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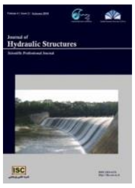

Urmia Lake desiccation and the signs of local climate changes

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Abstract

The water crisis is one of the important issues in the Middle East countries. Many lakes are drying up and/or facing critical situations, exerting tremendous impacts on the socio-economics of their region. Lake Urmia, in northwestern Iran, currently is facing critical situations and is on the brink of total shrinkage and environmental disaster. This paper investigates the roots of crises through trend analysis of hydrologic variables and shows the impact of the lake desiccation on altering the local climate. The results indicate an increase in temperature, a decrease in lake inflow, and limited significant trends in precipitation. They also indicate that increasing agricultural water consumption is the main cause of the current crisis of Lake Urmia. Further investigation reveals a significant change in the local climate as a consequence of Urmia Lake water shrinkage. This change occurs in the dominant wind direction where before its desiccation the lake was acting as a cooling medium. This phenomenon vanished after the desiccation of the lake causing a sharp increase in the temperature of the affected areas.

Keywords: Climate change, Trend analysis, Local climate alteration, Urmia Lake.

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1. Introduction

The potential impacts of climate change on human life have received a great deal of attention during recent decades. According to the Intergovernmental Panel on Climate Change (IPCC), global warming due to enhanced greenhouse effect has the potential to alter environmental phenomena namely: temperature, humidity, precipitation and sun radiation 1]. Therefore, changes in streamflow, intensified drought frequency and severity, higher temperatures in colder months leading to the shifts in snow melting process and, decreases in streamflow in warmer months are some of the well-known consequences of the global warming.

Many researchers have used trend analysis to explore impacts of climate change. Non-parametric Mann-Kendall (MKnp) test [2],[3] is one of the widely used methods for trend

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analysis (e.g., [4]-[8]). Also, since most trends are related to seasonal changes, Seasonal Mann-Kendall (SMKnp) test was adapted by some researchers for detecting seasonal trends [9]. Lettenmiare et al. [10] applied the SMKnp method to examine the trends of four monthly hydrologic variables for the continental United States. Kahya and Kalayci [11] used the SMKnp test to estimate monthly streamflow trend of 26 basins over Turkey.

Later, Hamed and Rao [12] offered a modified Mann-Kendall test to resolve the inaccuracy problem in Mann-Kendall when positive autocorrelation exists in data. Mondal et al. [13] also processed daily rainfall data of 40 years duration over a river basin in Orissa, India to explore the monthly variability of rainfall using MKnp test together with a Modified Mann-Kendall and Sen's Slope Estimator for determining the trend and slope magnitude. A review of literature shows that there are only a few published papers and reports on trend analysis in Iran. These include a work by Tabari et al. [14] on evapotranspiration, and the one by Kousari et al. [15] who investigated drought severity trend using non-parametric Mann-Kendall statistics and Sen's slope estimator.

Nevertheless, climate change has affected many aspects of our world. It has been stated that several important lakes around the world are currently facing serious drought problems where some of them are in the brink of total vanishing from the face of the earth. These include Lake Waiau, Aral Sea, Cachuma Lake, Lake Urmia, and Dead Sea [16]. Extreme fluctuations of the lake water level can affect the ecosystem and cause enormous socio-ecological and economical losses. Meanwhile, the lake shrinkage in recent decades has become one of the most important issues all around the world. Trend analysis has been widely used for studying the lake systems (e.g., [17]-[21])

The simulation and prediction of lake water level has been also the subject of many research. Methods used for this purpose include data driven procedures such as regression based methods, times series, and neural networks -and conceptual or physical hydrologic models ([22]-[25]). The ecosystem of some important lakes has been widely investigated using different available modelling tools and from different aspects. Although the causes may differ from one lake to another, but there are similarities and lessons that can be used for finding solutions for currently desiccating lakes such as Lake Urmia.

Aral Sea, located 1200 km to the northeast of Lake Urmia [26], is among many lakes on the Earth which are facing catastrophic condition and in the brink of total disappearance. The similarities on the causes between the two lakes were strong enough to persuade Aghakouchak et al. [27] to claim that the Lake Urmia is also vanishing by the so-called Aral Sea syndrome. Aral Sea crisis has been the result of unsustainable and unrestrained agricultural development during the Soviet Union era. Glantz et al. [28] investigated the socio-ecological causes and consequences of Aral Sea water level decline. Aladin and Potts [29] also studied the changes in Aral Sea ecosystems as a result of increases in the lake water salinity.

As another example, the situation of Dead Sea was investigated by Salameh and EL-Naser [30]. Their results indicated that considerable amounts of groundwater were driven into the Dead Sea as a result of the seaward migration of the freshwater/saline water interface. Radwan [31] also developed a water balance model for the Dead Sea by considering different hydrological components and investigated different scenarios with an aim to find ways to save the Dead Sea.

As mentioned earlier, Lake Urmia is one the five most important lakes in danger of total disappearance from the earth surface. It is the largest lake in the Middle East and the second largest hypersaline lake on earth (Utah's Great Salt Lake being the first). Recent prolonged drought along with excessive water consumption has caused a considerable drop in lake's water level and consequently its surface area in less than a decade. Satellite images in 2014 show that nearly 88 percent of the lake's surface area has been lost to this cause [27]. People in the region have already begun to experience the environmental consequences of the loss through windblown salt-storms, a familiar phenomenon also seen in the Aral Sea region after drying up. On the other hand, the prolonged drought and water deficits in the area have exerted tremendous stress on groundwater resources, so that in many areas poor water quality has become a major problem for irrigated agriculture. The region, which was once famous for its orchards and high-quality exportable fruits, is now facing heavy economical losses due to water deficits and water quality issues.

