadi basin spans both Odissa and Chhattisgarh states, as shown in *Figure 13*). The Central Water Commission, the National Remote Sensing Commission, the India Water Resources Information System (WRIS), the India Meteorological Department and the Central Groundwater Board are the national-level organisations and together, they provide most of the monitoring in the basin. Each state has a State Water Resources Department, which oversees permitting, and monitors reservoir levels and flows.

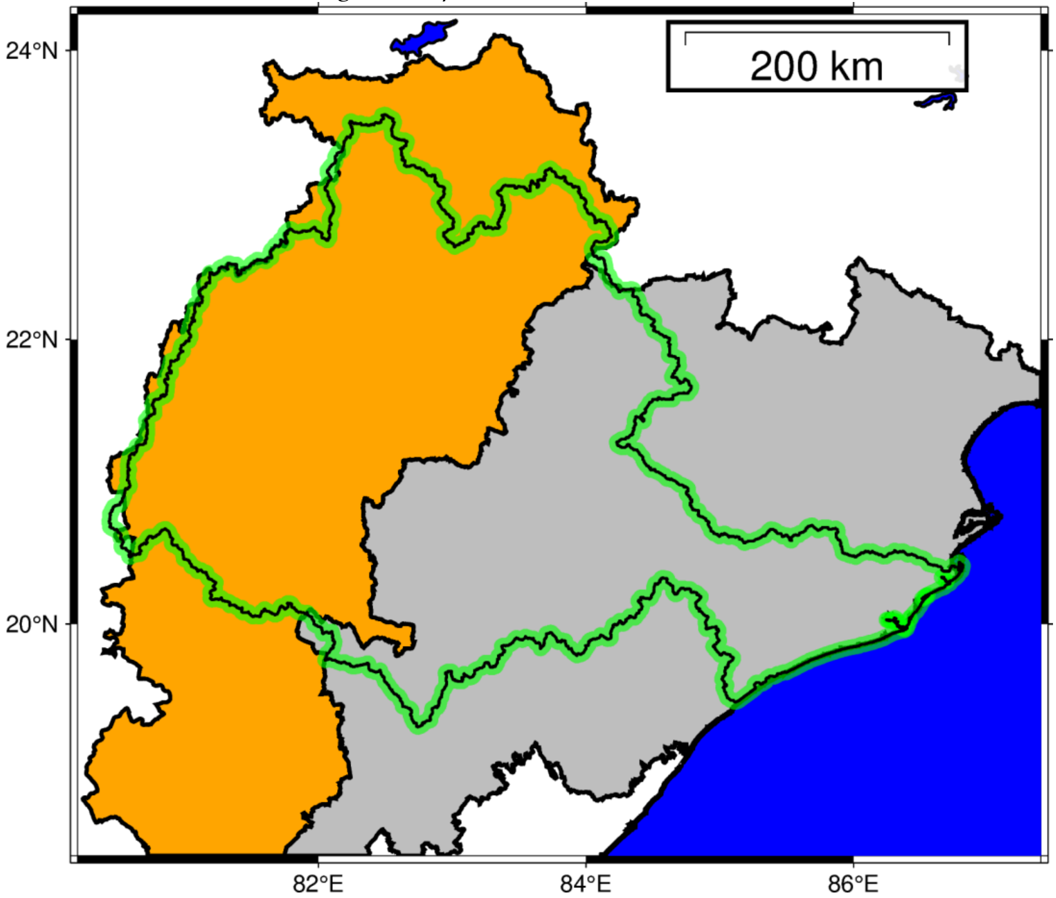

Figure 13 Map of the Mahanadi river basin (green-and-black outline) showing that the downstream portion lies in Odissa state (grey) and the upstream portion lies in Chhattisgarh state (orange).

Water availability monitoring

Precipitation is monitored at daily resolution using a network of approximately 250 stations (*Figure 14*), and there is also a gridded product that interpolates between these stations. There is a network of in-situ temperature measurements (96 stations basin-wide), but no gridded product. There are many river gauging stations that measure river levels on the Mahanadi and its tributaries, and five streamflow stations are used to monitor streamflow. Both river levels and streamflow measurements are made with daily frequency. Basic characterisation of aquifers (including extent, type, storage, other properties) exists across the basin and there is a network of over 1000 groundwater monitoring wells from which groundwater levels are measured, either monthly or seasonally. Daily measurements of reservoir levels (from which volume can be calculated) and discharge are made at 74 reservoirs in the basin, including all major reservoirs.

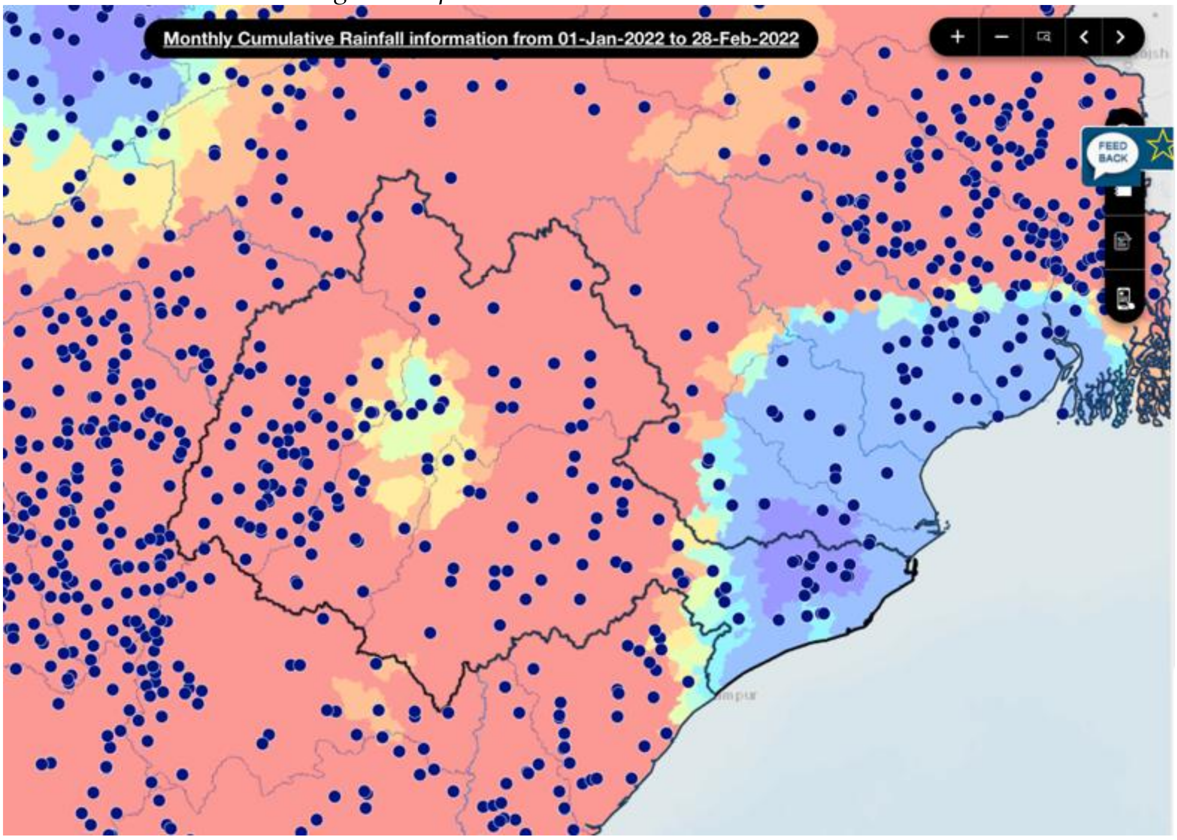

Figure 14 Screengrab of WRIS application showing locations at which precipitation measurements were made between Jan and Feb 2022. The thin black outline is the Mahanadi basin, which has an east-west dimension of 650 km. The direction of north is vertically upwards.

