Climate zoning under climate change scenarios in the basin of Lake Urmia and in vicinity basins

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Abstract
A study of climate change scenarios is presented in this paper by projecting the model of recorded precipitation/temperature data into three future periods by statistical downscaling methods through LARS-WG with data from 7 synoptic stations. The study area largely spans the closed basin of Lake Urmia with overlaps to some of the surrounding basins. The model is at two stages (the downscaling stage comprises the following: (i) it uses large-scale GCM models to provide climate variables (predictors), and (ii) the outcomes are downscaled to the local climatic variables for correlating with the observed time series (e.g. rainfall) for the period of T0, 1961–2001—40 years; the projecting stage comprises the derived precipitation/temperature values at T0 to T1: 2011–2030; T2: 2046–2065; and T3: 2080–2099 periods at synoptic stations using three standard scenarios of A1B, A2, and B1). The outputs are used to map the climate zones, which show the following: (i) climates at T1 are still similar to T0, and if there is any declining trend in precipitation during both periods, they are small to the extent that the shrinkage of Lake Urmia is unlikely to be driven by climate change; (ii) changes are likely at T2 and T3 periods including climatic regimes may turn peakier at the northern and drier at central regions; and (iii) precipitation is likely to decrease in some of the zones at T2 and T3 periods. This underpins the need for more responsive policymaking, and should this not be realised in the near future, the prospect seems bleak in terms of serious damages to Lake Urmia, depleting aquifers and subsequent immigration from the region, but can be averted by responsive planning.

1 Introduction
The distressed state of Lake Urmia, quite publicised even on the international scale, has been purportedly attributed to climate change by some researchers but not all, and as such, the message is mixed and confusing. While scientific evidence for worldwide climate change is overwhelming, it is a process that has kicked off and inflicts its initial impacts, but not necessarily a singular agent of disaster yet. The substantial amount of shrinkage of Lake Urmia took place in the living memory between 1990 and 2010, during which some 40 dams were constructed in this small basin, and this alone should be the first candidate for its shrinkage rather than climate change. An investigation is therefore presented here to examine potential trends in the region, covering both the basin of Lake Urmia and some of its surrounding basins with respect to the availability of the amount of water. Although the scope of the study is regional, the focus of the paper is on the basin of Lake Urmia with the projection of existing precipitation data towards the future by presenting the results of a LARS-WG model to gain an insight into the future conditions. The emerging insight from climate change modelling will touch on the depleting groundwater aquifers, and the role of policymaking.

The paper uses the science of climate change to study the climatic zoning of the basin of Lake Urmia and of some of the overlapping basins through a best practice modelling study. There are also to delineate study into areas to zones within different spatiotemporal resolutions.
The overwhelming international evidence for climate change is the driver for this topical research into the risk of climate change in the basin of Lake Urmia, to provide the basis to learn, among other things, local impacts to the drying of Lake Urmia. Any reference to climate change, arguing that this should be with caution of the industry-norm software applications, for the climate zoning of the study area. It uses local data and estimates correlations between the local and global data for generating future weather data under climate change drivers. LARS-WG is used widely, which randomises weather data generation models and is capable of generating daily precipitation, radiation, and maximum and minimum daily temperatures in a synoptic weather station under current conditions and future climate drivers. The results are taken further to delineate climate zone maps, and for this end, two widely used techniques of De Martonne Index and Köppen-Geiger climate classification method are employed to understand through the results.

2 Review of past studies on climate change for the Urmia Basin

Lake Urmia is between East and West Azerbaijan provinces in northwest Iran and is located in a geographical position near Turkey, and these provinces form a large proportion of the basin of Lake Urmia. Although the study area covers both the basin of Lake Urmia and some of the surrounding basins, the focus of the review here is on the lake as it is a topical research. The lake is located just 150 km to the east of Lake Van in Turkey, and a comparison of their water levels is given in Fig. 1. The figure shows a striking similarity until the year 2000 but a drastic decline in the water levels of Lake Urmia since then. Climatic studies in both countries are therefore relevant to a better understanding of the study area, which covers the basin. Some of the past studies related to the basin of Lake Urmia are presented in Table 1.

The various directions of research concerning the study area include climate change studies, trends in streamflows of some of the watercourses flowing to the lake as well as those of other hydrological variables, and prediction of water levels of the lake. These are reviewed for the study area with a focus on Lake Urmia and outlined for Lake Van. A study of trends in various hydrological variables may or may not detect any trend. The paper is not critically reviewing these published papers but is focussed on attributing any trend to climate change, arguing that this should be with caution of not encouraging no action to the restoration of Lake Urmia.

2.1 The shrinkage of Lake Urmia and its status now

Dam constructions in the basin of Lake Urmia were focussed on their physical provisions without any attention to their Environmental Impact Assessment (EIA) or even Strategic Environmental Assessment (SEA). Although the law for EIA was introduced in 1994 and the bill for the inclusion of SEAs in projects was considered in (2017–2021) during the 6th five-year national development plans, the applications of any
EIA then and now to the dams in the basin of Lake Urmia is still questionable, and the applications of EIA and SEA are generally loose in Iran, to say the least. It is not surprising that the minimum ecological flow through the dams into Lake Urmia is yet to be enforced in a transparent way. This minimum requirement was well established by a report (IMPI-LUB 2010), in which United Nations Development Plan (UNDP) was participating. This minimum value per annum is equal to 3 Billion Cubic Metres (BCM), with s corresponding water level.

The protection of wetlands including Lake Urmia is the broad responsibility of the Department of Environment (DoE) in Iran. This is a governmental department under the office of the president. The report (IMPI-LUB 2010), prepared by collaborating with UNDP, states that if this flow is maintained, ‘the Lake would continue its normal ecological functions including supporting biodiversity and Artemia reproduction’. It is almost certain that the flow to Lake Urmia has been effectively cut off, possibly since 1995. This is the key to its shrinkage, but it is normally discarded in various modelling studies. The outcome is the primary factor contributing to the shrinkage of the lake to the extent that its surface is now as low as 5% of what it was in 1990. Sadeghfam et al. (2022) discuss further aspects of the problem.

2.2 Climate change studies

A study of climate change in Iran by Amiri and Eslamian (2010) is indicative of increases in the average temperature in Iran by 2100 in the range of 1.5–4.5 °C should the CO₂ concentration doubles by then, and as such considerable impacts on water resources would be impending in the future. Abbaspour et al. (2009) investigated impacts of climate change on water resources in Iran using the SWAT model by generating future conditions under three scenarios A1B, A1, and B2. They found that in general, wet regions of the country will likely receive more rain, while those in dry regions will be likely to receive less. Sadeghfam et al. (2021) studied impacts of climate change on precipitation in Gilan province in Iran but considered the neighbouring meteorological data from Ardabil province using the SDSM software. They aimed to improve the robustness of their downscaling model by using Inclusive Multiple Modelling (IMM) practices, as discussed by Khatibi and Nadiri (2020) and Khatibi et al. (2020). Their projected results indicate a likely reduction in precipitation around Ardabil province in the future. Notably, Ardabil province is also included in the study presented in the paper, and this provides an opportunity to corroborate the respective results.