This paper investigates the roots of current crises in Lake Urmia and the basin through a trend analysis approach. The objective is to explore the factors and their role in causing the current situation. Officials mainly have claimed the climate change and recent droughts as the main reasons for the crises, mainly to justify ongoing water resources project developments in the basin. However, there are signs that other factors including exhaustive and boundless water resources project developments and excessive water consumptions, especially by the irrigated agriculture, are more important than the climate change factor. Finally, this paper investigates the possible alteration on local climate as a consequence of Urmia Lake water shrinkage.

2. Study Area and Relevant Data

Urmia Lake, among the most important saltwater ecosystems on the earth and a UNESCO designated Biosphere Reserve, a Ramsar Site, and National Park with an area of about 5 to 6 thousand square kilometers, is located in northwestern Iran, between East and West Azerbaijan provinces. The Urmia Lake Basin (Figure 1), between 35◦ 40´–38◦ 30´ northern latitudes and 44◦ 07´–47◦ 53´ with average altitude of 1735 m is also shared by Kurdistan province, and with an area of about 52 thousand square kilometers is considered as one of the large basins in the country. Situated in a semi-arid climate, the basin has mountainous morphology at the borders with low-lying plains and the lake at the middle.

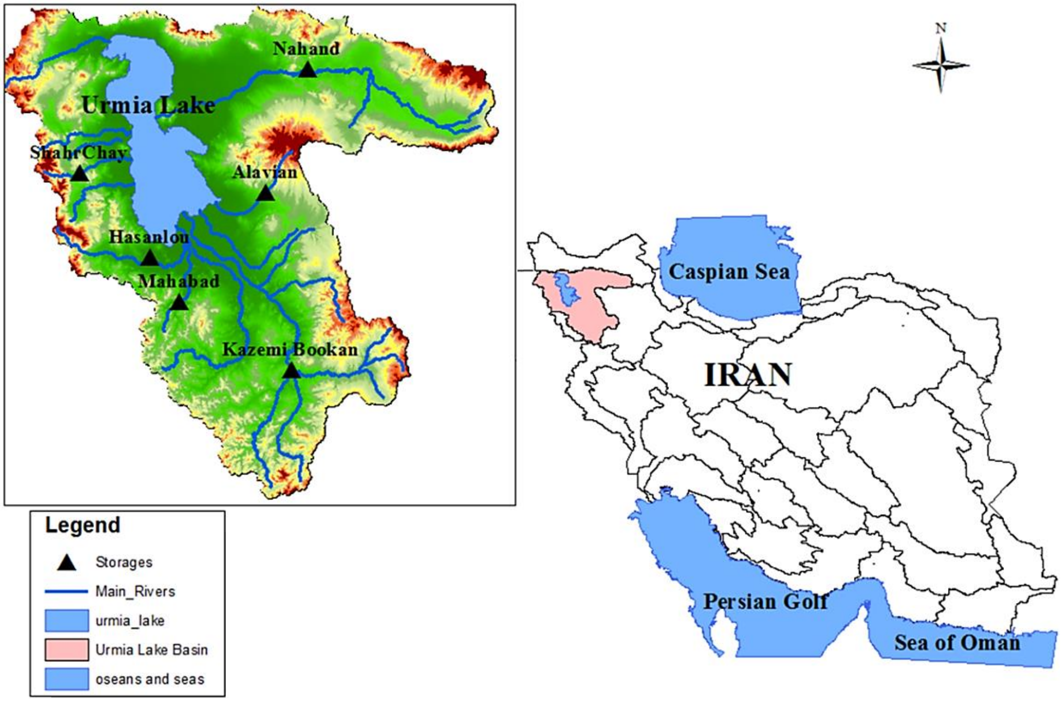

Figure 1. Location of Urmia lake and its basin in Iran

The inflows to the lake mainly consist of permanent and seasonal stream flows. According to statistics, the highest discharge in hydrometric stations occurs in late winter and early spring, during March throughout May, with about 70% of the total annual flow. Meanwhile, the remaining nine months together account for only about 30% of the total annual inflow in average. A common duration of 46 years (1966-2012) was used for detecting trends of precipitation (33 stations), temperature (18 stations) and streamflow (32 stations).

3. Methodology

The steps outlined below are the general steps that must be followed for any trend analysis:

- The first step is to select the variables to be studied. These variables must be appropriate for expressing the hydrologic conditions. The variables used in this study include streamflow, precipitation and temperature.
- The second step is to choose the stations to be investigated. The chosen stations must have both complete record length and must be scattered over the whole basin to give a comprehensive overview of the trend in the basin.
- The third step is to check for the presence of trends in chosen variables using an appropriate method.
- The final step is to determine the significance of the trend for each variable and whether it is positive or negative.

3.1. Mann-Kendall non-parametric method

In this study the trend of annual and monthly streamflow, precipitation and temperature has been analyzed using the MKnp method. For this purpose, the Mann-Kendall test static S, variance of S (VAR(S)) and the test static Z must be calculated using the following relations:

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}\left(x_j-x_i\right)$$

$$where\ \operatorname{sgn}(\theta)=\begin{cases}+1 & \theta>0\\ 0 & \theta=0\\ -1 & \theta<0\end{cases} \tag{1}$$

$$VAR(S)=\frac{1}{8}\left[n(n-1)(2n+5)-\sum_{p=1}^{8}t_p\left(t_p-1\right)\left(2t_p+5\right)\right] \tag{2}$$

$$Z=\begin{cases}\dfrac{S-1}{\sqrt{V(S)}} & S>0\\ 0 & S=0\\ \dfrac{S+1}{\sqrt{V(S)}} & S<0\end{cases} \tag{3}$$

A positive value of S indicates that there is an increasing trend and a negative value indicates a decreasing trend. The test statistic Z is used as a measure of significance of the trend.