Water use monitoring

Evapotranspiration in the basin is estimated through a national-scale model – developed based on the VIC model – which has 25 km resolution and reports values aggregated to the scale of the entire basin. Land use/cover has been mapped in 2006 and 2020, in both cases using satellite remote sensing (from ResourceSat-1 for 2006 and using the WorldCover product developed by ESA for 2020). Agricultural productivity is not monitored at the basin level but is monitored at administrative levels. In general, there is no monitoring of water use, although local agencies may hold some data on abstractions.

3.7. Caplina-Mauri-Desaguadero System

Who is monitoring?

Monitoring of water use and availability in the Caplina-Mauri-Desaguadero basin is primarily undertaken by national agencies in Peru and Bolivia. Those involved in monitoring are: the National Meteorology and Hydrology Service of Peru (SENAMHI), the National Meteorology and Hydrology Service of Bolivia, the National Water Authority of Peru, and the Ministry of Water and Environment in Bolivia. Additional monitoring and data come from two local initiatives: the Special Project for Strengthening and Expanding the Water Resources of Tacna (PET) and the Autonomous Binational Authority of the Hydrologic System of Lake Titicaca, Desaguadero River and Lake Poopó and Salar de Coipasa (ALT).

Water availability monitoring

In Peru and Bolivia, there are networks of gauges where in-situ precipitation measurements are made at daily-to-monthly resolution, with 52 points in Peru and 27 points in Bolivia. Additionally, in Peru, the PISCOp product contains precipitation grids, with daily resolution, for the period 1981-2018. The PISCOp precipitation grids were created using a sophisticated integration of gauge data, geostatistics and information from multiple satellites (Huerta et al., 2022). However, SENAMHI has withdrawn support for PISCOp and it is unclear whether an up-to-date version is still produced. Similarly, the GMET-Bolivia product – commissioned by the Ministry for Environment and Water of Bolivia and produced by Stockholm Environment Institute -- contains grids of daily precipitation from 1980-2016, but it is unclear whether GMET-Bolivia continues to be updated (Wickel and Escobar, 2019). These gridded datasets cover the entire basin, apart from a narrow portion of the basin in the Arica-Moquegua corridor (*Figure 15*) where there is no gridded temperature data.

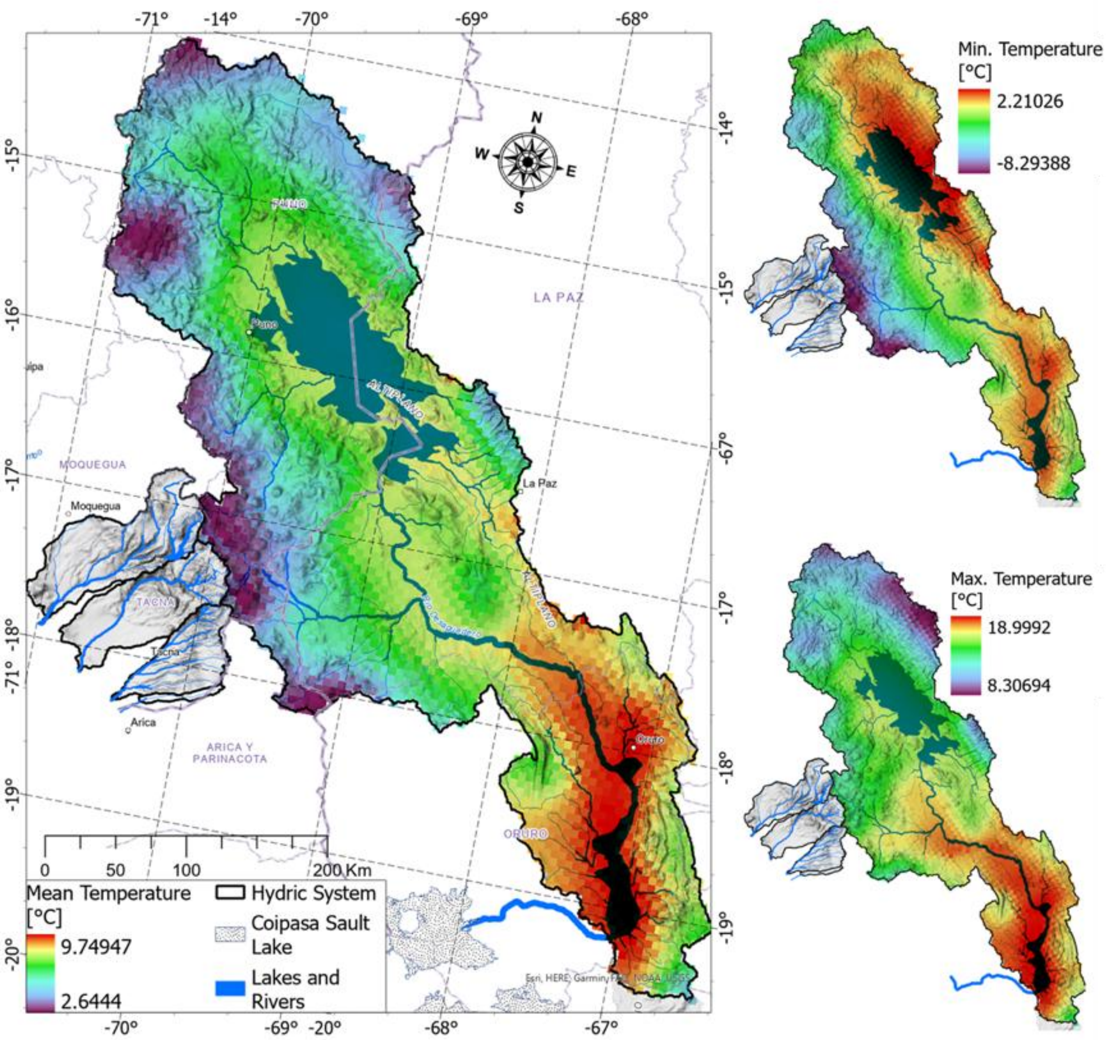

Figure 15 Illustration of the gridded temperature data products across the basin. Note the comprehensive spatial coverage with the exception of a narrow corridor between Moquegua and Arica. Source: image provided in survey response

There are approximately 30 in-situ hydrologic stations for monitoring streamflow and river stage across the basin, with all reporting either daily or monthly measurements. Boreholes/wells are used to monitor water levels in four of the basin's aquifers (El Aryo, Purapurani, Challapampa and Yarada) with typical measurement frequencies of twice per year or better. There is general characterization of these aquifers (describing type, extent, hydrogeologic parameters), and a different level of detail is known about each: the El Aryo and Purapurani aquifers are better characterised, with estimates of transmissivity and storage coefficient in the former and hydraulic conductivity and water quality in the latter, but there is only qualitative information on the other two aquifers. There are further aquifer units for which there is little or no monitoring. Reservoir levels and flows are monitored on the major lakes/reservoirs across the basin, with monthly-to-annual reports available from reservoirs in Bolivia and daily-to-monthly data from reservoirs in Peru.