Systematic studies on baseline and recent climatic changes in Turkey are outlined by various studies. One study (see https://www.climatechangepost.com/turkey/climate-change/) outlines climate change impacts on precipitation as follows. In general, precipitation decreases in the T3 period with respect to T0 (1961–1990) along the Aegean and Mediterranean coasts and increases along the Black Sea coast of Turkey. Central Anatolia shows little or no change in precipitation. The most severe (absolute) reductions will be observed on the southwestern coast. These observations are valid both for the annual and the winter totals, according to which different climate change scenarios are likely to inflict a decrease of 5% in mean annual precipitation by 2030. In 2050, mean annual precipitation is likely to decrease by approximately 10%. Decreases are likely in precipitation in all months with sharp decreases in spring and autumn because summers in the region are already dry.

Ahmadaali et al. (2017) evaluate the indices of environmental and agriculture sustainability using performance criteria influenced by climate change and water management strategies for the River Jighati (Zarrinehrud) and River Tatovu (Siminehrud) basins, the largest basins in the basin of Lake Urmia. Their results are indicative of highest values of indices of environmental and agricultural sustainability to stem from the scenario of combining the crop pattern change with improving
| Papers                                      | Scope (river, or sub-basin basin) | Length of data                                      | Methods                                                                 | Trend detection (Y/N) |
|---------------------------------------------|-----------------------------------|----------------------------------------------------|-------------------------------------------------------------------------|-----------------------|
| Abbaspour et al. (2009)                     | 37 climate stations across the country | 22 Yr (1980–2002) Discharges and rainfall          | Canadian Global Coupled downscaling and SWAT model                       | Yes: trend is detected |
| Alizade Govarchin Ghale et al. (2017)        | Lake Urmia Basin                   | 40 Yr (1975–2016); on salt, salty soil, waterbodies | Remote sensing techniques                                               | No                    |
| Azzizzadeh and Javan (2018)                 | Lake Urmia Basin                   | 27 Yr (1987–2014) Temperature                     | Mann–Kendall test                                                      | Yes: trend is detected |
| Sanikhani et al. (2018)                     | Urmia Basin: Aji Chay and Mahabad-Chay basins | Rainfall, solar radiation, $T_{\text{min}}$, $T_{\text{max}}$, and runoff | LARS-WG for downscaling and gene expression programming (GEP) for simulating runoff | Yes: trend is detected |
| Zamani Nuri et al. (2013)                   | Lake Urmia Basin                   | Rainfall, temperatures, De Martonne Index          | New methodology and spatial downscaling                                | Yes: trend is detected |
| Hosseini-Moghari et al. (2020)              | Lake Urmia Basin                   | 10 Yr (2003–2013) data, the loss of lake water volume and of GW; total water storage in the entire Lake Urmia Basin | WaterGAP Global Hydrology Model (WGHM)                                 | Detected no trend     |
| Delju et al. (2012)                         | Lake Urmia Basin                   | 40 Yr (1964–2005) mean monthly temperature and precipitation data | Kruskal–Wallis method; Palmer Drought Severity Index; Water Balance; Emberger classification; Mann–Kendall rank correlation | Result related to CC  |
| Ahmadi Jamal and Hasanlou (2017)            | Lake Urmia                         | 6 Yr (2010–2016)—daily hydrological data; precipitation, surface evaporation, and discharge | Polynomial regression technique combining polynomial with periodic behaviour | Detected no trend     |
| Hatami Majoumerd and Borhani Dari-ane (2015)| 19 stations of Lake Urmia          | 40 Yr temperature and water levels                 | Mann–Kendall-non parametric tests                                      | Detected no trend     |
| Ghorbani et al. (2018)                      | Upper Jighati River                | 40 Yr streamflow                                   | Detecting signals from records used in modelling river levels using Inclusive Multiple Models | Detected no trend     |
| Jalili et al. (2016)                        | Lakes Urmia and Van                | Urmia data (1966–2014 for Urmia), (1944–2014 for Van) water Level | Sequential test analysis of regime shifts; the Mann–Kendall test and Coherency analysis | Detected no trend     |
| Alborzi et al. (2018)                       | Urmia Lake Basin                   | Water level ecological level                       | River basin decision support system model of flow networks              | Detected no trend     |
| P. Razmara et al. (2013)                    | Lake Urmia basin                   | 30 Yr (1960–1990) Temperature and rainfall        | LARS downscaling, regional rainfall-runoff by ANN; beta function for uncertainty in climate variability | Yes: trend is detected |
| Khatibi et al. (2020)                       | Lakes Urmia and Van                | Water level: Urmia: 40 Yr; Van: Yr                 | One objective was to search for trends in the model residuals            | Detected no trend     |
the total irrigation efficiency under the B1 emission scenario (B1S4). Razmara et al. (2013) study the effect of climate change on the runoff entering Lake Urmia using AOGCM-AR4 models with two scenarios (A2 and B1) for T1 (2013–2040 years) and report a decrease in streamflow into the lake in scenario A2 at the risk levels of 25%, 50%, and 75% with reductions of −21%, −13%, and −0.3%, respectively, and an increase by 4.7%, 13.8%, and 18.9% in scenario B1, respectively.

2.3 Trend studies in various hydrological variables

A study of trends in various hydrological variables related to the basin of Lake Urmia is topical, some of which are outlined in Table 1. More often than not, no trend is detected, which brings to question the record length of the available data. If they conclude by identifying signals for climate change, their interpretations are for the disaster of the drying of Lake Urmia should justify how the lake reached the verge of drying up in the living memory of 10–20 years. Notwithstanding this, any explanation of the disaster falls short of identifying the role of the planning and decision-making system, which is the most likely explanation for the ongoing problems, and they fail to promote the way for a planning system to cater for incremental adaptations towards 2100.

Streamflows in the basin of Lake Urmia have been studied by various researchers including that by Ghorbani et al. (2018). They use a modelling strategy based on Inclusive Multiple Models (IMM) practices and formulate multiple models at two levels to enhance robustness and thereby ensure that the information content within the models are not impacted by modelling errors. In this way, they do not detect any trend in the error residuals. Similarly, Khatibi et al. (2020) formulated modelling strategies based on IMM practices and studied water level time series of Lake Urmia and Lake Van but did not detect any trend signals in the error residuals. Both acknowledge the importance of climate change but rule out the role of climate change on the Lake Urmia disaster, which is readily attributable to mismanagement since 1995.

