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RESEARCH ARTICLE

# Implications from the meteorological data effects on water level fluctuations of the Lake Van (Eastern Anatolia/Türkiye)

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## ABSTRACT

Lake Van is located in the eastern part of Türkiye and forms the largest soda lake in the world. In this study, we present the relationship between instrumental data which belongs to Lake Van level changes and meteorological parameters by performing a multilevel analysis. The data set consists of monthly average levels of Lake Van and monthly meteorological parameters (temperature, precipitation and wind speed) between 1944-2019 years. Two different multilevel linear models; random intercept, random intercept and slope model were used. Unstructured (UN) covariance structure and Maximum Likelihood (ML) were used for repeated measurements and estimation, respectively. Log-likelihood (ll), Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC) and AIC Corrected (AICC) were used for the selection of the best model. The random intercept and slope model (Model II) is explained as the best model for the lake level changes in this study. Statistical results in this study indicated that the temperature and wind speed are the key parameters controlling the Lake Van water level fluctuations, whereas the precipitation effect is minimal due to the type of precipitation (snowfall). For this reason, temperature, wind speed and also the type of precipitation (snowfall or rain) must be considered for disaster modelling in settlements of Lake Van and similarly closed basin lakes.

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## Introduction

Lake levels fluctuate naturally in response to tectonic activity, erosion, changes in groundwater level, precipitation, drought and/or human-induced activities (land use, irrigation activities, dams, etc.). Climate change is the most important cause of lake level changes and is due to the precipitation-evaporation change over the drainage basin. In the absence of natural and human-induced effects, the water level in closed lakes represents the balance of input (precipitation, runoff, and groundwater) and output (evaporation and seepage). Close and deep lakes are very sensitive to climate changes especially in arid/semi-arid region. Lake Van has an altitude of 1648 m above sea level, extending for 130 km WSW-ENE on the Eastern Anatolian high plateau, Türkiye (Figure 1). It is the fourth-largest terminal lake (area 3570 $km^2$, volume 607 $km^3$, maximum water depth 450m) and the largest soda lake in the world (Degens & Kurtman, 1978). Lake Van is surrounded by semi-active volcanoes of Nemrut (2948 masl) and Süphan (4058 masl). Due to evaporation processes, hydrothermal activity, and chemical weathering of volcanic rocks, the lake water is extremely alkaline (alkalinity 155 $meql^{-1}$, pH 9.81, salinity 21‰; Kempe et al., 1991). The origin of the lake is attributed to the cut of the outlet of an ancient river at ca. 600 ka as a combination of the presence of thick ignimbrites underlying South of Tatvan and Muş Basin and the growth of the Nemrut Volcano between Van and Muş basins (Sumita & Schmincke, 2013; Cukur et al., 2014a; Schimincke & Sumita, 2014).

Lake Van Basin is located at the crossroads of the North Atlantic, Siberian High Pressure and the mid-altitude subtropical high-pressure systems (Türkeş & Erlat, 2003; Akçar & Schlüchter, 2005). The basin has a continental climate characterized by cold and wet winters and dry summers (Landman et al., 1996a, 1996b; Wick et al., 2003). The annual precipitation of the lake's catchment is about 400mm/year (Landman et al., 1996a, 1996b; Wick et al., 2003). During the winter season, the precipitation type is snowfall which is typical in Eastern Anatolia (Kadıoğlu et al., 1997). The most freshwater that enters the lake occurs in spring with snowmelt and rain. The annual average temperature is 9-10°C. The driest and warmest period is between July and September, while evaporation is at its maximum during July-August (Kadıoğlu et al., 1997). The water that enters the Lake Van which is hydrographically closed is 2.1 $km^3$ via rivers and 1.68 $km^3$ via precipitation per year and an average of 3.78 $km^3$ of water is lost by evaporation (Landman et al., 1996a; Reimer et al., 2008). While the water body of Lake Van shows stratification during the summer with the effect of temperature, it mixes during the winter (Peeters et al., 2000). The lake is classified as a meromictic lake with a monomictic upper (70-100 m) layer (Kipfer et al., 1994).