Water use monitoring

Potential evapotranspiration information is available at six weather stations, three in Peru and three in Bolivia. There is a gridded product in Bolivia, an outcome of the GMET Bolivia project, which gives monthly estimates from 1980-2018. A continuous spatial map of potential evapotranspiration in Peru (excluding a slim corridor between Arica and Moquegua) was provided in the survey response, and these estimations were based on Penman Monteith methodology using data from in-situ meteorological stations (*Figure 16*).

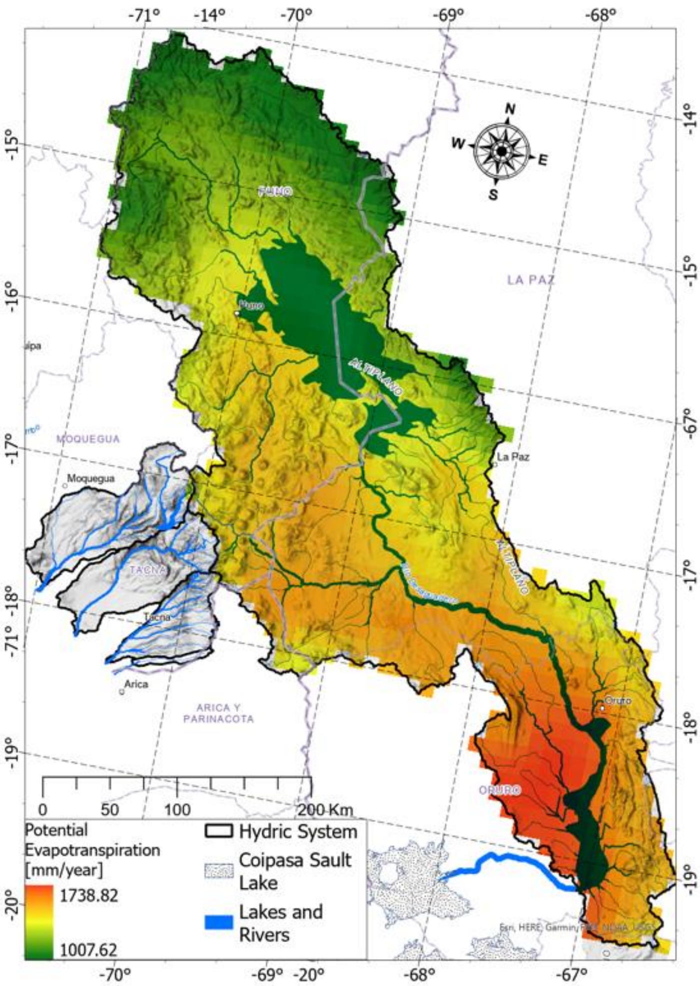

Figure 16 The potential evapotranspiration map provided in the survey response

Land use/cover monitoring is available in both the Bolivian and Peruvian parts of the basin. In the Bolivian part, land use/cover was mapped in 2010 with 30 m spatial resolution and in the Peruvian part, it was mapped in 2016 with 90 m spatial resolution. Additionally, ESA Worldcover data have been used to monitor land use/cover across the entire basin. Agricultural productivity is monitored although these data must be requested from local entity reports (Peru) and the regional survey (Bolivia). There is limited monitoring of abstractions, although in Peru a "Basin Committee" reports agricultural abstractions at monthly/annual timespan, and in Bolivia there are some estimates of potential abstractions rates based on local irrigation projects.

4. Synthesis of monitoring and implementation status

How does monitoring differ across the seven living labs? Are certain aspects of water use and availability poorly/well monitored in all cases, or do practices vary from basin to basin? Is the current monitoring sufficient to support water management and allocation decisions? To provide a basis from which to consider these questions, and to synthesize the descriptions of monitoring in this report, we developed a qualitative assessment of the monitoring in each basin. Specifically, we used the following assessment standard: "Did the monitoring in basin X meet the standard which would be required to support water accounting and management decisions relating to allocation?". We focused on four categories of water availability (meteorological, rivers, reservoirs, groundwater) and four categories of water use (evapotranspiration, land cover/use, groundwater abstractions, surface water abstractions) and defined, for each, the monitoring needed to meet the assessment standard. We provide these definitions in Annex II. We then scored each basin "limited/no monitoring", "monitored but standard not met", "standard met", or "standard exceeded" for every category, and plotted the results as grouped bar charts. These bar charts are shown in *Figure 17* (water use) and *Figure 18* (water availability).