For checking the presence of any trend and determining its significance, P-value is calculated. The P-value is a probability, with a value ranging from zero to one; when P-value is less than a lower threshold, it means that the trend is significant [32]. In this paper a lower threshold of 0.05 is used. The trend is considered as significant for P-values less than 0.05; it is assumed as stable for values between 0.05 and 0.1; the trend is classified as poor for P-values between 0.1 to 0.2; and finally, when the P-values are more than 0.2 the time series indicates no trend.

4. Discussion and analysis

This section presents the summary of results of applying the Mann-Kendall test for annual and monthly streamflow, precipitation and temperature observations. The positive trends (increase) and negative trends (decrease) in all time series are displayed by "+" and "–" signs, respectively. Accordingly, seven different trend classes are defined as follows:

1. Significant Trend+, 2. Significant Trend-, 3. Stable Trend+, 4. Stable Trend-, 5. Poor Trend +, 6. Poor Trend - and 7. No Trend

In the following the result of each variable is shown and discussed. Then a discussion is carried out that links the trend analysis of variables to the Urmia Lake water level.

Figure 2 shows the trend of mean annual temperature. According to the results presented in Figure 2, the trend of mean annual temperature in most of the stations is significantly positive indicating a relatively noticeable rise in temperature throughout the basin.

Figures 3 shows that the trend of precipitation is not uniform over the basin. In some stations, precipitation has decreased considerably while in some others it shows slight decrease or even no changes according to this analysis. Moreover, as shown in Figure 4, there is a strong decrease in almost all streamflow stations meaning that the availability of water in the basin does not follow the precipitation trend.