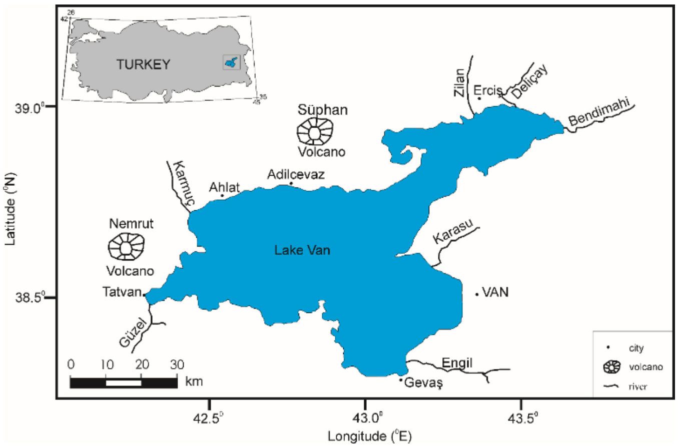


**Figure 1.** Map of Lake Van showing the major inflowing rivers and the volcanoes

An International Continental Drilling Project (ICDP)-PaleoVan Project was realized in Lake Van in 2010 to investigate its geological evolution and climate changes. Approximately 600,000 years of geological evolution and climatic variability of the region were revealed in this project (Litt et al., 2014). Earlier works show that the lake water levels have fluctuated drastically due to the climate changes over the last 20,000 years (Kempe & Degens, 1978; Lemcke, 1996; Landman et al., 1996a, 1996b; Kempe et al., 2002; Wick et al., 2003, Litt et al., 2009). Based on exposed terraces around the lake, it has been reported that the lake level rose to 107 meters from its current level in the past (Valeton, 1978; Kempe et al., 2002; Kuzucuoğlu et al., 2010). The seismic profiles obtained from Lake Van reveal that the lake level has fluctuated dramatically during the last 600.000 years (Çukur et al., 2014a, 2014b; Damcı et al., 2012).

Lake Van's water level fluctuates unsteadily today as it was in the past. Therefore, many studies have been conducted to explain the reasons for the level changes. The 2 m rise in the lake level recorded between 1944-1974 was attributed to sunspot cycles occurring at intervals of 10-11 years (Kempe et al., 1978). Afterwards these level changes associated with precipitation, evaporation, and temperature (Saraçoğlu, 1990; Gürbüz, 1994; Kadıoğlu, 1995; Gürer & Yıldız, 1996; Batur, 1996; Sezen, 1996). In addition to climatic factors, it has been reported that the groundwater controls the lake level (Kaynak, 1995; Batur, 1996; Gürer & Yıldız, 1996; Düzen, 2011). While investigating the causes of lake level changes, it was revealed that 50% regeneration in deep water occurred until 1994, according to studies on some trace elements (Kipfer et al., 1994). In the following years, trace element studies continued in the water column, and it was stated that in response to the lake level rise that started in 1994, the intensity of deep-water exchange decreased significantly, and anoxic conditions developed below 300 meters (Kaden et al., 2010). It was observed that the He concentration of the water samples from Lake Van in 2004 was higher than in 1990/91 (Litt et al., 2009). This revealed that the mixing (oxygenation) in deep water slows as the level rises. Fort this reason, it has been interpreted that the lake level changes in response to climate change affect the mixing dynamics over time (Litt et al., 2009).

The increases in the lake level had a significant impact on the settlements located around Lake Van, especially in the 90s, and forced the people living in that area to migrate. On the other hand, in Tatvan and Van Piers which are the important trade routes of the region, the railway tracks, warehouses belonging to the enterprise and the basements of the lodgings were completely submerged (Deniz & Yazıcı, 2003). These human and economic negativities in the vicinity of the lake shore have been tried to be eliminated by taking a series of measures.

