Anonymous Referee #1

In general it is an interesting work, showing how environmental tracers can be used for quantifying complex interactions among various water bodies in a coastal Mediterranean area.

- ➔ We thank Referee #1 for the comments. In detail, we answer to all of these comments below which helped to substantially improve the manuscript.

General comments:
In order to conduct a spatial analysis of the isotopic data, authors should unavoidably present their data on a map through the use of a GIS program.

- ➔ We can include the data into the map (Figure 1b) if required. We had this idea too before submitting the manuscript but decided against due to several reasons. The information might be too compact and spatial differences not easy to grasp; therefore we decided to present the final results i.e. the freshwater vs. saltwater influence as a function of space (see Figure 7) which is more relevant than data merely. In addition, the isotope data would be presented twice, i.e. in a Figure and in a Table, which would make the manuscript quite lengthy as we prepared other new Figures and text sections of the manuscript. We preferred having the data in the table. What we cannot do is a spatial regression of the isotope data like giving isolines which would be scope of a different study also requiring additional data.

The geological setting (i.e. geological map of the area) as well as the hydrogeological setting (piezometric map) and the conceptual model constitute essential information for the reader to understand the complex interactions taking place in the study area. For example what is the origin of thermal waters? I believe that authors should have based their conclusions on such figures.

- ➔ We included a Figure presenting the conceptual model of the area for the dry and wet period (see Figure 3). Please note, that we actually found that there is negligible input of groundwater in the dry season, and thus we revised our conceptual model which is thoroughly discussed in the manuscript. Further, we added information about the origin of the geothermal waters, the geology and refer to the geological map which is in detail presented in Bayari et al. (1995). Unfortunately, no additional information from the groundwater bores was available and therefore, a piezometric map cannot be provided.

  Modified sections in Chapter 2:
  "Köycegiz-Dalyan Coastal Lagoon is located at the southwest of Turkey on the Mediterranean Sea coast within the province of Mugla (Fig. 1a). The geology in this region is mainly composed of allochthonous and authochthounous Flysch and karstic facies overlain by plio-quaternary sediments (Garciansky ,1968). Due to tectonic activities, several faults were formed in this area. Details about the geology and a map can be found in Bayari et al. (1995). The total area of the watershed of Köyceğiz Lake is approximately 830 km^2 and of the lagoon is 130 km^2…."
  "…Groundwater is used as irrigation and drinking water in the area. We expect that the groundwater is mainly recharged locally from the surrounding forested mountains (up to 565 m asl; Figure 1) of the karstic areas…."
  "….Their environmental isotopic data and chemical data indicate that rainfall and stream flow are low density waters and thermal groundwater is the high density water

that controls the mixing dynamics of the lake. The main geothermal inflow at the southern lake coast (Sultaniye Basin) is the Sultaniye spring. It is located at a depth of 8-10 m and about 4 km north-west of the lake exit into the Dalyan channel which is shallow (0-6 m) (Bayari et al., 2001). Complete annual mixing cannot be observed in the lake, and the major factor that controls the stratification is the continuous high density thermal water input to the Sultaniye Basin…."

"…2.2 Conceptual Model

Identifying different water sources in the lagoon we set up a conceptual model distinguishing between dry (Figure 3a) and wet season (Figure 3b). For the dry season our hypothesis was that evaporation results in low water tables in the lagoon favoring both fluxes from Köycegiz lake and the Sea into the lagoon. However, higher water levels maintain in the main Dalyan channel with freshwater flow from Köycegiz lake to the Sea. Thus, we expected a density driven layering in the lagoon with freshwater input from the lake in the top layer which is influenced by evaporation and saltwater input in the bottom layer mixed with groundwater (Figure 3a). We further expected that the seawater influence decreases with distance to the coastline. For the wet season our hypothesis was that freshwater input, mainly from groundwater and lake during baseflow conditions and additionally from precipitation during events, results in high water tables in the lagoon favoring freshwater flow from the lake through the lagoon into the Sea. We expected the lagoon water to be well mixed without distinct density driven layering (Figure 3b). For both season, we excluded any direct influence of the geothermal Sultaniye spring to the lagoon, because the spring's influence was found only for the bottom layers of the Köycegiz lake (Bayari et al. 1995) not outflowing into the shallow Dalyan channel and the lagoon but discharging northwards. Still, other unknown geothermal springs in the lagoon cannot be excluded."

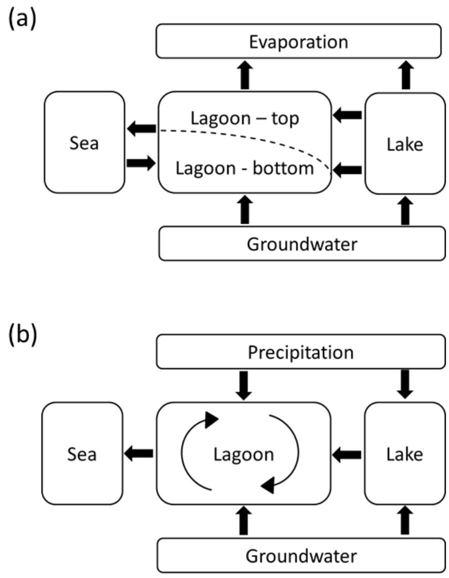


Figure 3: Conceptual model of flow connections between the lagoon and surrounding water bodies for the dry (a) and wet (b) season.

In the introduction section authors state much information that is already known (e.g.

lines 27 -32 of page 2). However, they should present the novelties of their work and their contribution to the state of the art regarding their methodology. Environmental tracers are applied in numerous applications. What are the original points of the present application?

➔ We mentioned the original points of the present application in the manuscript: “Still, it remains unknown in many lagoon systems what the contribution of different water sources is and how they change not only over time i.e. wet and dry seasons but also over space i.e. both horizontal, spatial locations in the lagoon and vertical, depth locations in the lagoon; the latter is of particular interest in wetland type lagoon systems or lagoons with stratification expecting a not well mixed hydrological systems.”
Thus, the added value of our study is to present an environmental tracer method to identify and quantify temporal dynamics (wet and dry season) and spatial heterogeneities (depth of the water column and distance to coastline) of water sources in a wetland type lagoon system. For clarification these original points were included into the text
Modified section in Chapter 1:
“Different sources of water (seawater, groundwater, lake water) were identified at different locations in the lagoon, including top and bottom water column depths, for wet and dry season. Thus, the novelty of this study is to present an environmental tracer method identifying and quantifying temporal dynamics (wet and dry season) and spatial heterogeneities (depth of the water column and distance to coastline) of water sources in a wetland type lagoon system. With improved, detailed understanding of heterogeneous and dynamic hydrological processes in groundwater dependent lagoon ecosystems, targeted strategies to better manage may be developed….”

Specific comments
Page 4, line 24: A mean annual precipitation of 1083mm for the specified area seems too high. What data and what was the time period used for extracting this mean value?

➔ On first glance, this value seems high for a warm and mainly dry region like Turkey. Nevertheless, these reported values are long-term averages which were taken in the study area from the State Meteorology Services of Turkish Republic for Köycegiz Meteorology Station covering the period 1976-2010. This value is also in agreement with the previous study in this area reporting 1202 mm (Bayari et al., (1995) and with the data provided by the IAEA together with isotope data in precipitation of Antalya (1111 mm). We included monthly precipitation data in a new Figure (see Figure 2 given below).

Page 5, line 5: Are there thermal waters present in the system? If this is so a fourth end member, i.e., thermal water should have been also examined. Please explain.