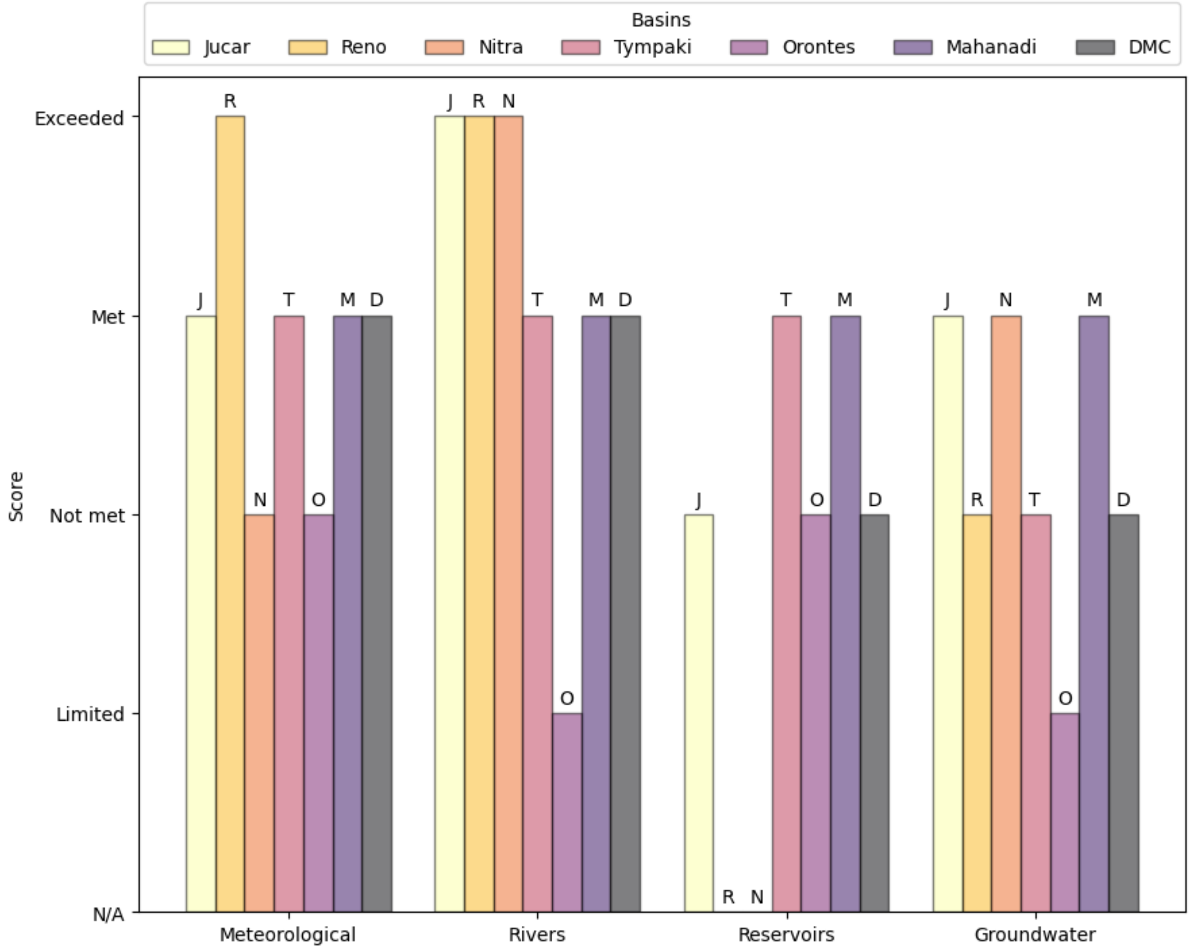

Figure 17 Grouped bar-chart showing resulting of comparative analysis for water availability across the basins. The x-axis shows each monitoring category and the y-axis shows the score. The labels above each graph code as follows: J = Jucar, R = Reno, N = Nitra, T = Tympaki, O = Orontes, M = Mahanadi and D = Desaguadero-Mauri-Caplina. N/A refers to the situation where insufficient information was available to make an assessment.

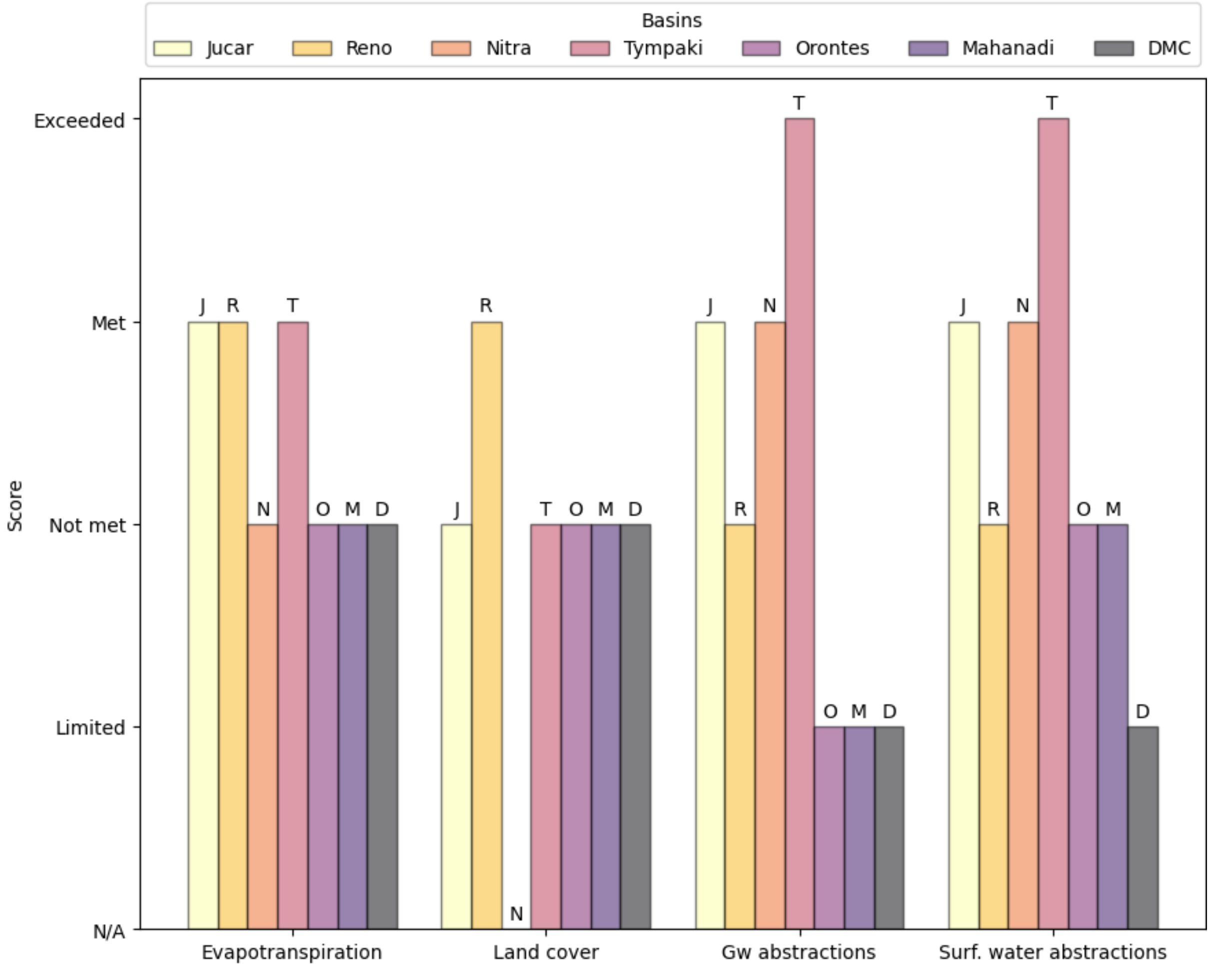

Figure 18 Grouped bar-chart showing resulting of comparative analysis for water use across the basins. The x-axis shows each monitoring category and the y-axis shows the score. The labels above each graph code as follows: J = Jucar, R = Reno, N = Nitra, T = Tympaki, O = Orontes, M = Mahanadi and D = Desaguadero-Mauri-Caplina. N/A refers to the situation where insufficient information was available to make an assessment.

The areas in which our assessment standard was most commonly met or exceeded were meteorological and rivers, indicating that there has been widespread installation of networks of weather stations and stream gauges and that these are regularly monitored. In contrast, fewer basins met our assessment standard for evapotranspiration and land cover. In the former case, this reflects the inherent difficulties in monitoring that variable. In the latter case, it may reflect a disconnect between the state of science – where studies showing uses of remote sensing and machine learning to classify land use are increasingly common – and adoption of these methodologies into practice. Surface water abstractions were more often monitored to our standard than groundwater abstractions, and we saw some deficiencies in many basins in the monitoring of reservoirs and groundwater. Generally, Jucar, Reno and Tympaki basins scored highly across most categories, whereas the challenges in monitoring in the geopolitical environment presented by the Orontes basin was reflected by it being the basin that most frequently did not meet our monitoring standards. Any assessment of monitoring against an objective standard is, by its nature, biased based on the standard that is selected. This analysis is no exception to that, and we suggest that our assessment can be used to provide a general sense of the differences in monitoring across basins and variables, but recommend caution in over-interpretation.

5. Monitoring gaps by living lab.

5.1. Jucar River Basin

Although monitoring in the Jucar basin is well developed, there remain some gaps. The method used to estimate evapotranspiration (satellite and in-situ data combined with the Penman-Monteith equation and crop coefficients) gives results that are dependent on the exact data and parameters used and, often, this can introduce significant uncertainty. In the Jucar basin, this uncertainty has not been quantified. Where CORINE Land Cover data is used, its relatively coarse resolution of 250 x 250 m and identification of broad crop categories (as opposed to specific crop types) constitutes a monitoring gap, as it may be desirable to know land cover information at higher spatial resolution and with higher crop specificity. Agricultural productivity is publicly known only at an aggregated level – the level of the province – and this is another gap as a finer resolution could be possible. (Although the ESYRCE survey contains plot-scale productivity information, it is neither spatially complete nor publicly available.) Finally, we expect that the accuracy of groundwater use monitoring is low. The first method – self-reporting by farmers in certain overdrafted areas – can be liable to error and/or manipulation, whereas the second – using remote sensing data or models to derive use volumes – can have large associated uncertainties (see, for instance, Ahamed et al., 2022).