The effects of climate change not only mean the increase in temperature in that region and therefore drought, but also the change in weather events (especially precipitation type and duration). It is insufficient to explain the lake level change with the annual average amounts of temperature and other meteorological parameters. To see the effect of meteorological events on the lake level, making an evaluation using monthly is one of the solutions to the problem. Considering the monthly changes means that seasonal changes can also be easily interpreted. With such evaluations, more sensitive approaches are obtained and thus the corrects interpretation of the parameters is ensured. The predictability of the impact of climate change on the Lake Van level will enable early measures to be taken against possible problems that may arise over time. The aim of this study is therefore to examine the water level changes of Lake Van, which may affect more than one settlement in our region with the effect of climate change. To show the which parameters control the lake water level changes, we present the relationship Lake Van water level changes data and meteorological parameters by performing a multilevel analysis.

## Material and Methods

The dataset of the study includes the average lake level of Lake Van between 1944 and 2019 and monthly average temperature, precipitation, and wind speed variables in the region of the same years. Lake level data were obtained from the Lake Van - Tatvan Station affiliated with the Turkish State Hydraulic Works Survey, Planning and Allocations Department. Monthly average temperature, precipitation and wind measurements were obtained from the Turkish State Meteorological Service.

Two different multilevel linear regression (MLM) models were used to analyze the data (Goldstein, 2011). The first model is the random intercepts model, and second model is the random intercept and slope model.

**Model I:** The equation of the random intercept model is

$$Y_{ij} = \beta_0 + \beta_1 X_{1ij} + \beta_2 X_{2ij} + \beta_3 X_{3ij} + u_{0j} + e_{ij} \qquad (1)$$

Where; $Y_{ij}$, lake level of the i[th] year and j[th] month; $X_{1ij}, X_{2ij}, X_{3ij}$, temperature, precipitation and wind speed values measured in the i[th] year and j[th] month; $\beta_0$, random intercept point and $\beta_1, \beta_2$, and $\beta_3$, coefficients; $u_{0j}$, level-2 error term and $e_{ij}$ shows level-1 error term. Error terms are normal distributed, and level-2 and level-1 errors are independent of each other. $u_j = u_{0j} \sim N(0, \sigma^2_{u_0})$ and $e_{ij} \sim N(0, \sigma^2_e)$ assumptions are made.

**Model II:** The equation of the random intercept and slopes model is

$$Y_{ij} = \beta_0 + \beta_1 X_{1ij} + \beta_2 X_{2ij} + \beta_3 X_{3ij} + u_{0j} + u_{1j} + e_{ij} \qquad (2)$$

The difference between Model II from the Model I is included in the second random error term model which assumes temperature values change from year to year randomly. Therefore, the random error term u_1j is added to the model. In this model, it could be a correlation among level-2 errors, however it is independent of level-1 errors. In other words, $u_j = [u_{0j}, u_{1j}]^T \sim N(0, \Omega_u)$, $\Omega_u = \begin{bmatrix} \sigma^2_{u_0} & \sigma^2_{u_{01}} \\ \sigma^2_{u_{01}} & \sigma^2_{u_1} \end{bmatrix}$ and $e_{ij} \sim N(0, \sigma^2_e)$ the assumption is still existing.

In Model I and Model II, ML (Maximum Likelihood: Maximum Likelihood) estimation method and UN (non-structural) covariance structure were used. For model selection, Log-likelihood ll, Akaike Information Criteria AIC, Bayesian Information Criteria BIC and Akaike Information Criteria AIC Corrected AICC (Akaike, 1974; Schwarz, 1978; Hurvich & Tsai, 1989) were used.

SAS (v9.4) and MLwiN (v2.02) statistical package programs were used while analyzing the data (Rashbash et al., 2010).