➔ (see new Chapter on conceptual model); as presented in Bayari et al. (1995; 2001) there are several geothermal springs in the lake area. However, these waters mainly are influencing the bottom part of the lake. On top and connected to the outflow of the lagoon is freshwater only as the layers in the lake are not well mixed. We clarified this in chapter 2.1 and the newly introduced chapter presenting the conceptual model.
Modified sections in the text:
“….Their environmental isotopic data and chemical data indicate that rainfall and stream flow are low density waters and thermal groundwater is the high density water that controls the mixing dynamics of the lake. The main geothermal inflow at the southern lake coast (Sultaniye) is the Sultaniye spring. It is located at a depth of 8-10

m and about 4 km north-west of the lake exit into the Dalyan channel which is shallow (0-6 m) (Bayari et al., 2001). Complete annual mixing cannot be observed in the lake, and the major factor that controls the stratification is the continuous high density thermal water input to the Sultaniye Basin…."
"For both season, we excluded any direct influence of the geothermal Sultaniye spring to the lagoon, because the spring's influence was found only for the bottom layers of the Köycegiz lake (Bayari et al. 1995) not outflowing into the shallow Dalyan channel and the lagoon but northwards. Still, other unknown geothermal springs in the lagoon cannot be excluded."

Page 5,
line 29: Where has the LMWL been estimated from? Was it a previous work?

➔ We wrote that the data were taken from the IAEA and that we calculated the LMWL based on the closest location in this database, i.e. Antalya. We restructured this part of the manuscript indicating in more detail, where these data were taken from. Further we included a new Figure according to the comment of Referee#2
Modified sections in the text:
"The results of the stable water isotope analysis from the observation area were compared to public available isotope contents in precipitation accessible through the IAEA (International Atomic Energy Agency) web database WISER (http://www-naweb.iaea.org/napc/ih/index.html; accessed 19.05.2014). Here, Antalya is the closest location of the Global Network of Isotopes in Precipitation (GNIP) having long-term isotope records in precipitation, which is 200 km east of the studied lagoon and 49 m asl. Based on these data, the Local Meteoric Water Line (LMWL; $\delta^2H=8\delta^{18}O+14.3$) and the annual weighted average isotope contents in precipitation ($\delta^{18}O$=-4.9‰; δ^2H =-24.9‰) were calculated; monthly long-term weighed averages are shown in Figure 2."

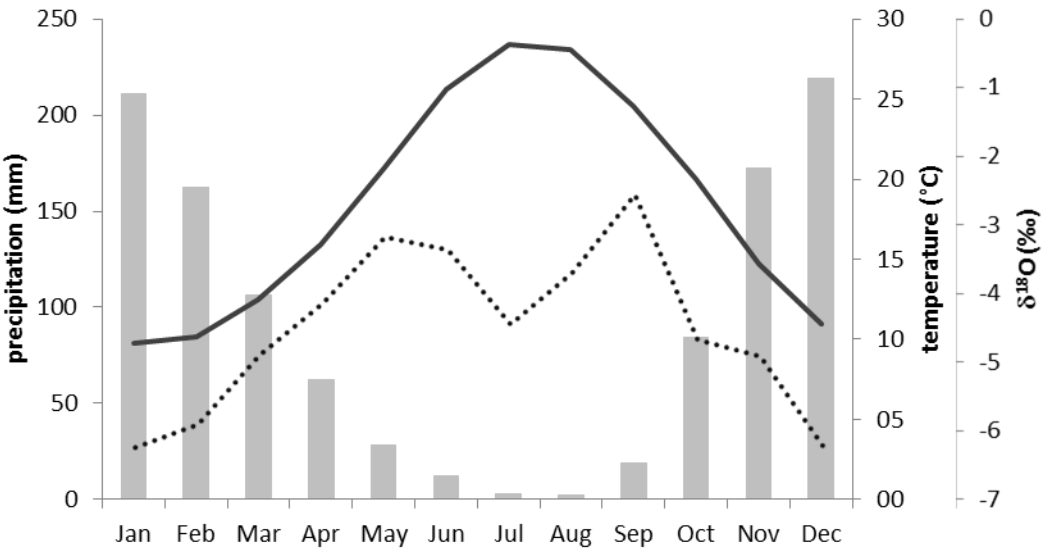


Figure 2: Long-term monthly data of average precipitation (grey bars) and air temperature (solid line) from Köycegiz meteorology station (1976-2010) and isotopic composition of precipitation in Antalya (dashed line). Data from Antalya are available at the IAEA database WISER (http://www-naweb.iaea.org/napc/ih/index.html; accessed 19.05.2014).

Additional references:

Graciansky, P.C.: Stratigraphy of the overlapped units of the Lycien Nappes in the Teke Peninsula and their position within the Dinaro-Taurids. Bull. Miner. Res. Explor. Inst., Ankara, Turkey, 71, 73-92, 1968.

Bayari, C.D., Kurittas, T., Tezcan, L.: Dynamics of Lake Köycegiz, SW Turkey: An Environmental Isotopic and Hydrogeochemical Study. In: Use of isotope techniques in lake dynamics investigations, IAEA-TECDOC-1206, Vienna, Austria, 73-69, 2001.

Referee #2 (K. Rozanski)

The authors discuss the results of a case study focusing on deciphering dynamics of water flow in Koycegiz-Dalyan lagoon located in the southwest of Turkey on the Mediterranean Sea coast using environmental tracers (heavy isotopes of water: oxygen-18 and deuterium) and water chemistry. The study demonstrates usefulness of environmental tracers in obtaining better understanding of coastal ecosystems functioning, with emphasis on lagoon-type environment. Such ecosystems are often home to rare species and need proper management. The discussed study is a valuable contribution to the available literature on the subject and deserves publishing in HESS journal.

- ➔ We thank K. Rozanski for the detailed comments on the manuscript which we appreciated. We followed the suggestions and answered accordingly below.

The conceptual model of the studied system is missing. It should be presented in the introductory part of the manuscript (possibly at the end of section 2.1.), accompanied by the hypothesis(es) being tested in the framework of the presented study. In fact, from the presented material it appears that it should be two separate conceptual models, one for the dry and one for wet period. Presentation of such conceptual model(s) in the introductory part of the manuscript would put the experimental data subsequently presented and discussed in a proper perspective and would facilitate the reading.

- ➔ We added a new chapter after section 2.1 which is called "2.2 Conceptual Model". Here, we present the conceptual models of our studied system for the dry and wet season, which is in accordance to the detailed referee suggestions below. Further, we also present the hypothesis. Having this new chapter including the new Figure 1S will certainly help to facilitate the reading and following our thoughts. Please note, that we actually found that there is little/negligible input of groundwater in the dry season which is different to the initial conceptual model, which is thoroughly discussed in the new and previous version of the manuscript.