5.2. Reno River Basin

Although monitoring in the Reno basin is generally well developed, there remain some gaps. A sophisticated model is used to estimate evapotranspiration, but the uncertainty in the evapotranspiration output has not been thoroughly quantified. Although the datasets used to monitor land cover in the Reno basin have 90 different categories for land use, there are only a few specific crop types within these categories, with many crops grouped together. This is an area in which further analysis could yield more detailed data. Finally, agricultural productivity in the Reno basin is only known at the province level, and the lack of finer-scale information on this variable is another monitoring gap.

There are also important gaps in the availability of monitoring data in the Reno basin. First, although river gauge and streamflow data are available, bulk download is difficult as primary access is through annual reports (pdf documents) rather than a single, collated dataset in a standard format (such as comma-separated value). Likewise, groundwater level data are provided in periodic reports from ARPAE, the most recent of which was ARPAE (2020), and this means it is difficult to access the most recent data and may present challenges for performing data analyses.

5.3. Nitra River Basin

The main monitoring gaps in the Nitra basin relate to spatial resolution of key variables. Additionally, it is common for monitoring data to be unavailable without specific request from the responsible agency/organisation – so there are often gaps in available data, even if monitoring is taking place. Below, we first outline the gaps in monitoring and then the gaps in available data.

There is a single weather station in the basin used for monitoring temperature and evapotranspiration. An interpolated product – for instance, one derived from remote sensing – is not used for monitoring temperature, precipitation or evapotranspiration, and this means there is a gap in monitoring the spatial variability in temperature and evapotranspiration in the basin. (Note that this gap is less pronounced for precipitation as there are 10 gauges at which that variable is measured.) There is no specific measurement or instrumentation for monitoring surface water-groundwater interactions, and this gap may be important given the significance of wetlands in the Nitra basin. There are only five boreholes where alluvial groundwater levels are made, and there could be improved spatial monitoring of the shallow groundwater levels. Minor domestic abstractions are unmonitored. The final gap that we identify is that there is no monitoring of agricultural productivity, which could become an important component of land and water use in the future.

Regarding availability of data, we identified the following gaps: precipitation and temperature data must be purchased; river monitoring data (river level and flow) must be requested from SHMÚ, except for available real-time measurements from the last 48 hours; and long timeseries of groundwater level measurements made in boreholes are not freely available and must be purchased from SHMÚ (although the most recent month of measurements are available).

5.4. Tympaki River Basin

Monitoring of water use and availability in the Tympaki basin is well developed, but we nonetheless identified a few gaps. Although there are meteorological stations in the basin, there is not an interpolated product automatically generated/readily available after 2006 for either temperature or precipitation (i.e. this has to be produced by the user using the data from the basin stations). The estimates of evapotranspiration do not contain uncertainty. The land cover monitoring using CORINE was not developed using a region-specific method, has relatively coarse resolution, and does not contain many specific crops types – therefore, there is a monitoring gap on the details of land use/cover. Agricultural productivity is only monitored at an aggregate level, and a finer level of detail might be desired. Although there are only two gauges measuring discharge (one river and one spring) in the basin, it is not considered that there is a gap in spatial monitoring of flows since streamflow is controlled, in large part, by the Faneromeni dam and the basin's water use is groundwater dominated. Finally, there were three instances where, although monitoring was undertaken, the data were not readily available online: only a subset of groundwater data were available to download, only a subset of streamflow/stage measurements were available to download, and some domestic abstractions data were private. These data can be provided upon request to the authorities, but there are applications where immediate availability of data could be desired.

5.5. Orontes River Basin

Many variables are monitored only in a sub-part of the Orontes basin, and there are some variables which were not monitored at all. In the following paragraph, we identify several of the key monitoring gaps in the basin.

A region-specific interpolated product for precipitation and temperature is not available in the basin, and there are only a handful of weather stations, all of which are in Lebanon. Hence, there is a monitoring gap in the spatial variation of precipitation and temperature. The evapotranspiration data available from WAPOR does not have a closely quantified uncertainty, which could lead to erroneous interpretations especially given the high cost and technical challenges of validating evapotranspiration estimates. Additionally, there is an evapotranspiration monitoring gap in Turkey, which is beyond the coverage of WAPOR.

Little is known across the basin about streamflow, river levels, reservoir levels or reservoir discharge, and the information that is gathered is not available without request. There is therefore a substantial gap in the monitoring of surface waters of the Orontes basin. In upstream areas of the basin, there is a lack of monitoring related to snowmelt and spring discharge dynamics, and while snowfall in the high mountains is likely to be hydrologically important in the Orontes basin, there are no data monitoring the extent, thickness, or volume of the snowpack. Groundwater information is only known for a small area in Lebanon, and in this area the latest groundwater level measurements are from 1970; this constitutes a significant monitoring gap in the extent, status and availability of groundwater in the basin.

Information on water use/abstractions is limited to estimates for the Lebanon portion of the basin, and these estimates are not corroborated by in-situ monitoring; there is a general monitoring gap in water use. Likewise, there is no information on agricultural productivity. Finally, although a dataset of land cover/use information across the entire basin was produced by Mhanna et al. (2023), there were only 10 classification categories and there is a monitoring gap in the specific crops being cultivated. This product is also static in time (i.e., not being updated), and the code/model used are not available, hindering efforts for future monitoring of land cover change.

Overall, there are large biases in data availability towards the smaller upstream part of the basin in Lebanon, with much lower access to data in Syria and Turkey. Further investigation is needed to determine if this is the result of monitoring not occurring in these downstream countries, or difficulties in access and sharing across countries.

5.6. Mahanadi River Basin

We identified several key monitoring gaps in the Mahanadi basin. Although there was an interpolated precipitation product, there was no interpolated temperature product provided, limiting understanding of spatiotemporal temperature variations. Evapotranspiration information is only available at the basin or district level and is primarily derived from a hydrological model, rather than through direct monitoring. Further, the evapotranspiration estimates do not contain uncertainty – this could be a significant monitoring gap as uncertainties in modelled evapotranspiration can be large. A related monitoring gap is the low temporal detail of land cover mapping. Land cover has been mapped twice in two decades, and these maps do not identify specific crop types. In the case of the 2020 survey, the land cover mapping did not use a region-specific methodology, so may be prone to inaccuracies.

In terms of surface water hydrology, one data gap in the Mahanadi is the relatively small number and uneven distribution of streamflow measurements, including of canal systems, within the basin. Although the basin's aquifers have been characterized at the broadest scale, there is a monitoring gap in finer-scale aquifer characteristics. Groundwater abstractions are not monitored, despite groundwater being the primary source of water for many agricultural and domestic users. Finally, agricultural productivity is available only at the state/province level, and there could be opportunities to improve monitoring by developing estimates of productivity at higher spatial resolution, supporting targeting of interventions around water use efficiency and productivity.