## Results and Discussion

### *Lake Van Level Fluctuations Between 1944 and 2019*

The minimum and maximum values of the lake level obtained from the State Hydraulic Works between 1944-2019 are given in Figure 2.

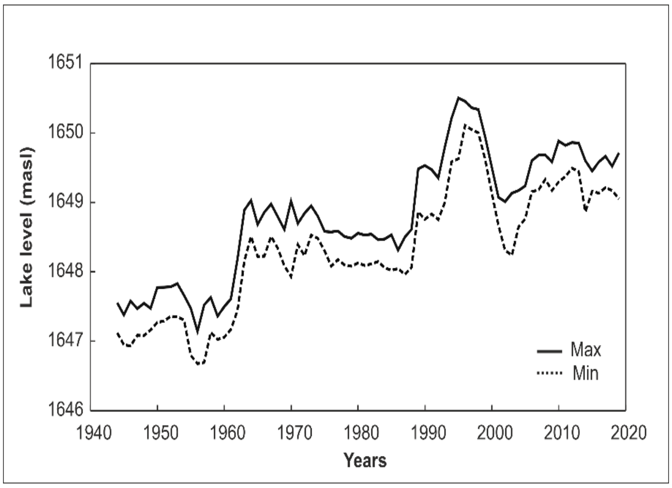


**Figure 2.** Lake Van minimum and maximum water level (Turkish State Hydraulic Works, 2019)

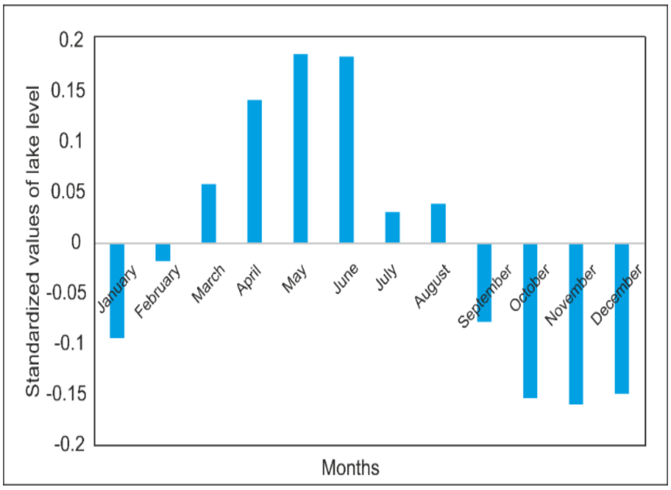


**Figure 3.** Monthly average changes of standardized lake level data (1944-2019)

The lake level fluctuates unsteadily according to instrumental data (Turkish State Hydraulic Works, 2019). The lake level increased between 1960-1965 and 1987-1997. Between 1965-1987 the level decreases relatively. In total 76 years of lake level data have been standardized and the monthly changes in the lake level are given in Figure 3.

The lake level was above the average between March-August, and the maximum lake level was recorded in May. The minimum value of the lake level, which fell below the average between September and February, was observed in November. In this study, which investigates how much this fluctuation can be explained by temperature, precipitation, and wind speed, the standardized data (monthly average temperature, precipitation, wind speed (Turkish State Meteorological Service, 2019) and lake level (Turkish State Hydraulic Works, 2019) are also presented together (Figure 4).

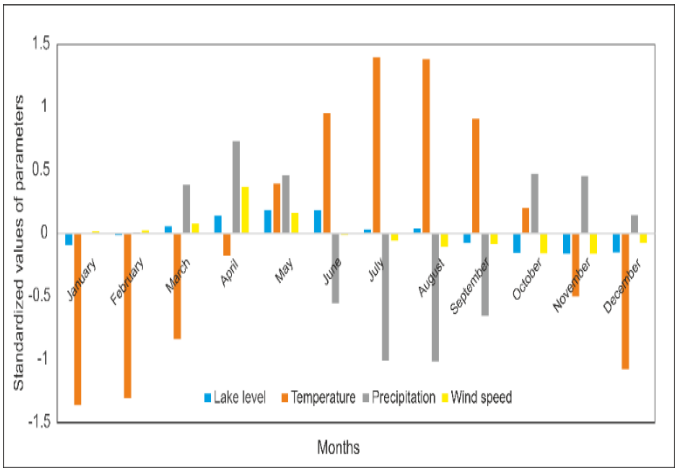


**Figure 4.** Monthly average changes of standardized lake level, precipitation, temperature, and wind speed data (1944-2019)