  Modified sections

  "…2.2 Conceptual Model

  Identifying different water sources in the lagoon we set up a conceptual model distinguishing between dry (Figure 3a) and wet season (Figure 3b). For the dry season our hypothesis was that evaporation results in low water tables in the lagoon favoring both fluxes from Köycegiz lake and the Sea into the lagoon. However, higher water levels maintain in the main Dalyan channel with freshwater flow from Köycegiz lake to the Sea. Thus, we expected a density driven layering in the lagoon with freshwater input from the lake in the top layer which is influenced by evaporation and saltwater input in the bottom layer mixed with groundwater (Figure 3a). We further expected that the seawater influence decreases with distance to the coastline. For the wet season our hypothesis was that freshwater input, mainly from groundwater and lake during baseflow conditions and additionally from precipitation during events, results in high water tables in the lagoon favoring freshwater flow from the lake through the lagoon into the Sea. We expected the lagoon water to be well mixed without distinct density driven layering (Figure 3b). For both season, we excluded any direct influence of the geothermal Sultaniye spring to the lagoon, because the spring's influence was found only for the bottom layers of the Köycegiz lake (Bayari et al. 1995) not outflowing into the shallow Dalyan channel and the lagoon but discharging northwards. Still, other unknown geothermal springs in the lagoon cannot be excluded. "

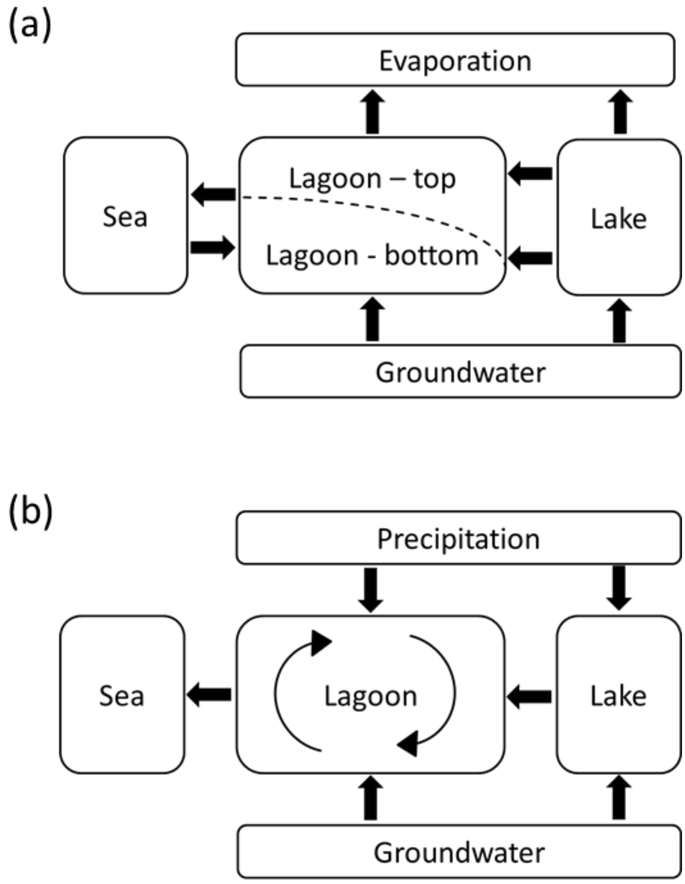


Figure 3: Conceptual model of flow connections between the lagoon and surrounding water bodies for the dry (a) and wet (b) season.

I would encourage the authors to get more out of the experimental data they are presenting (see discussion below). Also, I cannot see in their data any definitive proof that groundwater component is indeed making discernible contribution to the water balance of the studied lagoon system.

- ➔ We will answer to this question in detail in the specific comments given below

Specific comments:

1. p7231, line 21 - in the coastal context 'increased marine water influence' is the most frequent but not unique response to the enhanced withdrawal of groundwater. Also, deeper lying groundwater of non-marine origin can be mobilized in such cases.

- ➔ We agree and added this important point to the manuscript: "For example, pumping of groundwater can influence the quality of the withdrawn drinking/irrigation water due to increased marine water influence or due to the mobilization of groundwater from deeper layers."

2. p7233, line 7 - it is not obvious which watershed the authors refer to. Only much later in the text it becomes clear that this is the watershed of Köycegiz lake.

- ➔ We changed the text accordingly: "The total area of the watershed of Köycegiz Lake is approximately 830 km^2 and of the lagoon is 130 km^2.

3. p7233, lines 11-14 - please give numbers for water level fluctuations in Köycegiz lake. Are there any data for the flow rates of water in the Dalyan channel during wet and dry period?

➔ We refer to some long-term observations given in Bayari et al. (2001) as we have not measured water levels in the present study. We changed the text accordingly: "The upstream located Köycegiz Lake (2 m asl) is directly connected through surface water with the lagoon and further to the Mediterranean Sea by the lagoon and its various branches (Figure 1b). Due to seasonal changes in water levels, hydraulic gradients change considerably over time. During winter, most of the branches in the wetland areas in the lagoon are connected and the discharge from the lake into the lagoon is highest (up to 110 m^3/s; Bayari et al. 2001)). In summer, Köycegiz Lake water level decreases up to 1 m (Bayari et al. 2001). In the lagoon, water levels decrease even more drastically disconnecting some of the side branches from the main Dalyan Channel (personal communication). The discharge from the lake to the lagoon is strongly reduced. On average, the discharge from the lake into the lagoon is about 33 m^3/s and the depth of the main Dalyan channel decreases from 5 m upstream near the lake to about 1 m downstream near the Sea."

4. p7234, lines 2-5 - is would be beneficial to provide a picture summarizing basic climatology of the study area from near-by meteorological station (monthly means of surface air temperature and rainfall amount). Skip the sentence starting from 'Although the region is controlled......" It is too vague and out of the scope of the manuscript.

➔ We deleted the mentioned sentence and included a Figure giving monthly air temperatures, rainfall amount from the study site and also isotopic composition of precipitation from the data provided by the IAEA (i.e. Antalya)

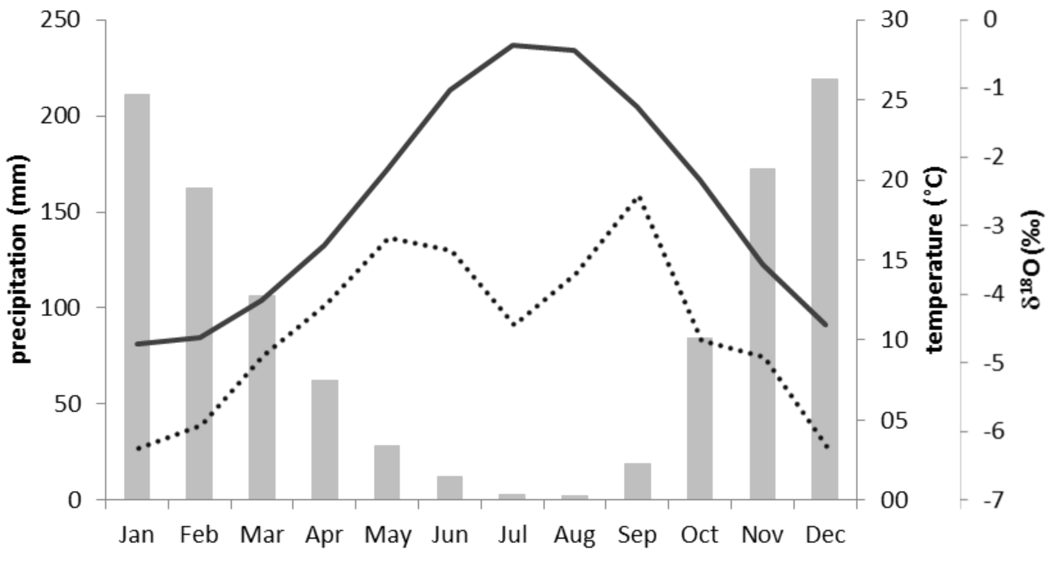


Figure 2: Long-term monthly data of average precipitation (grey bars) and air temperature (solid line) from Köycegiz meteorology station (1976-2010) and isotopic composition of precipitation in Antalya (dashed line). Data from Antalya are available at the IAEA database WISER (http://www-naweb.iaea.org/napc/ih/index.html; accessed 19.05.2014).

5. p7234, lines 6-17 - it would be beneficial to enlarge the area shown in Fig. 1b to include entire Köycegiz lake with its Sultaniye basin.

➔ As the lake is quite large, we decided to keep the Figure as is. Otherwise, the sampling points will be difficult to distinguish in a wider resolution. Further, we refer to Figures presented in Bayari et al. (1995, 2001) for further details of the study area, and we clearly indicated in the text, that the water from the deeper Sultaniye basin drains northwards, i.e. not into the lagoon (see modified section on conceptual model presented earlier).