In addition to the monitoring gaps described above, some of the monitoring data that are collected in the Mahanadi basin are not readily available, either requiring request or purchase from the agency that collected them. This includes: in-situ temperature data (must be purchased), river gauge and streamflow data (data freely available but bulk download difficult), reservoir data (must be requested), and water use data (must be requested).

5.7. Caplina-Mauri-Desaguadero System

In the Caplina-Mauri-Desaguadero basin, some monitoring data are gathered but not available without request or purchase from the agency that made them. We identified the following gaps of this kind:

- Stream flow/stage measurements
- Reservoir data
- Groundwater level data
- Agricultural productivity data

We further identified some gaps where monitoring is absent or could be improved. Regarding land use/cover, detailed land cover mapping has only been done once in each basin, meaning it is not known how land use/cover has evolved over time and limiting our ability to understand how it may change under future policies or climate change. Additionally, the available land cover mapping does not identify specific crops, only broader categories, and is largely based on global land cover mapping products (ESA WorldCover) that have significant unquantified uncertainties at local to national scales. There are several monitoring gaps around groundwater. Some aquifers are entirely un-monitored, constituting a major gap. Saltwater intrusion has been identified in the Yarada aquifer but this is not monitored in three or four dimensions (as can be done using modern geophysical methods, see e.g. Panthi et al., 2023 or Goebel et al, 2019). Another gap is the lack of a complete inventory of surface water bodies in the basin. Finally, the glaciers in the high mountains have important hydrologic utility but not all of these are monitored, representing another data gap.

A final category of monitoring gap in the Caplina-Mauri-Desaguadero basin is that some datasets are not continuous over boundaries, both national boundaries and boundaries between the three constituent watersheds. In this category, we identified the following gaps:

- Gridded temperature and evapotranspiration data do not extent to the Caplina basin.
- Abstractions data are unavailable in the Mauri and Desaguadero basins, and where these data do exist, the completeness is uncertain.
- The gridded precipitation and temperature data datasets are different in Bolivia and Peru.

Summary

The seven living labs, each with their own geography, hydrology and socio-economic backdrop, contain a diverse range of water use and availability monitoring. In each, the monitoring is designed to best meet that basin's needs with the available resources. It is interesting to compare global monitoring trends to those observed in the living labs. Globally, there is a growing acknowledgement of a discrepancy in streamflow monitoring between wealthy nations and developing countries, with developing countries typically falling behind and seeing a reduction in their monitoring capacity while monitoring networks in wealthy countries are being sustained and expanded (Ad Hoc Group on Global Water Data Sets, 2001; Crochemore et al., 2020; Hannah et al., 2011; Ruhi et al., 2018). We saw some evidence for this in the seven living labs, as streamflow monitoring was of good standard across the labs (*Figure 17*), apart from in the Orontes basin. Groundwater monitoring was more heterogeneous across the living labs. Some labs (e.g. Jucar) have extensive hydrogeological monitoring networks, yet even here spatial aquifer dynamics are not fully captured. In other cases (e.g. Mahanadi, CMD), aquifers are not fully characterised and intelligence about groundwater storage dynamics is limited or insufficient in spatiotemporal detail.

Globally, there is some evidence for a similar trend with hydrometeorological observation stations, although most of the evidence of declining monitoring comes from sub-Saharan Africa (Giles, 2005; Walker et al., 2016). In the living labs analysed here, we do generally observe a higher standard of climatological monitoring in the wealthier countries, with the most advanced monitoring occurring in Reno and Jucar. Several of the basins (e.g. Orontes) have operational systems for monitoring actual evapotranspiration which could be used as a proxy for water usage by agriculture. However, none quantify or report uncertainties in these data, and in some cases monitoring is limited to only potential evapotranspiration which is insufficient to support water accounting policy and management.

Across all TRANSCEND's living labs, agriculture is the main land use and water user in some or at least part of the basin. A common theme is that monitoring of water abstractions and land use by agriculture is limited, consistent with global trends identified in the Deliverable 4.1 of TRANSCEND (monitoring white paper). Abstraction data where captured are often at aggregated spatial or temporal scales (e.g. CMD basin), based on self-reported data from farmers and other users (e.g. Jucar), or only capturing licensed volumes rather than actual use (e.g. Reno). We do not directly assess prevalence of illegal or unregulated water abstraction in this report, but anecdotal evidence from local partners and wider experience suggests this is likely to constitute a further gap in abstraction monitoring datasets. Land use monitoring typically only captures discrete historic snapshots of the distribution of general land cover classes (e.g. forest vs cropland), with no basins having in place a system for continuous disaggregated monitoring of land cover changes over time under future change.

The information collated in this report will be valuable in directing TRANSCEND activities. The general description of each basin's hydro-geographic characteristics will support both modelling and monitoring activities across the TRANSCEND project, while the identification of monitoring gaps will support discussions on where to direct the development of new technologies. Overall, the information contained in this report will provide an important foundation for the knowledge development activities within TRANSCEND.

References

ACTED, WeWorld-GVC, BTD, 2023. Consultancy Services for River Basin Management El Assi River Basin Baseline Report.

Ad Hoc Group on Global Water Data Sets, 2001. Global water data: A newly endangered species. Eos, Transactions American Geophysical Union 82, 54–58. https://doi.org/10.1029/01EO00031

AEMET, 2024. Datos diarios - Datos observacionales - Rejilla ROCIO_IBEB 5km [WWW Document]. URL https://www.aemet.es/es/serviciosclimaticos/cambio_climat/datos_diarios?w=2 (accessed 2.26.24).

Ahamed, A., Knight, R., Alam, S., Pauloo, R., Melton, F., 2022. Assessing the utility of remote sensing data to accurately estimate changes in groundwater storage. Science of The Total Environment 807, 150635. https://doi.org/10.1016/j.scitotenv.2021.150635

Amarasinghe, U.A., Sharma, B.R., Aloysius, N., Scott, C., Smakhtin, V., de Fraiture, C., 2005. Spatial Variation in Water Supply and Demand across River Basins of India, Research Report. International Water Management Institute.

Antolini, G., Auteri, L., Pavan, V., Tomei, F., Tomozeiu, R., Marletto, V., 2016. A daily high-resolution gridded climatic data set for Emilia-Romagna, Italy, during 1961–2010. International Journal of Climatology 36, 1970–1986. https://doi.org/10.1002/joc.4473

ARPAE, 2020. Groundwater report of Emilia-Romagna 2014-2019.

Beck, H.E., McVicar, T.R., Vergopolan, N., Berg, A., Lutsko, N.J., Dufour, A., Zeng, Z., Jiang, X., van Dijk, A.I.J.M., Miralles, D.G., 2023. High-resolution (1 km) Köppen-Geiger maps for 1901–2099 based on constrained CMIP6 projections. Sci Data 10, 724. https://doi.org/10.1038/s41597-023-02549-6

Confederación Hidrográfica del Júcar, 2023. PLAN HIDROLÓGICO DE LA DEMARCACIÓN HIDROGRÁFICA DEL JÚCAR - MEMORIA - ANEJO 2 INVENTARIO DE RECURSOS HÍDRICOS.