The standardized data show that the temperature in January is well below the average, the precipitation and wind effect are almost equal to the average and the lake level is below the average (Figure 4). This situation is similar in February and the lake level increases relatively but still below the average (Figure 4). In March, when the lake level rises above the average for the first time, the temperature is below the average, but increases compared to February (Figure 4). However, wind speed and precipitation are above the average. In April, when the precipitation is at its highest level above the average, the temperature increases compared to the previous month, precipitation and wind speed reach the highest level of the year, and the lake level continues to rise (Figure 4). All standardized data are recorded above the average and in May and the lake level is at its highest level (Figure 4). The effect of precipitation amount and wind speed decreases compared to the previous month. The temperature continues to increase in June when the wind speed decreases to its average value and the precipitation falls below the average (Figure 4). Precipitation rate is the lowest and the temperature is highest at maximum in June and August (Figure 4). Lake level is about its average level and wind speed drops below the average. In September, the temperature decreases compared to August but is above the average (Figure 4). Although the wind speed has increased compared to the previous month, it is below the average. The lake level drops below the average from this month and this decrease is observed at the maximum level in November (Figure 4). The precipitation rate which rises above abruptly above the average in October, decreases until November, but it is observed above the average till January (Figure 4).

Sezen (1996) reported that there is a positive relationship between the lake level fluctuation and precipitation and that precipitation falling into the basin causes an increase in the lake level in the following months. It has also been revealed that the lake level change is related to the variations in precipitation, snow melt, and temperature (Gürbüz, 1944; Saraçoğlu, 1990). Düzen (2011) suggested that groundwater controls the lake level changes as well as climatic patterns. Based on standardized instrumental data, we show that the lake level is at its minimum level in November albeit it is below the average, starts to rise from December, and rises above the average in March. Lake Van is located on a high plateau and is adjacent to several mountain glaciers (Akcar & Schlüchter, 2005). It is fed mostly by river input and precipitation. The predominant precipitation type is snowfall in the basin because of its location. In line with the increase in temperature, the transformation of precipitation type into the rain and the increase in wind speed, the snow-mass in the higher elevations begin to melt and the lake level rises above the average in March. The water input to the lake peaks in May with the increase of snowmelt and the water level reaches its maximum then begins the decrease in June. The lake level is still above the average between July and August due to the continued snowmelt at higher elevations. Despite the increase in the amount of precipitation compared to the previous month, the lake level drops below the average in September and this decrease continues until November due to the precipitation type is snowfall. The decrease in the lake level in autumn can be explained by the cold weather in the region and the fact that the snow doesn't turn into water, and thus the decrease continues until the temperature increase. The lake level fluctuation cycle can be summarized throughout the year like this according to the length.

### *Statistical Models*

In multi-level models, the analysis is started with the random intercept model (Model-I). The data structure is two-level, in other words, the months are classified over the years. The intraclass correlation coefficient is calculated as 92% used by the ICC formula (Raudenbush & Bryk; 2002; Goldstein, 2003). These results reveals that the lake level fluctuates significantly over the years, and this should be considered.

Temperature, which is one of the variables used to explain the lake level fluctuations, varies randomly according to the years. Therefore, in Model II, it was assumed that the temperature changed from year to year randomly and the data were analyzed accordingly. The goodness of fit results ($ll$ , AIC, BIC, AICC respectively) obtained to determine which model explains lake level changes are given in Table 1 for both models.