A study of the water balance in Lake Urmia in conjunction with the surrounding aquifers and surface water inflows is described by Vaheddoost and Aksoy (2021). They conclude that groundwater and evaporation are significant variables on the decline in the water level of Lake Urmia, but the effect of groundwater surpasses all other variables. In spite of these results, the decline should not be attributed to droughts as prolonged droughts are rare in the region, but those detected ones are often operational during peak demands. Sadeghfam et al. (2018) studied risks of drought in the Maragheh-Bonab aquifer, located at the southwest bank of Lake Urmia. They notice that groundwater drought is mainly affected by groundwater overabstraction rather than deficit in precipitation. Also, the spatial distribution of groundwater drought risk is more critical in the direction from the upper catchments towards its lower reaches near Lake Urmia.

2.4 Lake water levels

Khatibi et al. (2020) refer to the plethora of predictive models of water levels of Lake Urmia driven by research interests and argues that these models serve very little practical purpose, as the lake has no navigation value in its present state and no water resources value for being a salt lake. Further reviews of the vast volume of research on predicting water level of Lake Urmia are therefore of little value.

2.5 Overview of the reviews

The above conflicting results are natural and expected. These all underpin the need for management plans and action plans to put in place incremental actions under the auspice of the precautionary principle. This has been endorsed by several international treaties since the beginning of the 1980s, and it is principle 15 of the Rio Declaration on Environment and Development in 1992 [Ref 1], which states ‘where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation’, see Gollier and Treich (2013). The paper argues that the threat to Lake Urmia and the population at its basin stems from overlooking the vital importance of the minimum ecological flow of 3 BCM, as outlined in Sect. 2.1. Based on the precautionary principle, this flow needs to be safeguarded. Any research work not minded with the principle would be research for the sake of research. No plan is yet accessible to the public, which is driven by the precautionary principle in relation to Lake Urmia, if they exit. Instead, climate change is used as a pretext for no action, but it should underpin the need for preparation for the impacts.

3 Methodology by using downscaling tools

The paper uses LARS-WG as a statistical downscaling technique to project daily precipitation and temperature under different scenarios into three future periods based on statistical characteristics of the variables. The projection results are represented by using De Martonne Index (DMI)
and Köppen-Geiger climate classification to gain a deeper insight into the climate variability within the study area.

### 3.1 The modelling strategy

At the first stage, the process of downscaling by LARS-WG comprises: (i) use large-scale GCM climate variables, referred to as predictors, which are a large set of variables, but they are internally screened by LARS-WG; and (ii) statistically downscale the selected predictors to the local climatic variable of observed data at daily timescale referred to as predictand (e.g. rainfall, sunshine hours, or temperatures), which are observed for a reasonable length of time at one or more synoptic stations. LARS-WG provides tools to establish relationships between the GCM predictors and local scale predictand. Various metrics are available to test the goodness of fit, e.g. the T and F tests.

At the second stage, LARS-WG models are used to project future values of predictands (projected precipitation and temperature) under the following selection of climate change scenarios: A1B, a balanced emphasis on all energy sources; A2, a world more divided, but more ecologically friendly; and B1, a world more integrated, and more ecologically friendly. The projections are normally carried out for the three periods of 20 years: (i) the first period (T1: 2011–2030), the second period (T2: 2046–2065), and the third period (T3: 2080–2099).

Although projections are at daily or monthly intervals, due to high uncertainties associated with the future values, a normal practice is to average the values at each month of the ‘average year’ for each period. For example, the values during T3 comprise a hydrograph from 2080 to 2099, but they are presented in the form of 12 values, one value per month from January to December, and each value is the mean of their corresponding value for 20 years from 2080 to 2099.

The projected values are then used to assess possible climatic zoning for the synoptic station. One such technique is the De Martonne Index, and the comparison of observed and generated zoning provides an indication towards possible patterns of climate change at the synoptic station. These are described below.

### 3.2 The LARS-WG model

LARS-WG is a statistical downscaling model, which seeks the establishment of a relationship between large-scale predictors and local predictand. It is also a weather generator to produce statistical models from observed sequences of weather variables by using complex random number generators. Their inputs comprise a set of large-scale predictors, and outputs include daily weather data at a particular location as a predictand. It has a capability to produce semi-empirical weather generator to approximate probability distributions of dry and wet series, daily rainfall, minimum and maximum temperatures, and solar radiation, based on a series that may be used in simulating meteorological data in an individual station (Semenov et al. 1998; Semenov and Brooks 1999; Racsko et al. 1991). The capability is also used to study the present and future climatic conditions.

For any climate variable $V_i$ corresponding to the probability $P_i$, is calculated through the following equation:

$$V_i = \min \{ V : P(V_{obs} \leq V) \geq P_i \} \quad i = 0, \ldots, n$$

where $P(\ast)$ is probability in terms of the data observed or $V_{obs}$. For any climatic variables, the $P_o$ and $P_n$ are equal to 0 and 1, respectively; they are constant with the relevant $V_n = \max(V_{obs})$ and $V_o = \min(V_{obs})$ (Semenov and Stratonovitch 2010).

### 3.3 Study area and the data

The study area, shown in Fig. 2, comprises seven synoptic stations, each located within a city at three provinces of (i) the province of Ardabil (using the stations at Ardabil and Parsabad), (ii) the East Azerbaijan province (using the stations at Ahar (Eher), Julfa, and Tabriz), and (iii) the West Azerbaijan province (Khoy and Urmia). These stations are located in northwest Iran with daily meteorological data, which cover the period from January 1961 to December 2001 (40 years), as provided by Iran Meteorological Organisation. The 40-year length of data record at 7 stations is best available for the region to enable a good accuracy at each station. More observation stations are ideal to gain a better insight for the spatial resolution of future patterns. The following needs to be stated clearly: (i) a better temporal resolution (say, with 40 years of recorded data) is at the expense of having sparse observation stations; (ii) a better spatial resolution with more observation stations is possible, but it is necessary to suffice to a lower temporal resolution (say, 20 years); and (iii) at the southern parts of the study area, there is no station with 40 years of recorded data. These are highlighted more and discussed further in Sect. 5. Table 2 presents their statistical summary.