6. p7235, lines 11-17 - I would strongly recommend to give additional table showing the long-term monthly isotope and precipitation data for the Antalya station. Are the reported annual averages of delta(H-2) and delta(O-18)weighed or arithmetic means?

➔ We included the monthly data in the new Figure 2 (see above). All given isotope precipitation data are weighed means which emphasized in the revised manuscript.

Modified sections in the text:
"The results of the stable water isotope analysis from the observation area were compared to public available isotope contents in precipitation accessible through the IAEA (International Atomic Energy Agency) web database WISER (http://www-naweb.iaea.org/napc/ih/index.html; accessed 19.05.2014). Here, Antalya is the closest location of the Global Network of Isotopes in Precipitation (GNIP) having long-term isotope records in precipitation, which is 200 km east of the studied lagoon and 49 m asl.. Based on these data, the Local Meteoric Water Line (LMWL; $\delta^2H=8\delta^{18}O+14.3$) and the annual weighted average isotope contents in precipitation ($\delta^{18}O$=-4.9‰; δ^2H =-24.9‰) were calculated; monthly long-term weighed averages are shown in Figure 2."

7. p7235, lines 18-22 - uncertainties of chloride and salinity measurements should be reported as well.

➔ We give the uncertainties of chloride and salinity measurements in the text: "Chloride concentrations (±0.22 mg/L) were measured by using Merck test kits (catalog number 1.14897.0001). NaCl stock solution, which has 1 mg Cl^- in 1 mL, was used in order to prepare standard solutions for controlling the reliability of chloride measurements carried out with Merck test kits. Salinity measurements (±0.1 mg/L) were conducted in-situ with YSI 6600V2 Multiparameter Water Quality Sonde."

8. p7235, lines 24-26 - my favorite end-members would be slightly different – see comment No.14.

➔ see detailed answer below

9. p7237, lines 1-2 - please give the elevation range of possible recharge area(s) for groundwater being exploited by the sampled wells. More detailed discussion of the apparent difference between the isotopic composition of groundwater and local (Antalya) precipitation would be in place here. I disagree with the general statement that the differences between dry and wet season at not significant. They are significant for some wells: GW11 (7.3 ‰ difference in delta(H-2)), GW18 (0.40‰ difference in delta(O-18)), GW20 (0.83 ‰ difference in delta(O-18)). The question of course arises what do they mean. If real, they would point to rather short residence time of water. But they could also indicate some problems in well construction. This has to be sorted out in the text.

➔ The elevation of the nearby surrounding mountains is up to 565 m asl, which is given in the text now (chapter about study site: "Groundwater is used as irrigation and drinking water in the area. We expect that the groundwater is mainly recharged locally from the surrounding forested mountains (up to 565 m asl.; Figure 1) of the karstic areas."). We also give the elevation of the Antalya station (49 m asl.; see answer comment 5). Assuming an average differences in elevation between Antalya and the mountain range of about 400 m (plateau like structure) and an average difference in isotope content of about 1.16‰ δ^{18}O (10.0‰ δ^{2}H) results in an altitude gradient of 0.29‰/100m for δ^{18}O (2.5‰/100m for δ^{2}H). These gradients are in accordance with values reported for Southern Adriatic region (0.24‰/100m; Vreca et a. 2006), the global and Italian gradients (0.2‰/100m; Bowen and Wilkison 2002, Longinelli and Selmo 2003) and simulated values for the Mediterranean Sea region (Lykoudis and Argiriou 2007). We included this discussion into the text. Additionally, we calculated a Local Evaporation Line and compared it to other studies (see detailed answer to comment 14)

Further, we removed our general statement about uncertainties and added some points of discussion about short residence times and issues associated with well constructions.

Modified sections in the text:
"Groundwater samples were the most depleted samples ranging from -6.2 to -5.7‰ for δ^{18}O, and were even lower compared to average precipitation contents (-4.9‰ for δ^{18}O). Assuming only negligible differences in isotopic composition of precipitation between Antalya and our observation area due to close proximity and similar location on the Mediterranean Sea, these differences support our assumption of higher altitude precipitation from surrounding mountains as major recharge source of groundwater. Average differences in elevation (400 m) and isotope contents (1.17‰ for δ^{18}O; 9.9‰ for δ^{2}H) give an altitude gradient of 0.29‰/100 m for δ^{18}O (2.5‰/100 m for δ^{2}H). These gradients are in accordance with values reported for Southern Adriatic region (0.24‰/100 m; Vreca et a. 2006), the global and Italian gradients (0.2‰/100 m; Bowen and Wilkison 2002, Longinelli and Selmo 2003) and simulated values for the Mediterranean Sea region (Lykoudis and Argiriou 2007)."

"In groundwater, more depleted contents were generally observed in the wet season compared to the dry season; however, absolute differences between seasons were small (0.21‰ for δ^{18}O; 2.8‰ for δ^{2}H). These differences can either result from a fraction of local seepage water with short residence times or from uncertainties of groundwater sampling. Well screening depths are unknown and therefore we expect some minor uncertainties when taking groundwater samples, i.e. water from same depths and taken with same flow rates during sampling."

10. p7237, lines 7-9 - are the isotope and chemical signatures of this hypothetical geothermal water contributing to Köycegiz lake known? Please report if this is the case. Also note that from stable isotopes alone you cannot make any statement about geothermal origin of a lake water (eventual geothermal signal in O-18 will be always hidden in the evaporation signal).

➔ Indeed, there are some isotope and chemical signatures reported in the previous lake studies. Here, the isotope signatures of geothermal waters range between -4.87 and -0.81 ‰ for δ^{18}O. As already mentioned by the referee any eventual geothermal signal is hidden in the evaporation/mixing signal as the data would plot directly on the mixing line (see Figure A below; not included in revised manuscript but values given in text). Therefore, we are careful with any interpretation on geothermal water influence here and elsewhere in the manuscript as we don't have any direct evidence and as we cannot distinguish from isotope data between diluted seawater or evaporated water and geothermal water origin. We changed the text in the manuscript accordingly and included information about the Local Evaporation Line too (details see answer comment 14):

“All Köycegiz Lake water samples plotted below the LMWL indicating enrichment due to evaporation and potential geothermal water origin as found in previous studies (Bayari et al. 1995; 2001). When considering isotope contents of reported geothermal origin in the area (-0.81‰, -4.87‰, -4-76‰ and -2.9‰, -30.0‰, -27.2‰ for $\delta^{18}O$ and $\delta^{2}H$, respectively; Bayari et al. 1995), it is evident that the geothermal origin is hidden in the evaporation signal and therefore these two sources cannot be distinguished considering isotope contents only. Additionally, a Local Evaporation Line (LEL) was determined considering the top lake samples for both seasons only. The resulting LEL ($\delta^{2}H = 5.40\delta^{18}O - 0.3$) is similar to another Turkish lagoon ($\delta^{2}H = 5.29\delta^{18}O - 0.55$; Lecuyer et al. 2012). It intersects the LWML in -5.85‰ $\delta^{18}O$ (-31.9‰ $\delta^{2}H$) which is also close to the average groundwater contents (-6.08‰ $\delta^{18}O$ and -34.84‰ $\delta^{2}H$) supporting assumption of higher elevation recharge area for the catchment..”

“It remained unknown though whether an additional water source in the system has to be considered which was of geothermal origin as found for Köycegiz Lake (Bayari et al., 1995) and as common in this area due to geology and tectonic activity (Mutlu and Gülec, 1998).”