**Table 1.** Fit criteria for two-level linear regression models

| Models | $-2ll$ | AIC | BIC | AICC |
|---|---|---|---|---|
| Model I | 375.6 | 387.6 | 401.5 | 387.7 |
| Model II | 281.7 | 289.7 | 289.8 | 299.0 |

Model II is the random intercept and slope model. The fit criteria results ($ll$ , AIC, BIC and AICC, respectively) obtained using the ML estimation method for this model were significantly smaller than the fit criteria of Model-I. The results revealed that the best model for the study data is Model II. Because the model with the smallest fit criteria is reported as the model that best explains the change (Akaike, 1974; Schwarz, 1978; Akkol & Denizhan, 2016; Akkol et al., 2018). The estimation, standard error, and significance level obtained by using Model II are presented in Table 2.

**Table 2.** The analysis results of Model II

| Fixed effect | $\bar{X} \pm SE$ | t | Random effect | $\bar{X} \pm SE$ | z |
|---|---|---|---|---|---|
| Intercept ($\beta_0$) | 1648.32±0.1071 | 15396.80*** | $\sigma^2_{u_0}$ | 0.66900±0.11060 | 6.05*** |
| Temperature ($\beta_1$) | 0.005346±0.0019 | 2.83** | $\sigma^2_{u_1}$ | 0.00021±0.00005 | 4.787*** |
| Precipitation ($\beta_2$) | 0.000403±0.0003 | 1.38 | $\sigma^2_{u_{01}}$ | 0.00218±0.00157 | 1.39 |
| Wind Speed ($\beta_3$) | 0.07819±0.0782 | 3.21** | $\sigma^2_e$ | 0.04279±0.00230 | 18.61*** |