### 3.4 De Martonne Index

The De Martonne Index (DMI) is used in this study to characterise the climate of each station. The index is calculated for every year in each station, and then the average of these index values is obtained for each decade. DMI is calculated as follows:
\[ DMI = \frac{P}{T+10} \]  

where \( P \) is the annual amount of precipitation (mm) and \( T \) is the mean annual air temperature (°C). Generally, the climate types are characterised as per DMI ranges in Table 3, which also presents the values of DMI for each station during the years of 1991–2001. The values indicate that all stations are characterised as per arid and semi-arid climate zones.

### 3.5 Köppen-Geiger climate classification.

Unlike the climate zoning technique above, Köppen climate classification additionally uses vegetation for an empirical classification of climate, which has been in wide usage since early 1900. It divides climate into five zones denoted by characters: A, B, C, D, and E. These have been revised over time, and each zone is now associated with subdivisions based on various bands of temperature, precipitation, and vegetation. The paper uses a published software [Ref 2],

![Fig. 2 The location map and investigated synoptic stations](image)

### Table 2 The statistical annual characteristics of meteorological data (January 1961–December 2001)

| Station | \( T_{\text{Max}} / \text{Daily} \) (°C) | \( T_{\text{Mean}} / \text{Daily} \) (°C) | \( T_{\text{Min}} / \text{Daily} \) (°C) | \( SD_Y \) (°C) | \( P_{\text{Max}} / \text{Daily} \) (mm) | \( P_{\text{Max}} / \text{Yr} \) (mm) | \( P_{\text{Min}} / \text{Yr} \) (mm) | \( SD_Y \) (mm) | Dry Days (%) |
|---------|----------------------------------|----------------------------------|----------------------------------|----------------|----------------------------------|----------------------------------|----------------------------------|----------------|---------------|
| Ahar    | 40                               | 10.2                            | -28                              | 0.99           | 47                               | 495                              | 310                              | 198            | 14.0          | 81            |
| Ardabil | 39                               | 10.4                            | -34                              | 1.15           | 63                               | 621                              | 342                              | 189            | 14.5          | 78            |
| Julfa   | 44                               | 15.4                            | -29                              | 1.41           | 52                               | 329                              | 207                              | 94             | 9.7           | 83            |
| Khoy    | 42                               | 12.6                            | -30                              | 1.27           | 44                               | 425                              | 223                              | 229            | 12.6          | 74            |
| Parsabad| 43                               | 15.0                            | -17                              | 2.05           | 65                               | 450                              | 283                              | 145            | 9.5           | 81            |
| Tabriz  | 42                               | 12.5                            | -25                              | 0.95           | 63                               | 547                              | 295                              | 148            | 15.2          | 78            |
| Urmia   | 38                               | 12.9                            | -24                              | 1.07           | 62                               | 564                              | 345                              | 126            | 18.8          | 80            |

### Table 3 Different climate type as per DMI values

| Types of Climate | DMI ranges | DMI at the Stations | DMI (1991-2001) |
|------------------|------------|---------------------|------------------|
| Arid             | DMI <10    | Ardabil             | 18.9             |
| Semi-arid        | 10 < DMI < 20 | Parsabad            | 10.1             |
| Mediterranean    | 20 < DMI < 24 | Tabriz             | 12.6             |
| Semi-humid       | 24 < DMI < 28 | Julfa              | 6.1              |
| Humid            | 28 < DMI < 35 | Ahar               | 11.5             |
| Very humid       | 35 < DMI < 55 | Urmia             | 14.9             |
| Extremely humid  | DMI > 55   | Khoy               | 11.4             |
| Colour Code      | Arid       | Semi-arid           |                  |

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which is based Köppen-Geiger climate classification. For a more detailed background on the technique, see Peel et al. (2007). It is noted that while the application of the technique is easy to use, for sparsely located positions of observation stations, the delineation of the zones is faced with problems, as to be discussed in due course.

### 3.6 Performance metrics

In the downscaling phase, the LARS-WG model is calibrated by carrying out statistical tests. The software provides the following tests: (i) the chi-square test is used to compare the seasonal probability distribution of dry and wet series, monthly rainfall distribution, seasonal distribution of the number of freezing days with a minimum temperature below 0 °C, and the number of hot days with a maximum temperature of more than 30 °C. (ii) Monthly averages of rainfall, minimum temperature, maximum temperature, and solar radiation are compared using the t-test. (iii) The F-test is used to compare the standard deviation of observational and synthetic data series. (iv) The calculated $p$-values are used in each of these tests, in which a very low $p$-value (less than 0.01 and 0.05) indicates that the probability of the generated data is not similar to observed data and model performance is poor. These test procedures are well-established in statistics and hydrological modelling and are not detailed here, but reference may be made to Semenov and Barrow (2002) and Khan et al. (2006).

### 3.7 Spatial modelling

Spatial modelling is used to interpolate the point data, such as observed precipitation, or modelled values, including DMI or mean precipitation, to gain an insight into their spatial distributions. There are various techniques available, but the paper uses the Inverse Distance Weight (IDW) technique. Notably, the kriging interpolation techniques produced spurious results, and hence only IDW results are reported here.

## 4 Results

In this research, climate change data for each synoptic station is investigated by LARS-WG for the following periods—T0 (1961–2001), T1 (2011–2030), T2 (2046–2065), and T3 (2080–2099) at two stages of downscaling and projection.

### 4.1 Downscaling results

In the first stage of climate modelling by LARS-WG, a statistical downscaling model is developed, which comprises the following steps: (i) for a given synoptic station, LARS-WG obtains a daily large-scale set of GCM climate variables, normally referred to as ‘predictors’, which are processed through a number of internal steps, e.g. screening the predictors (LARS-WG caters for these processes automatically, so they are not described here); (ii) the daily precipitation and temperature data at the synoptic stations are further processed by the modeller by estimating the mean monthly precipitation and temperature over typical months within the T0 period, which are used as the dependent variable (referred to as predictand) in a regression equation; (iii) LARS-WG establishes multiple regression equations between predictands and predictors, one for each month of downscaling periods.

The results produced by LARS-WG for each station and each month of the T0 period are then analysed by the modeller. One set of downscaling results is shown in Fig. 3 for Tabriz station and compares downscaled precipitation values with their corresponding observed values for each month of the averaged year together with simple linear

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Fig. 3 Comparing observed and modelled precipitation in Tabriz station (T0: 1961–2001)
trend for each month using their 40 years of record. The visual consideration of the results in Fig. 3 indicates that (i) there are distinct wet and dry periods, (ii) there is a slight trend in the precipitation values for each month (no trend for February and July; slight up trend for March, September, October, November, and December; and slight down trend for the remaining months), and (iii) the modelled values by LARS-WG largely converge with the observed values, but there are also deviations, which are analysed statistically in Table 4. The table gives the mean monthly precipitation averaged over the observed period and their performance statistics and probabilities, all for the T0 period (1961–2001). The probability values are also given in the table, according to which at the 5% level of significance, the LARS-WG results and observed data are derived from the same population. Also, the modelled results are acceptable in terms of their standard deviations at the significance level of 5% except for January and October. Statistical analysis of the results for all the stations confirms that (i) the trend is of similar order, although the down trend for Ardabil station is somewhat more than the others; and (ii) the means and standard deviations of the results and observed data are drawn from the same population.