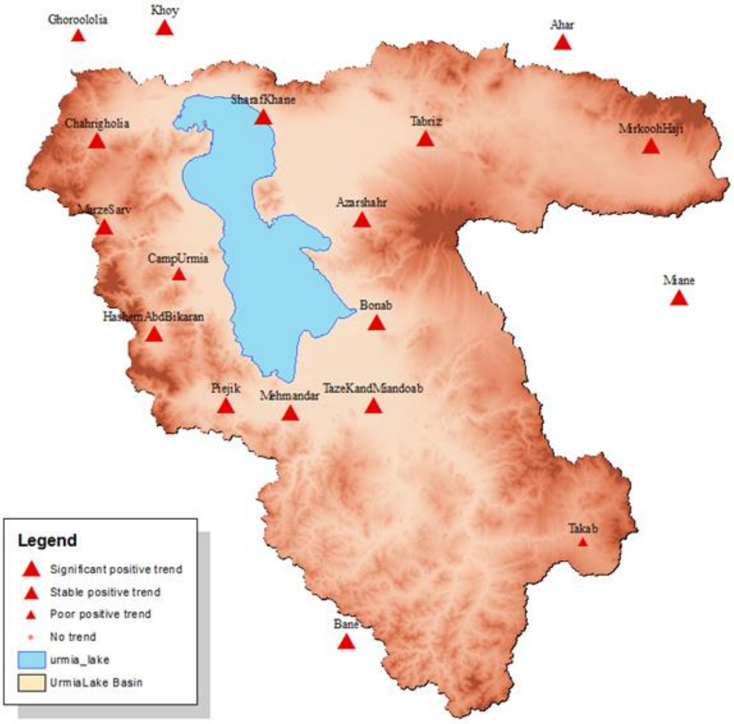

Figure 2. Annual temperature trends in Urmia Lake Basin

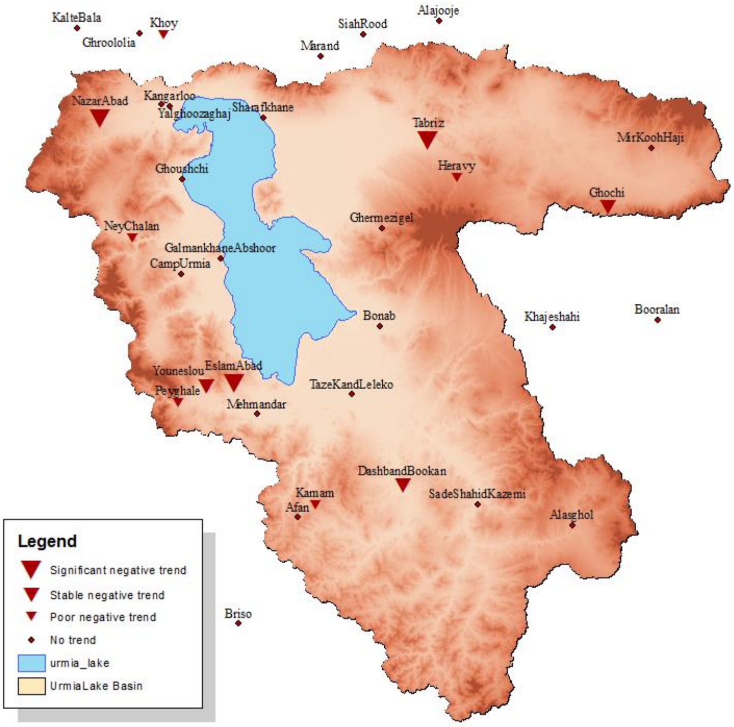

Figure 3. Annual precipitation trends in Urmia Lake Basin

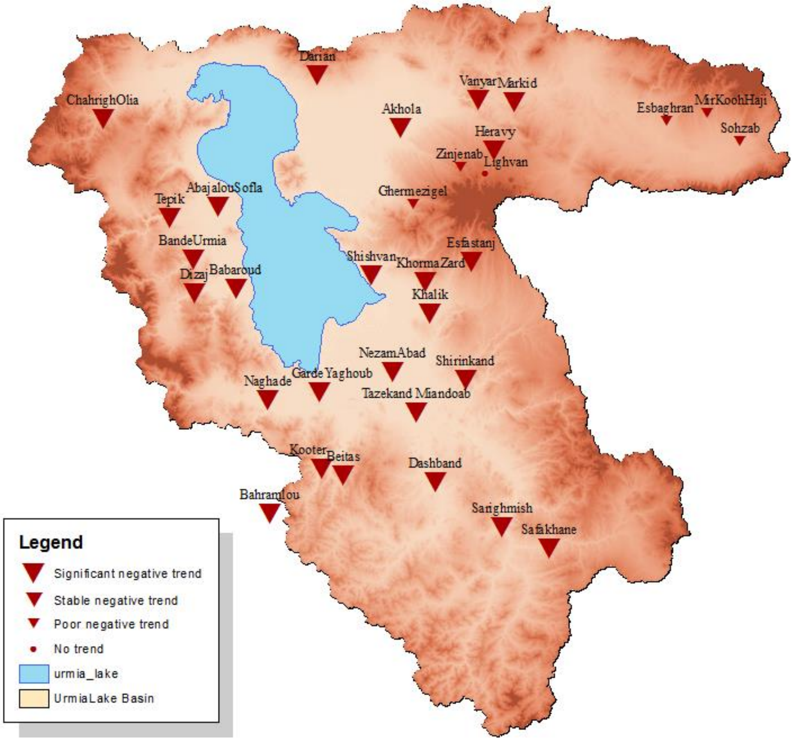

Figure 4. Annual discharge trends in Urmia Lake Basin

In addition, the graphs shown in Figure 5 which depict the relative number of stations for each type of trend category, indicate that the mean annual temperature is the only parameter enjoying an increase during the study period. The rise in mean annual temperature to some degrees is evident in all stations. In fact, about 83% of stations have a sharp increasing trend classified as "Significant Trend+", 11% have "Stable Trend+" and the remaining 6% have poor positive trend. There is no station with "No Trend" or negative trend condition.

On the other hand, unlike the annual temperature, there is no positive trend either in mean annual precipitation or discharge time series. For the annual precipitation, 67% of stations show "No Trend" and the remaining indicate weak (15%), stable (9%), and significantly decreasing (9%) trends. Similar results on precipitation were obtained by others (see [33],[34]).

The annual discharge shows completely different behavior. Here, 81% of stations indicate "Significant Trend-", 16% indicate poor trend, and only 3% of stations show no change in annual streamflow. Obviously, these figures do not follow precipitation as the source of available water in the basin. Therefore, other factor(s) may have caused the massive decline in streamflow discharges throughout the Urmia Lake Basin. It is interesting to note that because of streamflow data availability, when the study period was extended to cover from 1956 rather than 1966, the results changed considerably as shown in Figure 5. Therefore, precautions should be taken when using these methods. A safe action would be to check the results by another method. Nevertheless, the overall conclusion is valid in either case.

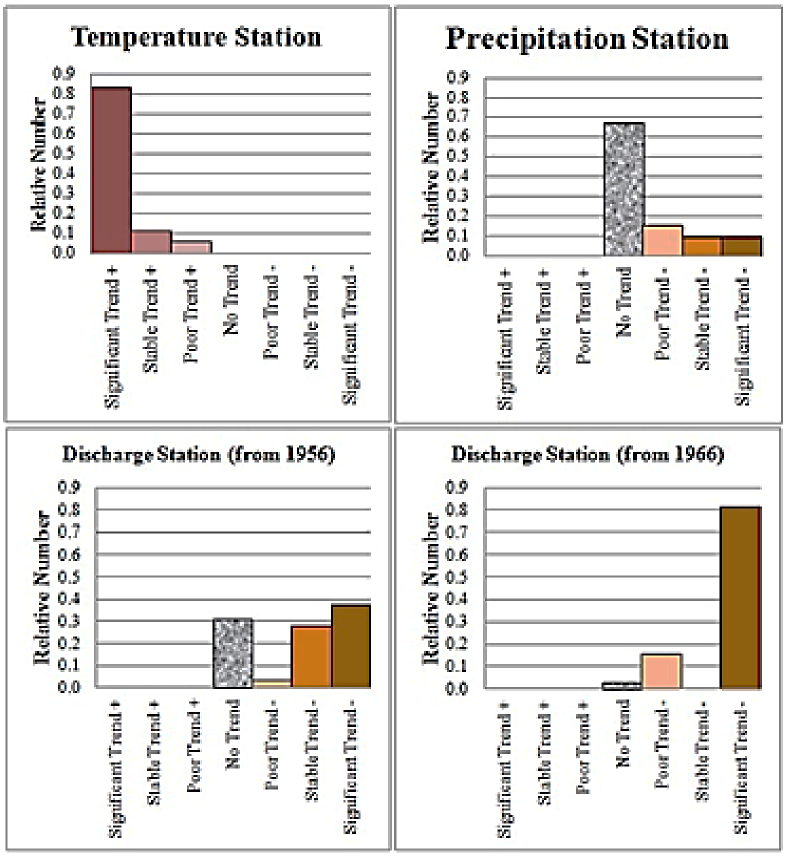

Figure 5. Relative frequency of trends using annual data

Another important point using the trend analysis for streamflow data is to note that the abovementioned results concerning the relative number of stations are based on discharges from different stations with wide range of river flow amounts. Since most of stations are located at the upstream river branches with little share in the total amount of basin discharge, therefore, precautions should be taken in deriving conclusions for the whole basin.