***Note:*** $\bar{X}$: mean, *SE*: Standard error, *t*: t value, *z*: z value, **: P<0.01, ***: P<0.001

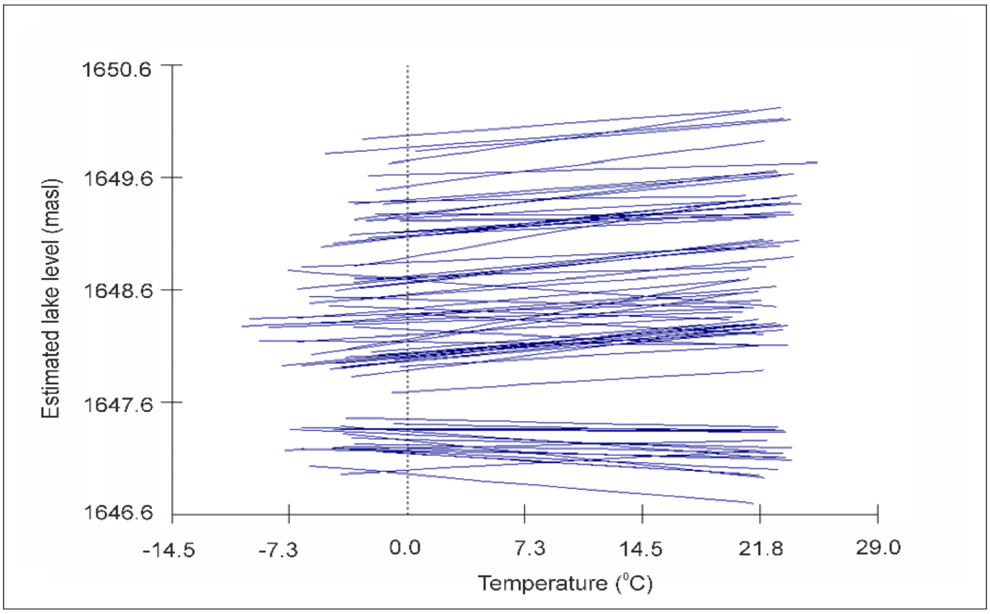


**Figure 5.** Estimated lake level and temperature relationship (1944-2019)

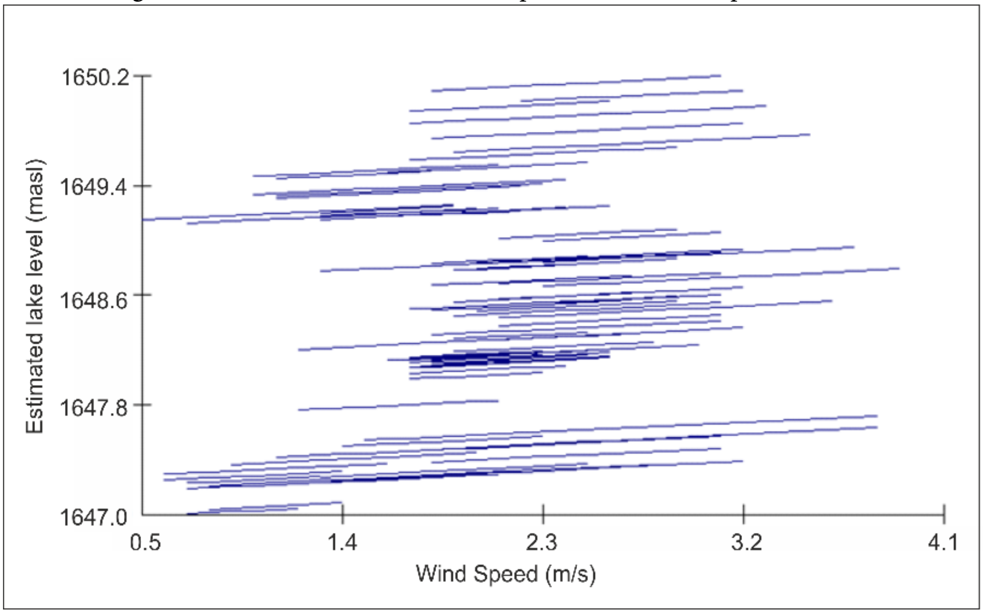


**Figure 6.** Estimated lake level and wind speed relationship (1944-2019)

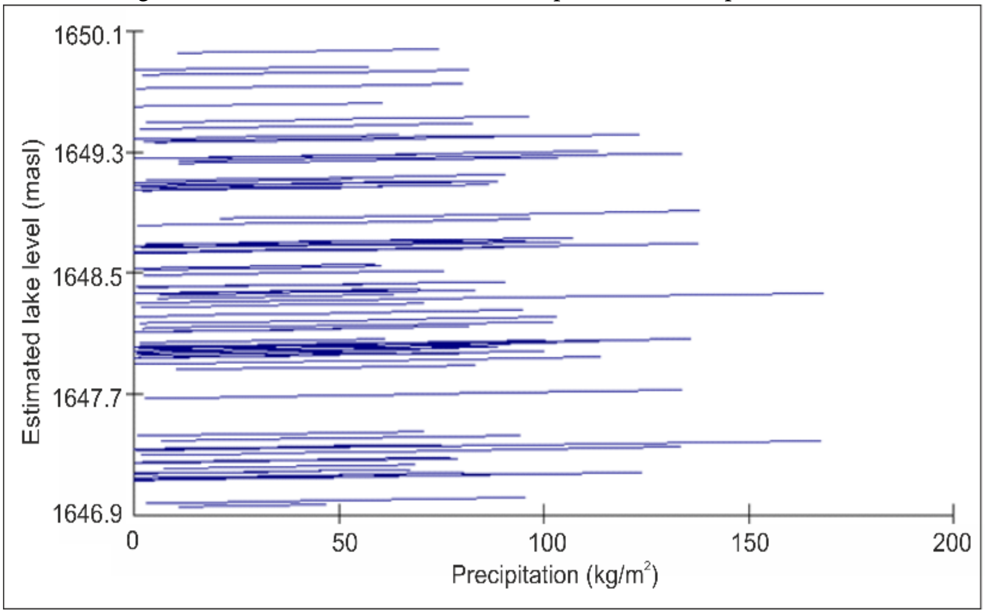


**Figure 7.** Estimated lake level and precipitation relationship (1944-2019)

The intercept (1648.32) from the fixed effect in Table 2 was found to be significant (P<0.001). In other words, the lake water level is 1648.32 units on average, which is an important amount. However, the effect of temperature and wind speed were found to be significant (P<0.01). An increase of 1°C in temperature causes an increase of 0.005346 m in lake level and an increase of 1 m/s of wind speed causes a 0.07819 m increase in lake level. The variations of the intercept and slope ($\sigma_{u_0}^2$ ve $\sigma_{u_1}^2$, respectively) and the covariance between the intercept and the slope ($\sigma_{u_{01}}^2$) were found to be significant (Table 2). It is seen that the random effects in Table 2 ($\sigma_{u_0}^2, \sigma_{u_1}^2$ and $\sigma_{u_{01}}^2$) are significant (P>0.001). When interpreting fixed and random effects together for intercept, the average lake level is 1648.32 units, and this value varies significantly from each other for each year. For temperature the fixed and random effect are interpreted the average temperature is 0.005346°C and the average temperature value has change significantly from year to year.

We examined the effects of temperature, precipitation, and wind speed to explain the fluctuation of lake level for the last 76 years. The estimated lake level values obtained from Model-II and the temperature relationship are presented in Figure 5. The lake level has a different average value for each year. The fact that the mean effect of temperature on the lake level and the change around the mean was found to be significant is explained by the fact that each regression line has a separate slope (Figure 5). This is explained by regression lines with different intercepts and slopes.

The estimated values for lake level obtained by model-II and wind speed relationships are presented in Figure 6.