4.2 Projection results

The downscaled results provide a relationship between the local downscaled predictands and the global-scale predictors for the T0 period. However, climate models provide the values of these predictors for T1, T2, and T3 periods, which are then used by the LARS-WG models to project local precipitation and temperature values onto T1, T2, and T3 periods, as a way to study climate change at local stations. The results presented in Table 5 summarise the projected climate results for all the synoptic stations. These comprise the results for the period T0 (1961–2001) and those for the projection periods of T1 to T3, as per scenarios A1B, A2, and B1.

The results in Table 5 indicate that (i) the maximum daily rainfall would occur in the first period (T1: 2011–2030) under scenario A1; (ii) the maximum annual rainfall would occur in the first period (T1: 2011–2030) under scenario B1; (iii) temperatures would increase over time (causing adverse impacts), according to which the highest temperature occurs in the third period (T3: 2080–2099) under scenario A2; and (iv) the lowest temperature would occur in the second period (T2: 2065–2046) under scenario B1.

Table 5 also give the full results, and those for precipitation are displayed in Fig. 4 in terms of annual mean precipitations for each month of each period, each scenario, and each station. These are further summarised in Fig. 5 in terms of total annual precipitation ratio (the ratio of (annual modelled precipitation – annual observed precipitation for the T0 period) divided to annual observed precipitation for the T0 period) for each scenario, each station and each period of T1, T2, and T3. According to Figs. 4 and 5, the following salient features are evident: (i) the conditions in terms of precipitation during the T1 period are quite similar to those during the T0 period for most of the stations, and if any difference, their precipitations are likely to be increasing except for a minor reduction at Ardabil and Julfa stations; (ii) for the T2 period, the climate change is likely to impact the region in terms of lesser amount of water availability, but the amounts are likely to depend on the prevailing scenario, although the conditions at Khoy are likely to improve as well as a few other stations; (iii) during the T3 period, some scenarios are likely to impact less but others to impact in greater amounts and inflict as much as 25% loss of water availability; and (iv) most regions seem likely to remain within the same climate zone, but the regions around Ardabil seems likely to suffer less water, as the temperature is likely to increase in the region.

The results in Fig. 5 provide a clear evidence that current situations designated in the T1 periods are much similar to the historic T0 periods, and if anything, water availability is somewhat greater in terms of precipitation. Therefore, using climate change to explain the onset of the catastrophe of Lake
| Parameters | Calibration | AIB T0 | AIB T1 | AIB T2 | AIB T3 | A2 T0 | A2 T1 | A2 T2 | A2 T3 | B1 T0 | B1 T1 | B1 T2 | B1 T3 |
|------------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Max Daily Rainfall | 47 | 44.7 | 39.1 | 45.8 | 40.2 | 41.6 | 50.8 | 57.4 | 44.9 | 48.3 |
| Max Annual rainfall | 494.5 | 501.2 | 451.7 | 461.6 | 492.6 | 492.8 | 394 | 506.1 | 477 | 449.1 |
| Max. Daily T - T<sub>min</sub> | 40 | 40.8 | 43.3 | 45.2 | 40.8 | 43.2 | 46.3 | 41.2 | 42.2 | 43.5 |
| Min Daily T - T<sub>max</sub> | -27.5 | -26 | -24.4 | -23.3 | -25.4 | -24.7 | -22.7 | -25.8 | -24.8 | -23.6 |
| Dry Day (%) | 81.02 | 82.21 | 82.10 | 82.11 | 82.98 | 82.97 | 82.94 | 82.98 | 82.21 | 82.31 |

**Kharbi station**

| Parameters | Calibration | AIB T0 | AIB T1 | AIB T2 | AIB T3 | A2 T0 | A2 T1 | A2 T2 | A2 T3 | B1 T0 | B1 T1 | B1 T2 | B1 T3 |
|------------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Max Daily Rainfall | 63 | 47.8 | 42.7 | 46.4 | 65.1 | 45.4 | 44.6 | 50.3 | 44.5 | 44.7 |
| Max Annual rainfall | 620.6 | 488.4 | 440.3 | 440.7 | 697.9 | 442.4 | 384.7 | 481 | 450.1 | 442.2 |
| Max. Daily T - T<sub>min</sub> | 39 | 39.1 | 41.6 | 43.5 | 39.4 | 41.4 | 44.8 | 39.6 | 40.5 | 41.9 |
| Min Daily T - T<sub>max</sub> | -33.8 | -26.8 | -25 | -24 | -24.5 | -25.3 | -23.6 | -26.6 | -25.6 | -24.4 |
| Dry Day (%) | 77.99 | 79.55 | 81.1 | 81.4 | 80.24 | 80.95 | 81.26 | 80.93 | 80.76 | 81.36 |

**Khoy station**

| Parameters | Calibration | AIB T0 | AIB T1 | AIB T2 | AIB T3 | A2 T0 | A2 T1 | A2 T2 | A2 T3 | B1 T0 | B1 T1 | B1 T2 | B1 T3 |
|------------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Max Daily Rainfall | 44 | 40.8 | 39 | 43 | 45 | 40.2 | 41.3 | 44.8 | 45.1 | 37.5 |
| Max Annual rainfall | 425.07 | 397.8 | 341.5 | 326.1 | 396.7 | 373.3 | 285 | 414.9 | 382.6 | 354.3 |
| Max. Daily T - T<sub>min</sub> | 42 | 43.2 | 46.2 | 48.4 | 42.7 | 45.4 | 48.7 | 43 | 45 | 45.6 |
| Min Daily T - T<sub>max</sub> | -30 | -25.2 | -23.2 | -22.1 | -27.4 | -26.3 | -24.4 | -28.5 | -26.4 | -25.3 |
| Dry Day (%) | 74.20 | 75.50 | 75.52 | 75.57 | 74.78 | 74.69 | 74.67 | 74.82 | 75.49 | 74.89 |