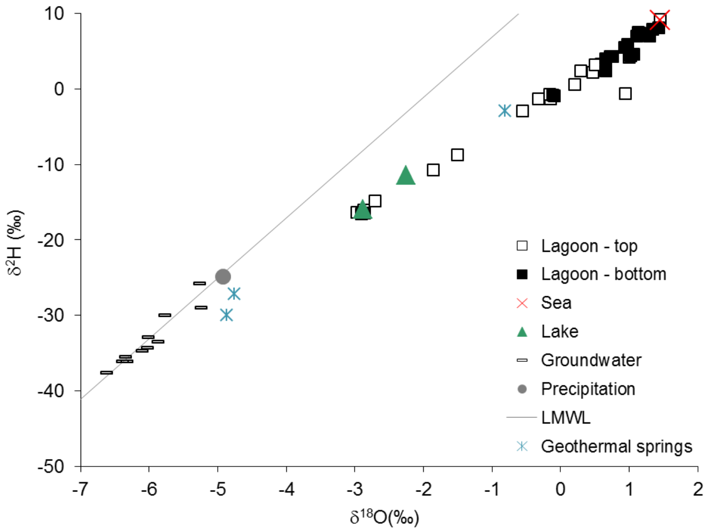


Figure A: Isotope composition of water sources in the dry season

11. p7238, lines 6-8 - as seen in Table 1, the chloride content in GW11 actually varies with stable isotope content of water (lower delta values accompanied by reduced chloride concentration during wet period).

➔ Yes, this is correct; it particularly varies for deuterium contents. We changed the text accordingly.

“Chloride was lowest in groundwater samples for both sampling times suggesting no or negligible seawater influence for most of these groundwater locations. Only one sampling site (GW11) showed increased chloride concentrations (460 mg/l in wet season and 2300 mg/l in dry season), which was also accompanied by higher water isotope contents in the dry compared to wet season (Table 1). If this was caused by mixing with seawater, it would result in an increased seawater contribution of 7±5% for the dry season in GW11. Another reason could be short residence times of recharge from the unsaturated zone. Consequently, chloride originating from agricultural activities (irrigation, pomegranates) would be leached and diluted by winter precipitation with low isotope contents in the wet season.”

12. p7238, lines 11-15 - as reported in Table 1, sea water was collected only on the top (10 cm depth). Was any sample collected also close to the bottom?

- ➔ Indeed, we took samples from the top only assuming that the current is strong enough to completely mix the water in the Sea. For the two endmember mixing approach, we additionally followed your suggestion in comment 14 and took the bottom sample of L8 as endmember for the dry season as it seems to be more representative for this two endmember mixing analysis. More details about the endmember mixing analysis is given below (answer comment 14).

13. p7238, lines 25-26 - see comment No. 10. Without information about isotope and chemical characteristics of the geothermal component it is hard to argue about its influence.

- ➔ Yes, we totally agree. According to the previously published chemical and isotope data of three different geothermal springs (Bayari et al. 1995;2001), our explanation here is actually wrong and not supported by these data. We have two explanations now: 1) erroneous analysis or let’s say evaporative loss during storage because we measured this particular sample twice, 2) enrichment due to evaporation as the data point is on the local evaporation line (details see answer comment14). Therefore, we changed the text. “One sample (L2B, dry period) had enriched isotope values even though chloride was quite low which we attributed to erroneous analysis rather than to water influenced by geothermal origin because of differences in chemical and isotope characteristics compared to geothermal springs in this area (Bayari et al., 1995).”

14. p7239, whole section 3.3, subsequent discussion and conclusions: I have a major problem with three component end-member mixing scenario proposed by the authors. The two components are obvious (outflow from Köycegiz lake and the seawater). But the third one, groundwater input, is highly questionable. I do not see any solid evidence in the data presented by the authors that groundwater is indeed contributing significantly to the water balance of the lagoon, neither in dry nor in wet season. If there are any other data/evidence that groundwater is indeed entering in significant amounts the lagoon, they should be presented and discussed at length in the manuscript. The key figures in the manuscript are Figs. 2 and 3. Figure 2a shows that during dry season essentially all lagoon data are plotting in delta(H-2)-delta(O-18) space on the mixing line between the seawater and the lake water (top) end-members. There is one clear outlier here (L14-top). It would be worth to check the numbers and eventually repeat the analysis. Spread of the data points towards the upper portion of the mixing line may stem from impact of evaporation going on within the lagoon. During wet season the situation is totally different (Fig.1b). Now majority of the data is grouped within tight cluster around the two other end-members: lake water (top) and local precipitation input. Also in this case the cluster of data points representing the isotopic composition of groundwater clearly stays away of the two-component mixing field. The outliers (L33(bottom) and the lake data: L13(bottom), L14(bottom), L05(bottom)) apparently represent ’memory’ of the lagoon with respect to the preceding dry period. The position of seawater suggest that there is a very little, if any, contribution from this source during the wet season. The data point representing the bottom of Köycegiz lake is irrelevant because the Daylan channel is apparently too shallow to receive significant contribution from this source. Now comes Fig.3 with the mixing triangles proposed by the authors. I would stay away of this scenario. For the dry period stable isotope data clearly point to two end-member mixing. If we draw a mixing line in Fig. 3a between the data points representing Köycegiz lake (top) *and the seawater, we have two problems: (i) majority of the data points is positioned to the right of this line, and (ii) at the upper end of this line we have several points which are clearly above the line i.e. they show distinctly higher chloride content than that adopted for the seawater component, although with comparable O-18 isotope composition. The first problem is relatively easy to explain. During the dry period we have strong evaporation of water going on in the entire lagoon. So, the impact of evaporation on both delta(O-18) and chloride content has to be taken into account. Rough assessment suggest that during evaporation of an isolated water body an increase of chloride content by 10% due to water loss will be accompanied by the increase of delta(O-18) in the order of 2-3‰˙In chloridedelta (O-18) space in Fig. 3a this would be an almost horizontal line along which the data points are dragged away of the mixing line, to the right. This is in fact seen in Fig. 3a. As to the second problem, I can offer the following explanation. It is apparent from Table 1 that highest salinities (and chloride content) were measured during the dry period in points L8 and L9 (bottom waters). As far as I could see in Fig. 1b, point L8 sits directly in the channel connecting the lagoon and the open sea. Unfortunately, no bottom sample was collected for the open sea. Then, if we accept that the bottom sample of L8 represents true seawater input during the dry season (and this is most reasonable assumption in view of possible density currents, etc.) than the position of seawater end-member in Fig. 3a should be shifted up vertically to the position of the two topmost data points. Now, essentially all data points would plot to the right of the modified mixing line. For explanation, see problem (i). Summarizing, my favorite conceptual model for the system studied by the authors would be as follows:*

A. During summer (dry period), with essentially no rainfall and high temperatures dominating in the region, surface water from Köycegiz lake feeding the lagoon is predominantly lost by evaporation within the lagoon (some mass balance calculations would be welcome here). This creates favorable conditions for invasion of seawater to the lagoon, predominantly via bottom flow through the channel connecting the lagoon to the open sea. This water has specific chemical and isotope signatures (chloride content in the order of 24000 mg/L, delta(O-18) ~ +1.3 ‰ delta(H-2) ~ +8 ‰. Influence of this water can be traced up to the point L22 (Dalyan channel). Essentially entire lagoon is impacted by the seawater input. In my view, the two-component mixing would be the most appropriate option here, with two end-members: (i) the sea water as specified above, and (ii) Köycegiz lake represented by surface water sample. Note: eventual mixing proportions in different regions of the lagoon should be calculated rather from the chloride-delta(O-18) plot, after correcting the data points back to the mixing line. As seen in Fig. 2a, disentangling the evaporation effects from the mixing is practically impossible in this case.