To reveal more details, monthly trends of variables were also examined. Here, in order to avoid prolongation and to save space, only part of the results are shown in Figures 6, 7, and 8. The graphs illustrate relative number of different trend classes for each month. The legends are borrowed from Figure 5. As is can be seen from Figure 6, none of the months experience decline in temperature. Also, while the temperature shows no significant trend in colder months (i.e., Nov-Jan.), but in most of the other months a considerable increasing trend in temperature is observable. This positive trend is more remarkable in some months including the October, February, May, June, July, August and September (i.e., late spring and during summer). Increasing temperature in February is the most important since it causes premature snow melting of higher altitudes and faster depletion of water supplies than before. These phenomena can lead to less river discharge in the following months. Consequently, there would be a water supply problem for irrigation areas that use the river flow as the source. Moreover, most of the snow water would be lost as early spring floods and less infiltration and groundwater recharges would occur.

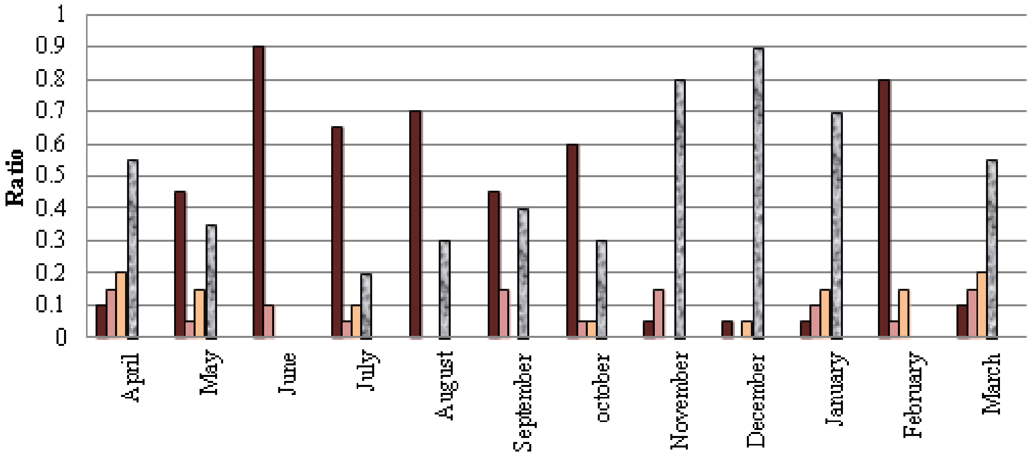

Figure 6. Relative number of trend classes for monthly temperature

Similar analysis for the trend of monthly precipitation indicates that for most of the months there is not a tangible trend (Figure 7). March and June are facing a relative decrease in the amount of precipitation which is happening only in some parts of the basin as shown in Figure 3. It also indicates a slight increase in the amount of precipitation during summer months such as July and August. However, these increases are because of scattered showers in summer days and do not have much importance in term of water resources. These events are also negligible due to their small share in the total annual rainfall.

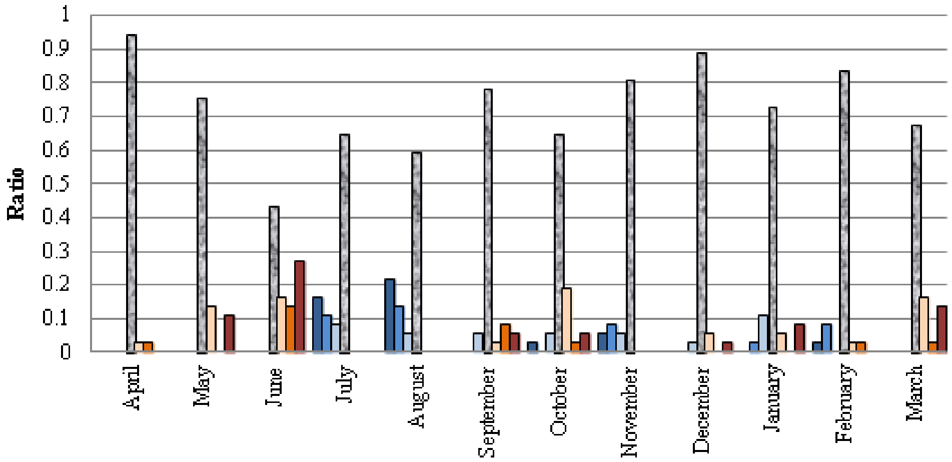

Figure 7. Relative number of trend classes for monthly precipitation

Monthly trend analysis of hydrometric stations shows a consistent decrease during all months. As it can be seen from Figure 8, June shows the highest number of stations with significant streamflow decline. It is interesting to note that river discharge decline occurs in cold months as well, where no significant agricultural activity is in place. Therefore, water consumption for other means such as municipal and industrial uses and most importantly for filling the storage of reservoirs scattered throughout the basin could be the main cause.