**Farahabad station**

| Parameters | Calibration | AIB T0 | AIB T1 | AIB T2 | AIB T3 | A2 T0 | A2 T1 | A2 T2 | A2 T3 | B1 T0 | B1 T1 | B1 T2 | B1 T3 |
|------------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Max Daily Rainfall | 65.4 | 62.5 | 43.2 | 41.4 | 64.4 | 61.9 | 51.3 | 59.8 | 50.3 | 59.3 |
| Max Annual rainfall | 449.5 | 571.9 | 507.3 | 507.6 | 547.9 | 550.9 | 463.7 | 583.3 | 539.3 | 502.6 |
| Max. Daily T - T<sub>min</sub> | 42.6 | 43.5 | 46.1 | 48.2 | 43.7 | 46.2 | 49.5 | 44 | 45 | 46.4 |
| Min Daily T - T<sub>max</sub> | -16.5 | -14.7 | -12.2 | -9.4 | -14.1 | -13.5 | -11.5 | -14.6 | -12.5 | -12.2 |
| Dry Day (%) | 81.34 | 82.54 | 83.42 | 83.52 | 82.54 | 82.20 | 82.27 | 82.38 | 83.41 | 82.69 |

**Tabriz station**

| Parameters | Calibration | AIB T0 | AIB T1 | AIB T2 | AIB T3 | A2 T0 | A2 T1 | A2 T2 | A2 T3 | B1 T0 | B1 T1 | B1 T2 | B1 T3 |
|------------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Max Daily Rainfall | 63 | 63.5 | 42.6 | 53.9 | 63.1 | 60.2 | 50.1 | 60.9 | 42.5 | 58.8 |
| Max Annual rainfall | 547.2 | 541.6 | 383.6 | 376.6 | 359.9 | 508.3 | 386.7 | 557.3 | 398.4 | 492.2 |
| Max. Daily T - T<sub>min</sub> | 42 | 41.3 | 44.1 | 46.2 | 41.4 | 44.1 | 47.5 | 41.6 | 43.2 | 44.3 |
| Min Daily T - T<sub>max</sub> | -25 | -18.4 | -20.7 | -19.6 | -17.6 | -16.9 | -15 | -18.2 | -21.2 | -15.9 |
| Dry Day (%) | 77.99 | 78.0 | 78.5 | 78.5 | 78.0 | 78.0 | 78.0 | 78.0 | 78.5 | 78.1 |

**Urmia station**

| Parameters | Calibration | AIB T0 | AIB T1 | AIB T2 | AIB T3 | A2 T0 | A2 T1 | A2 T2 | A2 T3 | B1 T0 | B1 T1 | B1 T2 | B1 T3 |
|------------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Max Daily Rainfall | 62 | 76 | 72.3 | 61.8 | 69.2 | 69.8 | 57.8 | 76 | 68.2 | 66.2 |
| Max Annual rainfall | 564 | 508.4 | 457.2 | 428.3 | 699.9 | 485.3 | 380.7 | 530.4 | 468.1 | 461.8 |
| Max. Daily T - T<sub>min</sub> | 38 | 38.6 | 41.4 | 43.6 | 38.6 | 41.4 | 44.8 | 38.8 | 49.6 | 41.7 |
| Min Daily T - T<sub>max</sub> | -24 | -22.8 | -20.8 | -19.8 | -22.2 | -21.3 | -19.4 | -22.7 | -21.5 | -20.4 |
| Dry Day (%) | 79.6 | 80.97 | 80.95 | 81.04 | 81.02 | 81 | 80.98 | 81 | 81 | 81 |

**Colour Code**

- Increase in T<sub>max</sub>
- Decrease in T<sub>max</sub>
- Increase in P<sub>max</sub>
- Decrease in P<sub>max</sub>
- Increased Dry Day
- Decreased Dry Day

Note 1: Temperature increases are considered adverse and shown in coloured.
Note 2: Precipitation decreases are considered adverse and shown in red.

**Table 5** Comparison between climate variables for calibration and projection periods
Urmia cannot be justified on scientific grounds, although science is not fixed, and more evidence needs to be gathered.

The results in Table 5 are used for climate zoning as presented in Fig. 6 for the T0, T1, T2, and T3 periods. As it may be seen from the figure, the climate in the study area is characterised by-and-large as semi-arid or arid under the T0 period, as well as under T1, T2, or T3 periods. There are marginal areas within the borders of each zone that are dependent on the scenario runs, which may undergo climatic changes. Otherwise, there does not seem to be any drastic sensitivity to climate change at the T1 period. These are discussed further in the next section. Interestingly, the results show that those at the T0 and T1 periods are quite similar. This is a significant finding as climate change has not yet kicked off but creeping in.

4.3 Climate zoning

While it is possible to study the results for each of the stations in the above manner, this would be an unwarranted belief into projected results in the foresight future. However, it is customary to study possible changes in the climate zoning, as explained by the De Martonne Index in Eq. (2). Therefore, the projected results at the synoptic stations are used to study the likely changes in the future climate patterns. Using the DMI values at each stage, they are also projected into the future for each period and for each scenario, and their values are presented in Table 3. The table shows that DMI in all the investigated meteorological stations increase when compared with those at the T0 period (1991–2001), except for Ardebil station in the first period (2011–2030). Thus, with the passing of time, the northwest zone is likely to be exposed to a greater risk of drought. In some scenarios, DMI is less than 10, which indicates that the zone may change from semi-arid to arid climates.

Rahimi et al. (2013) use DMI to study climate zoning in Iran under historic and report a shift towards warmer and drier zones. They report that the current extra arid-cold climate covers the largest area of the country (21.4%), and climate change scenarios (A1B and A2) in the 2050s and the 2080s will occupy the largest area of the country (A1B by 21% and A2 by 38%). Their mapped results are compared visually with those presented in the paper, which generally agrees with one another, but they do not present specific results for the basin of Lake Urmia for a more focussed study.

The Köppen-Geiger climate classification technique is also investigated, which complements those of the DMI results. The results are presented in Fig. 7, and their visual intercomparison confirms that the two techniques display quite similar zones, but it is observed that some deterioration is possible during the T2 or T3 periods, and some divergences between the respective results are evident. Elaboration on the projected results is not justifiable due to their inherent level of uncertainty.

Rahimi et al. (2020) also use the Köppen-Geiger climate classification technique to study climate zoning in Iran under historic conditions and the projected future conditions. They report a shift towards warmer and drier zones similar to the above but additionally report reduced precipitation and snow covers. Generally, a visual intercomparison of their results with those presented in Fig. 7 agree with each other, but they do not present specific results for the basin of Lake Urmia for a more focussed study.

It is noted that the zones are drawn by simple polygons when using Köppen-Geiger climate classification, and therefore their borders depend on the number of datapoints. Thus, the southern parts of the results in the study suffer from sparse data representations, and therefore they are subject to larger uncertainty than those in the northern part of the basin.