B. During winter (wet period) the lagoon is 'flooded' by freshwater originating both from the increased input of Köycegiz lake (some numbers would be welcome here) and from the local precipitation (ca. 1 meter of rainfall is reaching the lagoon during wet season). There is essentially no evidence for seawater entering the lagoon (L8 has 'freshwater' isotope and chemical signatures, both at the top and at the bottom of the water column). The 'memory' of the dry season is seen only in very few places in the lagoon. The two-component mixing scenario would also apply for this season, this time with Köycegiz lake (top) and the local precipitation as two end-members. Because these two end-members are very similar in terms of their isotopic composition, while chloride contents are inconclusive (possible agriculture input by surface runoff), I would not attempt any balance calculations for this season.

I would conclude emphasizing once more that in my view, neither isotope nor chemical data presented in the manuscript suggest any discernible groundwater input to the studied lagoon system. Of course, the lagoon ecosystem depends indirectly on groundwater via the Köycegiz lake which is apparently groundwater dependent.

- ➔ We thank the referee for these thorough thoughts and helpful suggestions. We followed the referee's suggestions for the dry season and compared results from the

two endmemeber mixing (2EMMA) approach to previous results of the three endmember mixing approach (3EMMA) which is included in the manuscript discussion now. For the 2EMMA we (i) simplified our assumptions and neglected any groundwater influence, (ii) took L08B as seawater endmember, (iii) corrected the data due to evaporation (see details at the end of this answer), (iv) calculated mixing ratios based on a two component mixing approach (lake and seawater) and using evaporation corrected lagoon data.
The newly calculated freshwater and seawater contributions are similar to the previously presented results (new Figure 8, Table 3), and therefore, the main conclusions and message of the manuscript is not changing. This gets even more obvious when comparing the data directly. Both, the freshwater (Figure 8a) and seawater fractions (Figure 8b) of the mixing approaches plot close to the 1:1 line. Differences can be considered as insignificant due to the uncertainty of the method (see error bars in Figure 7).

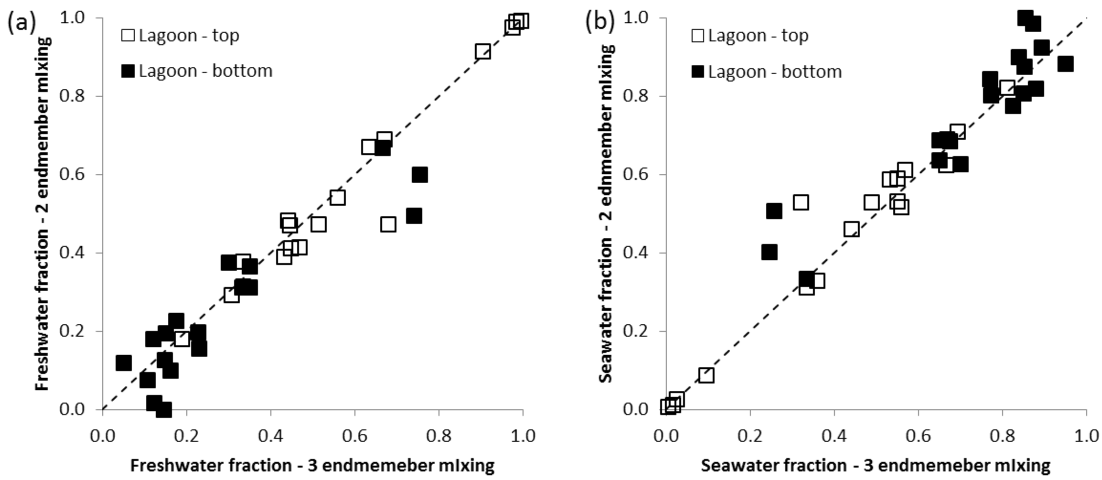


Figure 8: Fractions of freshwater (a) and seawater (b) contributions in the top and bottom lagoon samples calculated from two and three endmember mixing approaches; dashed line gives 1:1 line.

Now, coming back to the correction of the data for the dry period: We correct the data according to the suggestion of the referee to account for enrichment due to evaporation. Therefore, we determined a Local Evaporation Line considering the measurements of the lake top samples in the dry and wet season (δ^2H=5.40 δ^{18}O-0.3) which is almost similar to data presented by Lecuyer et al (2012) (δ^2H=5.29 δ^{18}O-0.55). The calculated LEL insects the LWML in -5.85‰ δ^{18}O (-31.9‰ δ^2H) which is also close to the average groundwater contents (-6.08‰ δ^{18}O and -34.84‰ δ^2H) and actually supports our previous statement about differences in Antalya precipitation and average groundwater contents. Further, we calculated the evaporation line also based on the δ^{18}O-chloride relationship aiming in zero chloride for the average intersect of -5.85‰ (Cl=670 δ^{18}O+4000; see figure below); by the way, this also explains the outlier in Fig. 3a. With the slope of this relationship, we corrected the lagoon samples in the dry period moving them back onto the mixing line. The determined relationship is in agreement with the roughly assessment given by the referee, i.e. 10% increase in chloride accompanied by 3.4% increase in δ^{18}O. These calculations also enabled us to do some mass balance calculations on evaporation estimates as suggested by the referee. We additional preformed the same procedure for the salinity-isotope data to account for uncertainties. The evaporation results are given in the revised Table 3. For the top lagoon samples the results (average of 3.4%) are in agreement with our expectations. However, similar values of evaporation were found for the bottom lagoon samples (average of 2.2%) which physically make no sense. Further, the correction of the data back to the mixing line is kind of arbitrary without knowing the actual evaporation. Only detailed information about spatial distribution of evaporation would enable a precise correction of the isotope-chloride data which would probably put some of the data to the left side of the lake-seawater mixing line requiring a three component mixing approach though. We included these critical points in the discussion section.

For the wet season, we are convinced that groundwater is a major component of the water in the lagoon due to several reasons:
(i) Water residence times in the lagoon in the wet season are short which is supported by the high outflow rates from the lake (see answer comment 3) and by modeling results of Ekdal (2008) indicating residence times <2 days for the wet season in the main lagoon channel. Therefore, the lagoon responds to rainfall only on short terms and contributions of precipitation are certainly higher when sampling during events. Due to the fast response, the main water sources under “baseflow conditions” need to be other sources than precipitation. Certainly, some precipitation is indirectly inherent in the lake and groundwater component anyway which is why we also give freshwater vs seawater contributions in the end of the manuscript. As indicated by Bayari et al. (2001) the lake levels respond quickly –i.e. within several days- to changes in rainfall, and we expect even faster response times for the lagoon as the water surface area is much smaller than that of the lake. The sampling in the wet season was during “baseflow conditions” without major antecedent rain events and therefore, a significant contribution of precipitation can be excluded. We will certainly include these points in the revised version of the manuscript.
(ii) Most of the lagoon sites range between -5 and -4‰ which is a significant variation. A linear mixing line between lake water (or precipitation) would not account for this scattering to the left and right of a two-component mixing approach (see Figure B given below but not included in manuscript as is). In contrast, the variation is perfectly covered by the triangle between average winter gw, seawater and lake water. The only locations outside are samples from the lake structures within the lagoon which are (a) enriched in both chloride and isotopes due to the “memory of the lagoon with respect to the preceding dry period” as suggested by the referee and as presented in the manuscript and (b) lying on the local evaporation line which is discussed in the revised version of the manuscript. Additionally, only one of the top lagoon samples had small chloride concentrations compared to the lake which is unlikely if dilution due to precipitation plays a major role (because relative contribution of precipitation to lagoon water volume much larger compared to lake water volume). Also here, the salinities perfectly match the different endmembers enveloping the lagoon samples.