Crochemore, L., Isberg, K., Pimentel, R., Pineda, L., Hasan, A., Arheimer, B., 2020. Lessons learnt from checking the quality of openly accessible river flow data worldwide. Hydrological Sciences Journal 65, 699–711. https://doi.org/10.1080/02626667.2019.1659509

DAI/KREDO, 2015. Water supply and wastewater systems master plan for the Bekaa water establishment.

Estrela, T., Aránzazu, F., Fullana, J., Maestu, J., Pérez, M.A., Pujante, A.M., 2004. Jucar Pilot River Basin - Provisional Article 5 Report.

Fanack Water, 2022. Lebanon Water Report: Shared Water Resources in Lebanon.

Giles, J., 2005. Solving Africa's climate-data problem. Nature 435, 863.

Goebel, M., Knight, R., Halkjær, M., 2019. Mapping saltwater intrusion with an airborne electromagnetic method in the offshore coastal environment, Monterey Bay, California. Journal of Hydrology: Regional Studies 23, 100602. https://doi.org/10.1016/j.ejrh.2019.100602

Hannah, D.M., Demuth, S., van Lanen, H.A.J., Looser, U., Prudhomme, C., Rees, G., Stahl, K., Tallaksen, L.M., 2011. Large-scale river flow archives: importance, current status and future needs. Hydrological Processes 25, 1191–1200. https://doi.org/10.1002/hyp.7794

Herrera, S., Fernández, J., Gutiérrez, J.M., 2016. Update of the Spain02 gridded observational dataset for EURO-CORDEX evaluation: assessing the effect of the interpolation methodology. International Journal of Climatology 36, 900–908. https://doi.org/10.1002/joc.4391

Huerta, A., Lavado-Casimiro, W., Felipe-Obando, O., 2022. High-resolution gridded hourly precipitation dataset for Peru (PISCOp_h). Data in Brief 45, 108570. https://doi.org/10.1016/j.dib.2022.108570

Jaafar, H., King-Okumu, C., Haj-Hassan, M., Abdallah, C., El-Korek, N., Ahmad, F., 2016. Water resources within the Upper Orontes and Litani Basins: A balance, demand and supply analysis amid the Syrian refugees crisis. International Institute for Environment and Development.

Mhanna, S., Halloran, L.J.S., Zwahlen, F., Asaad, A.H., Brunner, P., 2023. Using machine learning and remote sensing to track land use/land cover changes due to armed conflict. Science of The Total Environment 898, 165600. https://doi.org/10.1016/j.scitotenv.2023.165600

Myriam, S.-S., Ahmed, H.A., Omar, S., François, Z., Ronald, J., 2018. Groundwater Balance Politics: Aquifer Overexploitation in the Orontes River Basin 11.

Panthi, J., Boving, T., Pradhanang, S.M., Ismail, M., 2023. Time-Lapse Geophysical Measurements for Monitoring Coastal Groundwater Dynamics in an Unconfined Aquifer. Groundwater n/a. https://doi.org/10.1111/gwat.13382

Peral García, C., Navascués Fernández-Victorio, B., Ramos Calzado, P., 2017. Serie de precipitación diaria en rejilla con fines climáticos. Agencia Estatal de Meteorología. https://doi.org/10.31978/014-17-009-5

Pérez-Martín, M.A., Estrela, T., Andreu, J., Ferrer, J., 2014. Modeling Water Resources and River-Aquifer Interaction in the Júcar River Basin, Spain. Water Resour Manage 28, 4337–4358. https://doi.org/10.1007/s11269-014-0755-3

Piña-Rey, A., González-Fernández, E., Fernández-González, M., Lorenzo, M.N., Rodríguez-Rajo, F.J., 2020. Climate Change Impacts Assessment on Wine-Growing Bioclimatic Transition Areas. Agriculture 10, 605. https://doi.org/10.3390/agriculture10120605

Ruhi, A., Messager, M.L., Olden, J.D., 2018. Tracking the pulse of the Earth's fresh waters. Nat Sustain 1, 198–203. https://doi.org/10.1038/s41893-018-0047-7

Walker, D., Forsythe, N., Parkin, G., Gowing, J., 2016. Filling the observational void: Scientific value and quantitative validation of hydrometeorological data from a community-based monitoring programme. Journal of Hydrology 538, 713–725. https://doi.org/10.1016/j.jhydrol.2016.04.062

Wickel, B., Escobar, M., 2019. GMET in Bolivia: building gridded climate datasets for water resource studies, SEI Brief. Stockholm Environment Institute.

Zwahlen, F., Bakalowicz, M., Gonzalez, R., Asaad, A.H., Jaubert, M.S.-S.& R., 2016. Groundwater flow in the Orontes River basin and the Syria–Lebanon water sharing agreement, in: Karst without Boundaries. CRC Press.

Annex I

1. Monitoring Systems and Data

This section should provide an overview of the main systems and infrastructure used to monitor water use and availability within your basin. These can be either in-situ monitoring, or can also include satellite or other remotely-sensed products if these are used in the monitoring and management of water quantity by stakeholders in the basin. Add additional rows if there any categories of monitoring data relevant to your basin not captured by the table below, and note any monitoring data types for which no data is collected or available in your basin. Note that it is not necessary to record information about water quality data and monitoring.

Variable	Method of collection (e.g. in-situ gauge, flow meters, satellite, model, etc)	Spatial resolution (e.g. point, 5km grid, district, etc)	Spatial extent (state area covered or number of points where data is collected)	Temporal resolution (e.g. hourly, daily, etc)	Temporal extent (stated range of years covered, or specific year(s) if data is only for specifics periods)	Which agencies are responsible for data collection, reporting, and providing access to these data?	Are these data available freely and publicly? (yes/no)		Web link to dataset or data description
							If yes, how can they be accessed and from what source?	If no, how can data be requested and with what restrictions?	
Streamflow									
River levels or stages									
Groundwater levels or depths									
Groundwater storage or aquifer thickness									

Soil moisture									
Precipitation									
Temperature									
Potential evapotranspiration									
Actual evapotranspiration									
Land cover mapping									
Land cover change mapping									
Agricultural land use and/or crop type mapping									
Agricultural production (e.g. crop yields)									
Water abstraction rights and permits (surface water)									
Water abstraction rights and permits (groundwater)									
Agricultural water abstractions									

(surface water)									
Agricultural water abstractions (groundwater)									
Domestic water abstractions (surface water)									
Domestic water abstractions (groundwater)									
Industrial or energy water abstractions (surface water)									
Industrial or energy water abstractions (groundwater)									
Reservoir levels or storage									
Dam outflow releases									
Hydropower dam energy outputs									
Canal flows or water levels									

2. Climate

This section should provide an overview the current and recent historic hydro-climatic conditions in your river basin. Information should be separated into three sub-sections focusing on: (1) precipitation, (2) temperature, and (3) evapotranspiration. Include maps, figures, and tables to support the description of your basin's hydro-climatic conditions and features (e.g. maps or time series of precipitation, map of climate classification zones, etc).