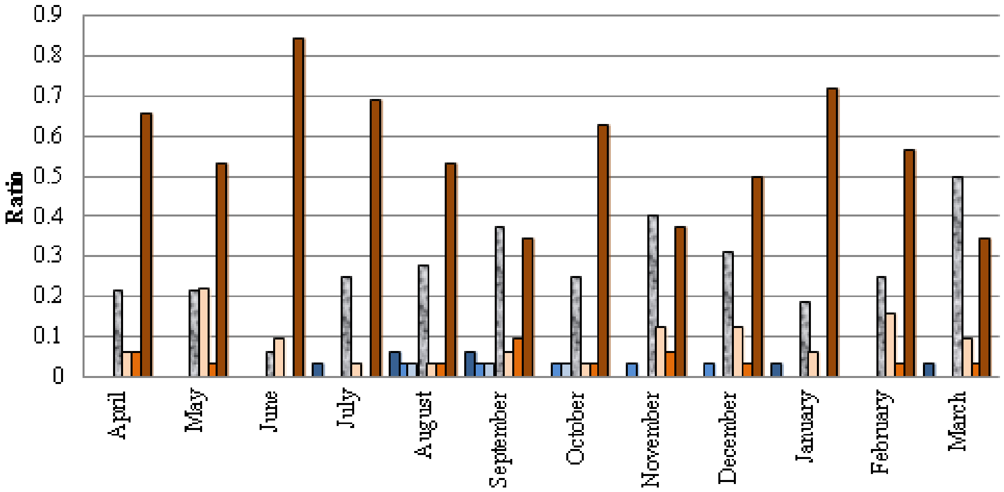

Figure 8. Relative number of trend classes for monthly discharge

The aforementioned analysis on hydrologic variables of the Urmia Lake Basin can be used to assess the causes and roots of the current crises of the Lake. Figure 9 shows the observed lake level during 1966-2012 period. In this Figure, the red horizontal dashed line at 1274m elevation is the minimum ecological elevation water level and the blue solid line at 1276m shows the average water level during normal period (1966-1996). As it is obvious from this Figure, the decline of water level which started in 1996, has continued until the end of the studied period. The water level dropped below the critical ecologic elevation in about 2001.

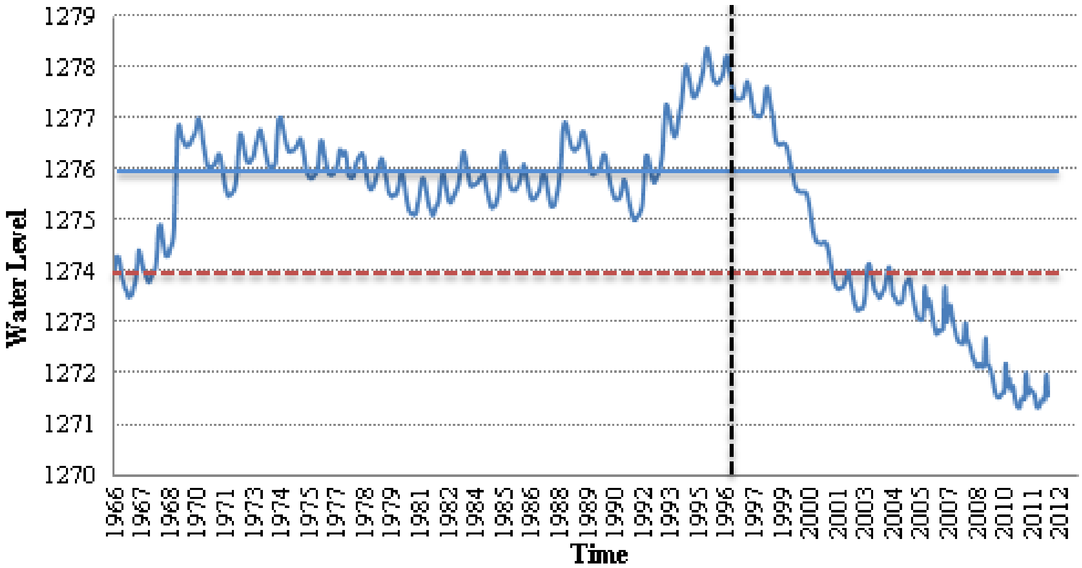

Figure 9. Water level elevation fluctuations (1996-2012)

As it was discussed earlier, although the MKnp method is useful in revealing some trend information of variables but the utilization of other methods is usually necessary for further exploration. Among many methods, the simple application of fitting a trend line over long-term time series proved to be suitable in this case. Through this procedure, further information about the trend of hydrologic variables and their relations with the lake level changes can also be explored. Unlike the MKnp method, here we could derive the parameters for the whole basin and use the areal amounts rather than the station data. Areal parameters were obtained through an ARC-GIS tool.

For this purpose, a duration extending from 1966-67 to 2011-12 water year was used. Then, the whole period was divided into two distinct periods, namely a normal period extending from 1966-67 to 1996-97, and a critical period from 1997-98 onward. Then, the slops of normalized variables as shown in Table 1 are calculated for each period and for the whole duration using annual data. It is worth mentioning that normalization is carried out using $\left(X - X_{\min}\right) \big/ \left(X_{\max} - X_{\min}\right)$ relation with a range between 0 and 1. Normalization is used for making comparable the slopes of different variables and of each variable in different durations. Also, normalization is useful in adjusting the intersection value of trend lines of each variable in different periods (i.e., normal and critical periods).

Table 1. Trend lines information

Parameter	normal (1966-96)		critical (1997-2011)		total (1966-2011)	
	Slope	change per decade	Slope	change per decade	Slope	change per decade
Temperature (°C)	0.0027	0.30	0.0051	0.68	0.0034	0.37
Precipitation (mm)	-0.0025	-8.5	-0.003	-10.5	-0.0029	-10.4
Upper Basin Discharge (mcm)	-0.0019	-109	-0.0027	-156	-0.0024	-146
Mid Basin Discharge (mcm)	-0.0029	-161	-0.0060	-321	-0.0048	-284
Inflow to Lake (mcm)	-0.0052	-256	-0.0111	-373	-0.0063	-340
Evaporation (mm)	0.0023	3.0	0.0034	5.2	0.0031	4.8
Relative Humidity (%)	-0.0035	-0.23	-0.0076	-1.41	-0.0039	-0.78

In general, as it can be seen from Table 1 mean basin temperature shows a positive trend (increase) while precipitation and discharge both experience negative trends (decrease) for the whole period. The overall result regarding the aforementioned three variables is similar to that found by MKnp method. However, the slope of precipitation calculated for the whole basin provides further information that was not available in the MKnp method using point station data. In addition, increase in evaporation and decrease in relative humidity (Table 1) was also expected due to the rise in temperature and decline in precipitation. Moreover, to analyze the impact of water consumption on river discharge, three different regions were considered. These include: 1. Lower Basin: consisting of total water inflow to the Lake Urmia, 2. Middle Basin: middle basin streamflow and 3. Upper Basin: stream flow at upper areas of the basin.