The effect of the wind speed is found to be significant, and it is explained by the fact that the regression lines have slopes. The effect of wind speed on lake level changes can occur with the Seiche event and can only be effective in a part of the lake (Rabinovich, 2009). Especially strong winds cause the changes in lake level. Since Lake Van is a very large lake in terms of area and volume, the strong winds in the basin may cause lake level change. It is also possible that the wind speed indirectly accelerates the snow melt and increases the lake level.

The relationship between the estimated lake level and precipitation is given in Figure 7.

The absence of slope of the regression lines indicates that the precipitation effect was minimal (Figure 7). This can be explained by the fact that the lake level in January for each year was different, but the amount of precipitation has an insignificant effect on the lake level.

## Conclusion

Previous studies have shown that there have been fluctuations in the lake level of Lake Van due to the tectonism, volcanism, and climate changes for the last 600,000 years. Especially in the studies on current lake level changes on Lake Van, it has been reported that there is a close relationship between meteorological parameters and lake level changes. In this study, we examined the relationship between meteorological parameters (temperature, precipitation, and wind speed) and lake level fluctuation by using statistical models.

The statistical models which are obtained from this study indicated that the lake level is affected by temperature and wind speed, but not by precipitation. Since Lake Van is located at 1648 meters above sea level, precipitation type is mainly snowfall and the drainage basin consists of high mountains, the most freshwater input to the lake occurs in spring with mixing of snowmelt and rain. This situation is explaining why precipitation effect seems to be insignificant. Therefore, while it is expected that the lake level would decrease due to the evaporation with the temperature, the increase in temperature has been associated with the increase of lake level by activating the water resources that feed the Lake Van. Another important result obtained from this study is that wind speed has a significant effect on the lake level (snowmelt).

## Compliance With Ethical Standards

### *Authors' Contributions*

AFM: Designed the study and collect the lake level data, wrote the first draft of the manuscript.
SA: Performed and managed statistical analysis.
OHD: Collected the meteorological data.
All authors read and approved the final manuscript.

### *Conflict of Interest*

The authors declare that there is no conflict of interest.

### *Ethical Approval*

For this type of study, formal consent is not required.

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