2.1. Precipitation (provide indicators of total precipitation over the basin in millimetres, including its spatial distribution and temporal variation both inter-annually and intra-annually)

2.2. Temperature (provide indicators of average, maximum and minimum temperatures over the basin in degrees Celsius, including the spatial and temporal (between years and within years, e.g. monthly/seasonal) variation)

2.3. Evapotranspiration (provide indicators of actual and potential evapotranspiration over the basin in millimetres, including its spatial distribution and temporal (between years and within years, e.g. monthly/seasonal) variation)

3. Hydrology

This section should provide an overview of the main hydrological processes and units that contribute to water supply and availability within your river basin. Information should be separated into four sub-sections focusing on: (1) streamflow, (2) groundwater, and (3) lakes and wetlands, (4) other features unique to your basin such as glaciers or snowmelt. Include maps, figures, and tables to support the description of your basin's hydrology (e.g. maps of streamflow network or aquifer bodies, discharge time series plot for major rivers, etc).

3.1. Streamflow (provide information about the locations of main rivers and sub-catchments in the basin. For each provide indicators of streamflow rates in units of m^3/sec (or as an equivalent cumulative volume over a specified time period), including the temporal (between years and within years, e.g. monthly/seasonal) variation in streamflow rates and any trends over time)

3.2. Groundwater (provide information about the locations of main aquifer bodies in the basin including their key geological characteristics. For each, provide indicators of the aquifer extent (km^2), storage (km^3), water levels (m), and any trends in water availability over time).

3.3. Lakes and Wetlands (provide information about the locations of main lakes or wetlands in the basin and any associated freshwater ecosystems. For each, provide indicators of the lake/wetland extent (km^2), storage (km^3), and/or water levels (m), and any trends in water availability over time).

3.4. Other features (e.g. glaciers, snowmelt – as above provide relevant quantitative and qualitative information, such as glacier size/extent and its change, to support your description).

4. Land Use and Land Cover

This section should provide an overview of the main types of land use and land cover within your basin, covering key categories such as agriculture, forests, urban settlements, natural ecosystems, etc. Information should be separated into two sub-sections focusing on describing the: (1) current land use and land cover; and (2) historic land use and land cover changes. Include maps, figures, and tables to support the description of your basin's land use and land cover (e.g. maps of irrigated and rainfed croplands, land cover change maps or tables, etc).

4.1. Current land use and land cover (provide information about the current land area in hectares – or as a percentage of total basin area – covered by different land cover types, including the spatial distribution of land cover types across the basin. Please disaggregate agricultural land use statistics by crop types and by rainfed vs irrigated production, including information about seasonal differences in land cover and crop yields (tonne/ha) where information on this is available)

4.2. Historic land use and land cover changes (provide quantitative and/or qualitative information about any major changes in land cover that have occurred in the basin over recent decades – i.e. the past 10-30 years. Please include specific information about changes in agricultural land use including changes in total area under production, the types of crops grown, and the areas of irrigated vs rainfed production)

5. Water Abstraction

This section should provide an overview of the major types of human water abstractions and use in your basin. Information should be separated into four sub-sections focusing on overall water use and sectoral breakdown by: (1) agriculture, (2) domestic and urban, (3) industrial and energy generation. Include maps, figures, and tables to support the description (e.g. maps of water rights, summary table of sectoral water use breakdown, etc).

5.1. Total water abstraction (provide information about the total volumetric human water abstraction (million m^3 or equivalent), how this varies spatially and temporally (between years and within years, e.g. monthly), and the breakdown by surface water vs groundwater sources. Please note any key trends (increasing or decreasing abstraction) over time and the sectoral drivers of these trends).

5.2. Agricultural water abstraction (provide information about the total volumetric agricultural water abstraction (million m^3 or equivalent), how this varies spatially and temporally (between years and within years, e.g. monthly), the breakdown by surface water vs groundwater sources and between different crop types).

5.3. Domestic and urban water abstraction (provide information about the total volumetric urban water abstraction (million m^3 or equivalent), how this varies spatially (e.g. between different urban centres) and temporally (between years and within years, e.g. monthly), and the breakdown by surface water vs groundwater sources).

5.4. Industrial and energy generation water abstraction (provide information about the total industrial and energy generation water abstraction (million m^3 or equivalent), how this varies spatially (e.g. between different urban centres) and temporally (between years and within years, e.g. monthly), and the breakdown by surface water vs groundwater sources).

6. Water Infrastructure

This section should provide an overview of the major types of human water supply and monitoring infrastructure in your basin. Information should be separated into two sub-sections focusing on: (1) dams and reservoirs, (2) large canals and river transfers/diversions. Include maps, figures, and tables to support the description of your basin's key water infrastructure (e.g. maps of dam locations, diversion schemes etc).

6.1. Dams and Reservoirs (provide information about the name, date of construction, location and associated rivers, storage capacity (million m^3 or equivalent), and purposes of use (including quantitative information about size or capacity of any associated irrigation or hydropower) of each major dam and reservoir. For smaller reservoirs and dams, note what is known about the numbers of these infrastructure and their impacts on catchment hydrology).

6.2. Canals and River Transfers (provide information about the name, date of construction, locations and associated rivers that are connected by the canal or transfer infrastructure, conveyance capacity or flow rates (in m^3/sec or equivalent volume over a specified time period, purposes of uses (e.g. if schemes are used to divert water for irrigation, cities, etc)).

Annex II

Here, the monitoring needed to meet the assessment standard: "Did the monitoring in basin X meet the standard which would be required to support water accounting and management decisions relating to allocation?" is provided for each monitoring category.

1. Water Use

1.1. Meteorological

Here, 'meteorological' refers to monitoring of precipitation and temperature. Monitoring needed to meet assessment standard: Coverage of both precipitation and temperature monitoring across the basin, with different elevations and/or climate zones are represented – this can be achieved through a dense in-situ network of monitoring sites, or a high-quality gridded product, or a combination of both. Measurement sampling rate of daily or better, and historic records of several decades (to provide climate normals).

1.2 Rivers

Monitoring needed to meet assessment standard: Measurements of streamflow and river stage at multiple points on the main river - particularly before/after areas where abstractions are made and/or significant inflows are expected - and on all significant tributaries. Measurement sampling rate of daily or better. Streamflow can be monitored either directly or through discharge-stage relations.

1.3 Reservoirs

Monitoring needed to meet assessment standard: Daily measurements on all reservoirs (apart from small/unused reservoirs) of volume, inflow, and outflow.

1.4 Groundwater

Monitoring needed to meet assessment standard: Piezometric network that covers all major aquifer bodies and measures groundwater levels with sampling rate of bi-monthly (once per two months) or better. Well-characterized aquifer hydrogeology (physical parameters, well yields, extent, etc.) with well yields reassessed periodically where heavy use occurs.

2. Water Availability

2.1 Evapotranspiration

Monitoring needed to meet assessment standard: spatially dense coverage – either through gridded product or in-situ stations – of actual evapotranspiration over major agricultural areas, with ability to understand the difference between growing season and non-growing season, as well as dry and wet years.

2.2 Land cover/use

Monitoring needed to meet assessment standard: annual record of which crops are being grown, with a high level of specificity (i.e., more specific than "field crops" vs "tree crops"). Monitoring can be at aggregated scale if the aggregation level is appropriate for water allocation (for instance, aggregated to water delivery units would be appropriate). There should be a sufficiently long record (10 years or more) to see long-term trends.

2.3 Groundwater abstractions

Monitoring needed to meet assessment standard: Aggregate and local monitoring of annual pumping volumes, with breakdown by sector (agriculture, domestic, industry).

2.4 Surface water abstractions

Monitoring needed to meet assessment standard: Aggregate and local monitoring of annual abstracted volumes, with breakdown by sector (agriculture, domestic, industry).