According to Table 1 the trend of discharge is negative for all three regions. However, the attractive point is that the sharpest decrease occurs for water inflows to the lake (lower basin), whilst the slope for middle stream flows is more gradual and the mildest trend occurs in upstream flows, suggesting that the excessive water consumption which increases from upstream to the downstream (with agricultural lands being mainly at low-lying areas) is the main cause of sharp decline of inflows to the lake rather than any other factor. In fact, the increasing water usage for irrigation is the main reason for intensified negative trend of discharge in middle parts and especially in areas near the lake in comparison to the upstream regions where in the absence of human interferences climate change could be the dominant factor. In overall, the irrigation water usage leads to slopes about 2.6 and 1.3 times sharper for the flows to the lake than upstream and middle stream flows, respectively.

Moreover, as it can be seen from Table 1, the slopes have changed drastically during the recent critical period. The rise in temperature and decline in precipitation and discharge has intensified during this period. For instance, the rate of temperature increase has changed from 0.0027 in normal period (1966-1996) to 0.0051 during the critical period (1997-2011), showing that temperature is rising about 2 times faster during the critical period as compared to the normal period. Other variables also show similar behavior.

In general, when total period is assumed, the inflow into the lake for each decade reduces by about 340 million cubic meters (mcm), whereas this value for mid-basin and upstream flows is 284 and 146 mcm respectively (Table 1). As it can be seen from Table 1, water withdrawal is intensified during critical drought period where more water demand is requested by the irrigated agriculture. On the other hand, temperature increasing only by 0.37 °C per decade cannot be the main reason for this amount of extra water extraction from the basin and consequently the drop in the lake water elevation.

By examining the slope of studied variables before and after 1997, interesting results can be extracted. A dramatic increase in the average temperature of the basin can be witnessed during the critical period. This positive slope from 1997 onward (critical period) is about 2 times more than that in the normal period. This incident may be due to the ongoing drought in the basin together with changes that are made to the lake ecosystem due to sever decline of lake water level. Under these circumstances, climate changes are intensified through local ecosystem destruction. The rising trend in temperature is also followed by positive trend in evaporation. The slope of trend in evaporation is 1.5 times larger in critical period in comparison to the normal one. Furthermore, the average relative humidity of the basin is also experiencing a negative trend during the whole period and while its slope is -0.0076 in the critical period, it is only -0.0035 during the normal period. The consequences of these changes will probably further be exacerbated affecting the social and economic situation of people living in the region. Also, as the plains at the middle part of the basin are one of the main regions for agricultural and horticultural products in Iran, the national losses would be extensive.

5. Local Climate Alteration

Lake Urmia is a massive water body in the region and it is assumed that its water shrinkage would probably affect the ecosystem and the climate of the surrounding areas. Having this in mind, an investigation was carried out to verify the validity of this assumption and to evaluate the extent of this effect. Considering the overall wind direction which is from southwest to northeast, the area most affected by the lake shrinkage would be mainly the Ajichay basin in north-west of the lake. Therefore, the whole basin was divided into the Ajichay and the remaining area, and the trend of hydroclimatic variables was investigated. Table 2 shows the slope of the trend line for temperature, relative moisture, evaporation, and precipitation during the critical and normal periods together with the whole interval of studied period for the two regions and the basin. According to this Table, there is more significant change in the climatic variables of Ajichay Basin as compared to the remaining area during the critical period where the Lake water shrinkage takes place. For example, the slope of temperature trend line during normal period with the lake enjoying abundance of water is the same for the two regions, but it is much higher in the Ajichay basin than the remaining area during the critical period during which the Urmia Lake is shrinking and losing its water. In fact, temperature increases 1.5 times faster in Ajichay region than the rest of the basin during the critical period. Similar phenomenon can be seen in other climatic variables including the relative humidity and evaporation. The trend in precipitation is somehow different, as it is not expected also to be affected by a local system. As it can be seen from Table 2, precipitation decreases by a slope equal to -0.0036 in Ajichay Basin and by -0.0019 in the remaining area during the normal period. Although, these figures increase to -0.0041 and -0.0027 for Ajichay and the remaining area during the critical period, but the ratio of changes in Ajichay to the remaining area has decreased from 1.9 in normal period to 1.5 during critical period. It is worthwhile to mention that although global climate change models are useful tools in general, but they are unable to consider these local interactions say between a lake and its surrounding region. Therefore, according to our achievements a local study should also accompany the global climate change study where these interactions are revealed and can be used in forecasting the long-term climate changes.

Table 2. Comparison of the slope of trend lines for regions in Urmia Lake Basin

Parameter	Region	normal	critical	Total
		1966-1996	1997-2011	1966-2011
Temperature	*Whole Area*	0.0027	0.0051	0.0034
	Ajichay	0.0026	0.0065	0.0039
	Rest	0.0027	0.0042	0.0034
Relative Humidity	*Whole Area*	-0.0035	-0.0076	-0.0038
	Ajichay	-0.0031	-0.0096	-0.0039
	Rest	-0.0035	-0.0075	-0.0038
Evaporation	*Whole Area*	0.0023	0.0034	0.0031
	Ajichay	0.0027	0.0051	0.0039
	Rest	0.0020	0.0031	0.0027
Precipitation	*Whole Area*	-0.0025	-0.0030	-0.0029
	Ajichay	-0.0036	-0.0041	-0.0039
	Rest	-0.0019	-0.0027	-0.0024

Finally, to see what would have happened if the basin was less altered by the human activity, we used our results on the three regions as mentioned earlier to simulate the system using the conditions of the Upper Basin region for the whole basin. In doing that, we changed the streamflows throughout the basin using the slope of the Upper Basin and ignored the human impacts in the Middle and Lower Basin areas. The simulation was carried out using a WEAP model prepared for the basin by Eamen and Dariane [35]. Figure 10 compares the observed and the simulated lake water level. As it can be seen from this Figure the Lake level would have been much higher and in better condition if the human activities in the basin were somehow limited to the extent practiced in Upper Basin area.