4.4 Overview of the results

All of the results above are summarised as follows: (i) at the T1 period, the difference with the T0 period is minimal, and if anything, a small increase in the projected precipitation is likely; (ii) some deterioration is likely at T2 and T3 periods, but this is dependent on the scenarios, as certain zones may benefit by increased precipitations; (iii) the role of planning and management is of the paramount importance and indispensable to cope with the future conditions. There is enough time to develop a good management system before the public is exposed to the man-made catastrophe of Lake Urmia.

5 Discussion

The results presented in the paper provide the basis to gain an oversight of the climate change within the basin of Lake Urmia and its vicinities. However, the authors are minded that the spatial extent of the paper is larger than the basin of Lake Urmia, yet the focus is on this basin even though its spatial resolution (2 observation stations) is low. The sparsity of the stations in the basin of Lake Urmia was forced by the author’s drive for a better temporal resolution (40 years), and therefore the spatial resolution had to give in. However, with the benefit of other research activities reported by Sadeghfam et al. (2022) and its extension to projection of drought results into the near and far future (the latter yet to be published), the authors can confirm here that they do have any serious concern on the spatial resolution, as their study now uses lower temporal resolution (21 years of record) and higher spatial resolution (67 stations in the
Fig. 4 Mean precipitation for each month at periods T0, T1, T2, and T3 at each station for scenarios A1B, A2, and B1 and historic data.
basin). The discussed results are concordant with those reported here, although there are some niceties at the zones adjacent to southern boundaries not discussed here. Based on the authors more refined insight not published yet, it is stated here that there is little conflict between these different results sets.

The findings conform with the international published data that during the onset of the catastrophe of Lake Urmia, the temperature was only 0.5 to 1.0 °C, and currently it is 1.5 to 1.6 °C; see CarbonBrief (2018). The paper in Fig. 5 shows clearly that precipitation during the T1 period corresponding to the present times is much like the period T0 corresponding to historic data available, and if anything, more precipitation is being available now. On account of climate change results presented in the paper, there is very little to explain any catastrophe or distress in the region. The large volume of literature on Lake Urmia attributing the problems to droughts or climate change are likely to be missing more critical explanations. This is not to deny the importance of climate change in any way, but the results underpin the fact that if the right actions are not taken before the onset of climate change, the future is likely to be bleak.

The study presented by the paper may be compared with a similar study by Sadeghfam et al. (2021). They use the SDSM software and apply it to the recorded synoptic data at two grid cells, with the main cell at the south of the Caspian Sea in northwest Iran largely covering southern Gilan province, and the second grid covers territories of East Azerbaijan, Ardabil, and Zanjan provinces. A comparison between observed and projected precipitation results indicates that precipitation is likely to reduce in the projected periods in cold seasons (October to February), but the projected precipitation will be likely to increase slightly in wet season (April and May). Their reported behaviour is quite corroborated for the projected results in the paper with similar conclusion concerning Ardabil province.

The incorporation of both temperature and precipitation to understand patterns of drought in the basin of Lake Urmia was studied by Sadeghfam et al. (2022) and by Abbasian et al. (2021). Sadeghfam et al. (2022) study meteorological drought and groundwater drought in the basin by using both meteorological and groundwater data with the objective of discerning anthropogenic impacts and resilience patterns by virtue of 21 years of monthly data records. Their modelling strategy includes (i) transforming recorded time series into Met/GW indices, (ii) extracting their drought duration and severity, and (iii) deriving return periods of the maximum drought event through the copula method. They state that the procedure is well established for meteorological droughts using the copula method and adapt a similar procedure to study groundwater droughts. Their output results include return periods and use them to discern natural and anthropogenic impacts. The results provide statistically significant evidence on (i) identifying the northern parts of the basin to suffer from mild meteorological droughts but with severer impacts on groundwater due to anthropogenic withdrawals; (ii) the watercourses and their basins flowing to the middle parts of Lake Urmia do not suffer from any notable droughts, but the relevant aquifers are being strained by overabstraction; (iii) the sub-basins flowing to the southern part of Lake Urmia display no meteorological droughts, and mild aquifer droughts are attributed to overabstraction. These results are concordant with the findings in the paper.

The authors’ research into various aspects of the risk of climate change in the basin of Lake Urmia and its vicinity basins are still in progress and yet to be published. In one such research work, the authors extend drought studies, as discussed by Sadeghfam et al. (2022), into the future. The results to be reported in due course indicate that even after the onset of climate change, the region is very likely to remain resilient to future condition. In another research, the 30 years of field measurements of overland flows are obtained from relevant authorities over 8 sub-catchments in East Azerbaijan, which unearths the ongoing depletion of aquifers. Both these research activities underpin the importance of good governance with good planning, without which water resources are likely to undergo permanent damage and fairly soon.

The results presented recently by Abbasian et al. (2021) address droughts in the basin of Lake Urmia. They develop a model based on the joint variability of precipitation–temperature, particularly under climate change and downscale precipitation and temperature at
Fig. 6  Zoning map for the study area under scenarios A1B, A2, and B1 for T1, T2, and T3 periods
Climate zoning under climate change scenarios in the basin of Lake Urmia and in vicinity basins

The above-reported work by Abbasian et al. (2021) is scrutinised critically here. Some of its peculiar aspects include (i) the curious use of ‘unfavourable for the revival of the lake’ versus ‘maintaining agricultural activities’; (ii) it puts blame on farmers for the shrinkage of the lake but yet allows water abstraction for agriculture at the expense of undermining the ecology of Lake Urmia and its basin; (iii) the omission of any information on the minimum flow requirement of 3 BCM, as determined by IMPfLUB (2010); and (iv) misconstruing a projected increase of approx. 10 mm in the annual precipitation during 2020–2040 (a possible volume of more than 500 million cubic metres). Evidently, their mindset in interpreting their results is biassed towards more agriculture, no restoration of Lake Urmia, both of which are contrary to both the spirit of sustainable development goals and the precautionary principle. Such an adversary mindset seems widespread and surprisingly not critiqued.

There are various ways for more robust projections for the study as outlined next. A primary step is to incorporate more synoptic stations, particularly at the southwest of the study area. At the time of this study, no data were available to the authors, but this is currently being addressed for the future studies. The GCM model runs serving the downscaling models in the paper were obtained automatically by LARS-WG. Another approach is to improve on the robustness of the downscaled result by using Inclusive Multiple Modelling (IMM) practices similar to Sadeghfam et al. (2021). Similarly, uncertainty studies can be applied to identify the sensitivities to the prominent parameters and measured data to identify possible climatic vulnerabilities and resilience, but the authors are not aware of any such study for the study area.