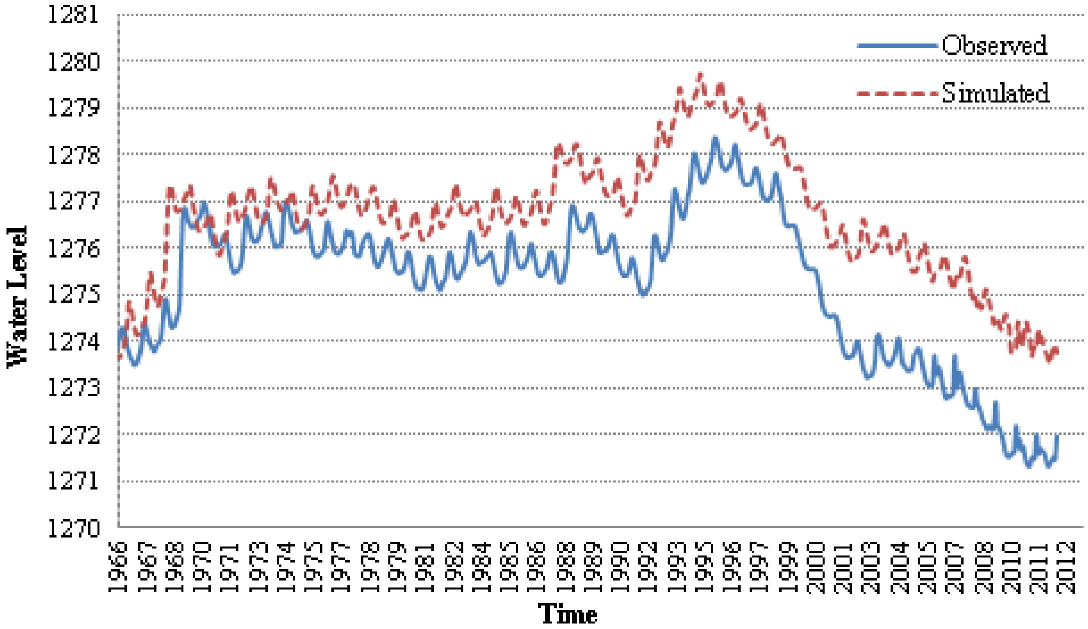

Figure 10.Comparison of observed and simulated Urmia lake water levels.

As it is obvious from the Figure, in absence of indiscriminate water usage over the basin, despite of the drop in water level elevation which began in 1997, the water level elevation never would have passed the ecological level (1274 m) and the basin would not have experienced current critical conditions. In fact, the simulated graph with WEAP model shown in Figure 10, can be considered as a manifestation of the effects of pure climate change with some limited human activities on the lake. Thus, recent excessive drop in water level elevation in observed data, is only as the result of unbounded water related developments in the area (irrigated agriculture) . Therefore, for saving the lake from current crisis, the emphasis should be on solutions that have the most impact on the lake water level, i.e., the agricultural water consumption.

There have been many scenarios suggested to tackle the problem of water level shrinkage in Urmia Lake in recent years. These can be classified in two groups of short and long-term solutions. Among short-term solutions, water transfer from nearby basins is probably the most suitable method. Water transfer from Caspian Sea, Aras and Zab Rivers are currently suggested and considered. However, water importation from Zab River is the only ongoing project that will take another 4 to 5 years for its completion. It is worthwhile to mention that although water transfer from another basin may help to overcome currently resenting problems of a basin, but it may intensify the situation in the long-term if proper management and specific rules are not enforced to avoid further developments in the view of new granted and abundant available water.

In the long-term, the solutions must tackle the roots of the problem which are excessive water consumption by the agriculture. In this respect, the development of new areas must be limited. However, most importantly the currently inefficient traditional irrigation system (with an efficiency around 35%) needs to be modernized and replaced by more efficient irrigation systems along with more suitable cropping patterns. The extra water released through this must be primarily allocated for the lake water demand while the remaining water could be used for other purposes. The farming system in the region is mainly made up from small size fields which makes it more difficult for applying such management actions. Percussions must be taken to evaluate the social, economical, and ecological aspects of the actions.

6. Conclusion

An investigation was carried out to determine the long-term trends in hydroclimatological variables of Lake Urmia Basin and to reveal the possible causes of current crisis in the Lake by the aid of these results. The application of Mann–Kendall nonparametric test (MKnp) showed that all variables including temperature, precipitation and streamflow are changing following the global warming trend. In other words, temperatures are rising, while precipitation and streamflows are declining. The rate of changes, however, are accelerated during the critical period (1997-2011) as compared to the normal period (1966-1996). It was shown that the decline in precipitation could not be blamed as the real cause of Urmia Lake’s water shrinkage. A comparison of streamflow conditions in upper, middle, and lower basin areas showed that the excessive water consumption by human activities, mainly through irrigated agriculture, is the main reason for decreased lake inflow and hence its water level drop. Changing cropping methods, modernizing the irrigation system, limiting further development projects, importing water from nearby basins, etc. are some of possible solutions to tackle the problem but very detailed studies are essential to find the most effective and efficient methods. It was shown that under climate change scenario and with minimum human interferences the lake level would have been much higher and above the so called ecological water level. Moreover, the impact of lake's water loss on local climate was investigated. It was shown that the local climate of regions affected by the lake is changing with higher speed than the rest of the basin. Thus, it is suggested that such interaction between the lake and surrounding areas should be considered in studying climate change scenarios.

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