The aquifers in the study area are at a serious risk of depletion. Broadscale published information on aquifers within the study area was reviewed as another source of information (see: https://www.feow.org/ecoregions/interactive-map) to understand relative situation of the study area in its international context. These are outlined below:

(i) the ecoregion designation of the basin of Lake Urmia is 446 with overlaps at ecoregions of 444 (Lake Van) and 434 (Araz); (ii) the percentage of areas equipped for irrigation at the study area is in the band of 10–15%, and this is a measure of potential adverse impacts on freshwater systems by abstracting water from natural systems and preventing or delaying its return through diversions and storage; the band is quite high globally, and therefore the basin is at risk; (iii) the average human footprint in the basin is in the band of 20–30, and this band is in the medium range, which incorporates human access, land use with infrastructure, and population pressure, while greater human activities in a region are likely to lead to greater impacts on freshwaters; (iv) water use at the study area is indicated to be at the stressed band, where water stress is defined as the ratio of water use (i.e. surface water withdrawn for domestic, agriculture, and livestock use) to water availability (the discharge by sub-basin, delineated using global maps at 25,000 km² resolution) and therefore measures the relative use of water to what is replenished naturally by precipitation and snow melt; (v) the band for consumptive surface water use at the study area is shown to be in the medium range, where it is defined as the average annual amount of surface water used in the ecoregion. All these give an indication of both water resources development and of the potential impact of water consumption on freshwater ecosystems. These general-purpose and openly available data show that human developments have concentrated their water use or where surface water resources are most exploited.

The above general-purpose published indicators correlate well with the local knowledge on the physical reality of the study area now and are an indication of inherent risks within the study area. They show that the future in the study area is faced with unprecedented risks; the exposures for which have been triggered circa 1990. These include (i) the onset of the green revolution in Iran; (ii) an unprecedented dam construction program at the basin of Lake Urmia; (iii) mismanagement of compensation flows and the absence of environmental impact assessment; (iv) the explosion of population, which grew from nearly 40 million in 1980 to nearly 80 million in 2016; and (v) uncontrolled developments, which broke the backbone of traditional agricultural practices and opened the gateways to pumping aquifers and using fertilisers. This is a typical background for the ‘tragedy of the commons’, which is created by individuals to maximise their benefit from a shared resource. Normal wells soon depleted aquifers at shallow depths. The practice then changed to using deep wells to deplete the aquifers even further. Although recently some organisational arrangements have been put in place to cater for abstraction controls under the Iranian Department of Environment, their functions seem to pass on the blame to users without putting in place a management system.
Fig. 7 Climate zoning by the Köppen-Geiger climate classification (Bsh, arid-dry summer-hot; BSk, arid-steppe-cold; Bwh, arid-dry winter-hot; BWk, arid-desert-cold; Csb, temperate-dry summer-warm summer)
Mitigation is only possible by adhering to the UN Sustainable Development Goals through policymaking, risk-based decision-making, and a set of attributes and principles as discussed by Khatibi (2022). The organisational arrangements for SDGs rely on a professional practice, in which mitigation is implemented by overhauling ad hoc practices on water use and putting in place an appropriate management practice by producing a raft of plans including drought plans, sustainability plan, water cycle management plans, and water resource plans.

Climate change mitigation and adaptation is primarily the responsibility of the National Climate Change Office in Iran, under the Department of Environment (which is a governmental agency overseen by the president). The government officials confirm being in favour of sustainable development principles. One recent report outlines 27 strategies to solve the Urmia Lake crisis [Ref 3], including (i) control and reduce extraction from the surface and underground resources of the basin, (ii) prevent unauthorised harvesting of surface water, (iii) organise the wells of the catchment area and use artificial intelligence to monitor the well metres, (iv) develop alternative cultivation with native salt-tolerant species and creation of green belt, and (v) increase the input flow to the lake from the watercourses at the basin in non-agricultural seasons. The problem with these plans/strategies is that they are one of many as Sadeghfam et al. (2022) and Khatibi et al. (2020) critique other plan/strategies that are not delivered. Also, the authors are not aware of any plans published for the public scrutiny or public consultation yet.

6 Conclusion

Topical research on Lake Urmia cross-references frequently to climate change, as the cause of its shrinkage. However, climate change may have triggered but not necessarily in full force. The difference between the two cases would affect decision-makers, as currently they do not invest on restoring the lake by blaming climate change. The paper provides a set of results which show that current problems on precipitation, associated with Lake Urmia, its basin, and some of the adjacent basins, are not necessarily induced by climatic changes but mismanagement is the likely cause.

The paper uses LARS-WG and applies to 7 synoptic weather stations within the basin (2 stations) and its overlapping basins (5 stations) at two stages of downscaling and projection. Downscaling by LARS-WG comprises (i) the use of global-scale GCM models for the prediction of climate variables and (ii) downscaling them to the local climatic variable using the LARS-WG model in terms of observational data at daily timescale. The study uses the data from synoptic stations in north-west of the country (Ahar, Ardebil, Julfa, Khoy, Parsabad, Tabriz, and Urmia) for a period of 40 years (T0: 1961–2001). At the second stage, the LARS-WG model projects its future climate changes under three scenarios (A1B, A2, and B1) for the three 20-year periods. These values are then used to calculate De Martonne Index and Köppen-Geiger climate classification techniques to delineate the climate zoning by different interpolation methods.

A simple linear assessment of trends in historic data does not warrant to explain the ongoing water crisis in the basin of Lake Urmia and its adjacent basins to be attributed to climate change, as there is a slight no-trend, up-trend, and down-trend for each month in each synoptic station. A comparison of observed and downscaled precipitation results indicates that the climates at the studied stations are moving towards drought but the northern region (including Julfa and Parsabad) will be drier and will be developed towards southern regions. The remaining areas relating to the synoptic stations largely remain within the same climatic band, but precipitation events are likely to be more extreme. The results underpin the need for streamlined water management plans as soon as possible or else the damage can become permanent.

Author contribution Rasoul Jani: Supervised the research work, produced the initial version, reviewed the finalised paper.
Rahman Khatibi: Critically reviewed the results, rewrote the manuscript, revised its communication.
Sina Sadeghfam: Critically reviewed the modelling results, revised the GIS plots, reviewed the manuscript.
Elnaz Zarrinbal: Carried out the modelling activities for her research work.

Availability of data and material Our data are available for anyone on request.

Code availability We used the standard LARS-WG, which is available online.

Declarations

Ethics approval We have conducted no laboratory tests for the paper and have involved no human participants and/or animals.

Consent to participate The journal has our full consent.

Consent for publication The journal has our full consent to publish our paper and the data.

Consent for figures We have produced all the figures ourselves and need no consent.

Conflict of interest The authors declare no competing interests.
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