Technical comments:

Table 1. There is something wrong with the salinity units. Definitely they are not in (ppt) as indicated in the Table (ppt indicates the ratio of 10 to -12). Salinity can be measured either as electrical conductivity or as total dissolved solids (TDS) expressed in mg/L. From the numbers it looks that these are ‰˙... I would suggest to mark the top and bottom position for each sample: eg. L01T, L01B, etc. Please report filter depth for the sampled wells, if available.

- ➔ We corrected to unit for salinity which is given in g/L. We also followed the suggestion and marked the top and bottom locations (L01T, L01B). Unfortunately, we do not have any detailed information about the sampled wells and screen depths.

Figure 1. Add the position of Antalya station in Fig. 1a. Enlarge the map in Fig. 1b to include entire area of Köycegiz lake. Make the labels of the sampling sites more visible (e.g. using white background). Indicate on the map the position of the sampling site representing Köycegiz lake.

- ➔ We added the position of Antalya in Figure 1a and made the labels more visible. The position of the sampling site in the lake is masked by the lake label; we changed it accordingly. As indicated above (see answer comment 5), we did not enlarge the map in Figure 1b.

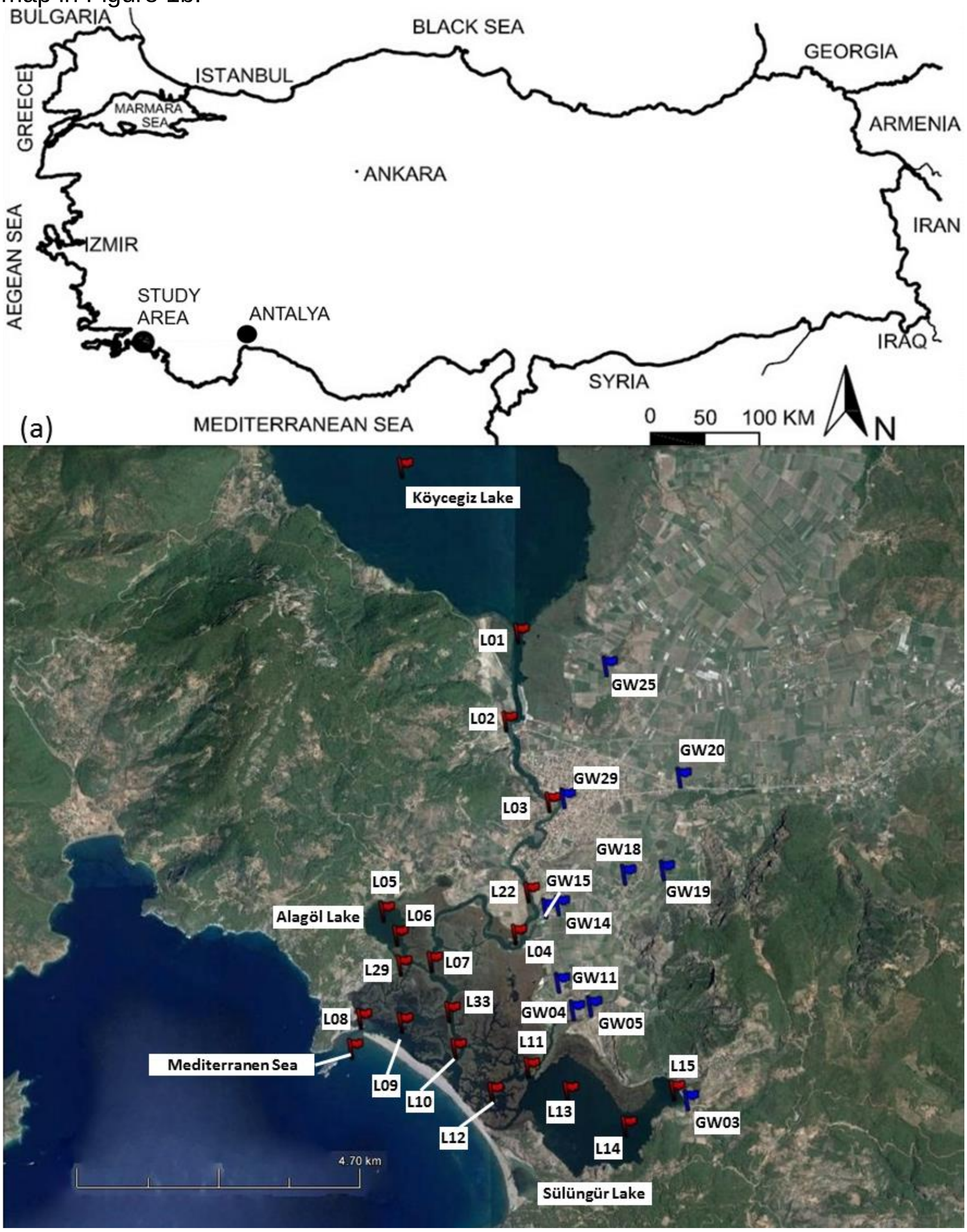


Figure 1 - revised. Geographic location of the Köycegiz-Dalyan Coastal Lagoon (a) and sampling locations (b); lagoon and groundwater sample sites are marked with red and blue labels; source of modified satellite picture was Google Earth (2014).

Figure 2. Make the horizontal scale of higher resolution (step: one per mill). Label the outliers with codes allowing their identification in Table 1.

➔ We changed the horizontal scale accordingly and marked the outliers:

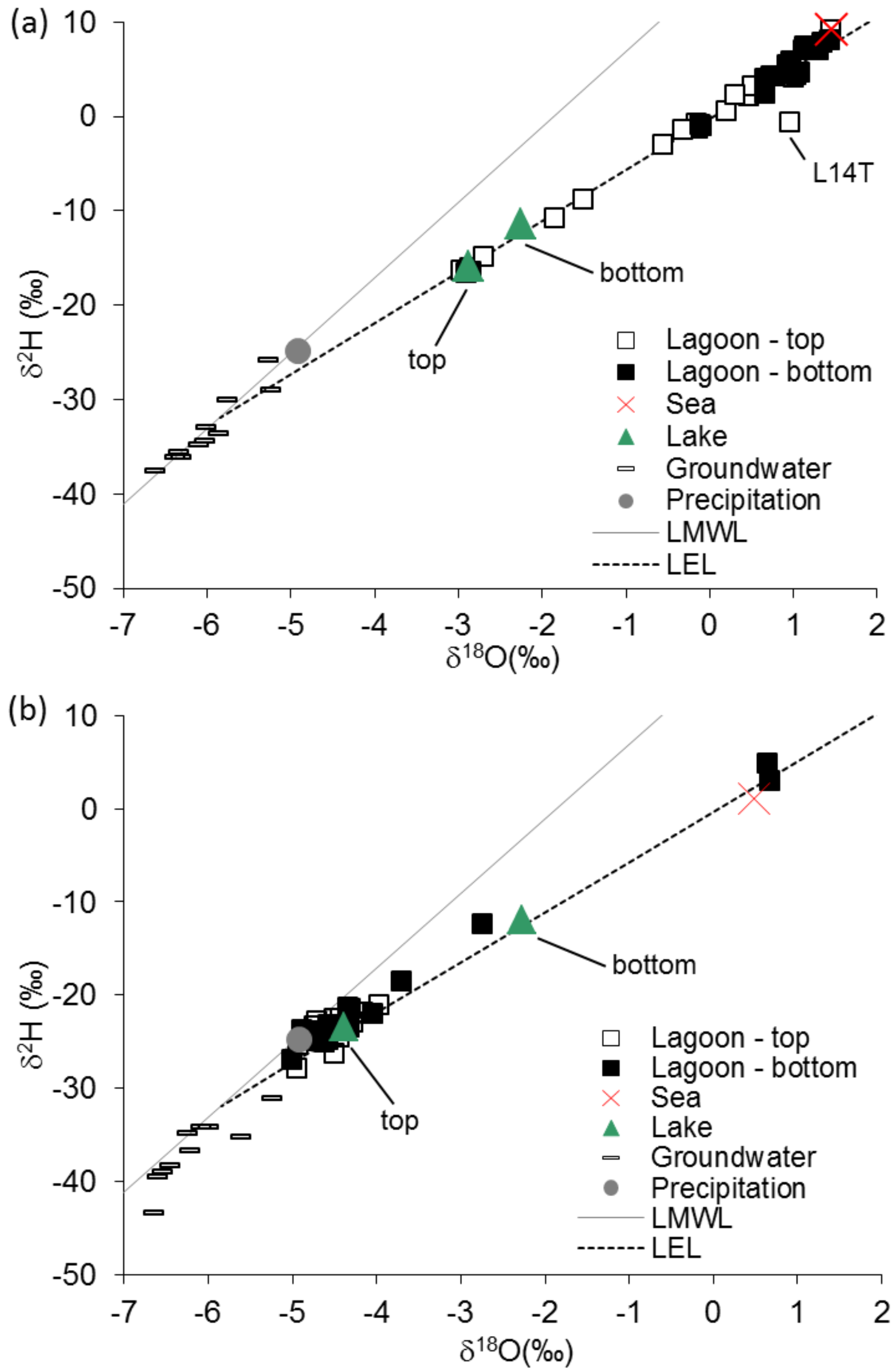
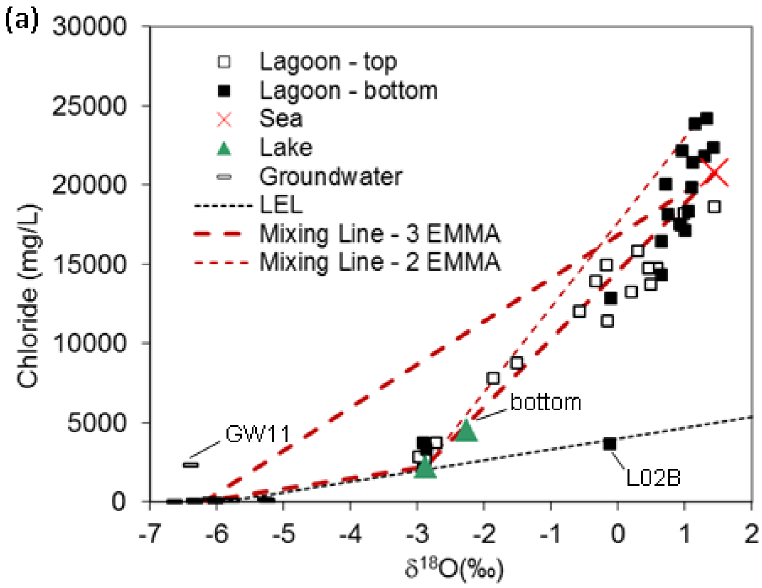


Figure 4 - revised. Dual isotope plot for (a) dry season and (b) wet season sampling campaign; LMWL and average precipitation taken from closest station of the GNIP data base i.e. Antalya.

Figure 3. Modify according to the discussion above. Make the horizontal scale of higher resolution (step: one per mill).

➔ We changed the horizontal scale accordingly and marked the outliers:



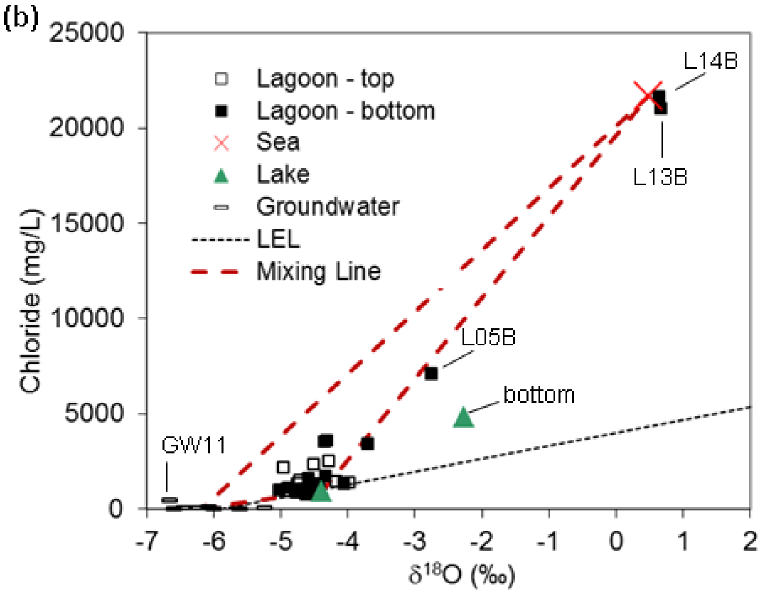


Figure 5 - revised. Chloride concentrations and $\delta^{18}O$ ratios for (a) dry season and (b) wet season sampling campaign; the dashed line connects the endmembers used for the two and three component mixing analysis, respectively.

Figure 4, 5. Modify according to the discussion above. Include additional table (monthly data for Antalya station). Include additional figure with local climatology (mean monthly surface air temperature and precipitation data).

➔ Instead of giving a table with monthly isotope data, we included these data in a local climatology figure (see Figure 2).

Additional references:

Bayari, C.D., Kurittas, T., Tezcan, L.: Dynamics of Lake Köycegiz, SW Turkey: An Environmental Isotopic and Hydrogeochemical Study. In: Use of isotope techniques in lake dynamics investigations, IAEA-TECDOC-1206, Vienna, Austria, 73-69, 2001.

Bowen, G.J. and Wilkinson, B.: Spatial distribution of $\delta^{18}O$ in meteoric precipitation. Geology, 30, 315-318, 2002.

Longinelli, A. and Selmo, E.: Isotopic composition of precipitation in Italy: a first overall map. J. Hydrol., 270, 75-88, 2003.

Lykoudis, S. P. and Argiriou, A. A.: Gridded data set of the stable isotopic composition of precipitation over the eastern and central Mediterranean. Journal of Geophysical Research-Atmospheres 112, D18, 2007.

Vreca, P., Bronic, I.K., Horvatincic, N. and Baresic, J.: Isotopic characteristics of precipitation in Slovenia and Croatia: Comparison of continental and maritime stations. J. Hydrol., 330, 457-469, 2006.

Hydrological dynamics of water sources in a Mediterranean lagoon

C. Stumpp[1], A. Ekdal[2], I.E. Gönenc[3], and P. Maloszewski[1]

[1]{Helmholtz Zentrum München, German Research Center for Environmental Health, Institute of Groundwater Ecology, Neuherberg, Germany}

[2]{Istanbul Technical University, Environmental Engineering Department, Maslak, Istanbul, Turkey}

[3]{IGEM Research & Consulting Co., Istanbul, Turkey}

Correspondence to: C. Stumpp (christine.stumpp@helmholtz-muenchen.de)

Abstract

Lagoons are important ecosystems occupying large coastal areas worldwide. Lagoons contain various mixtures of marine and freshwater sources which are highly dynamic in time. However, it often remains a challenge to identify and quantify dynamic changes of water sources, particularly in heterogeneous lagoon systems like the ~~Köyceğiz~~Köycegiz-Dalyan Lagoon (KDL), which is located at the southwest of Turkey on the Mediterranean Sea coast. The objective of this study was to quantify different contributions of potential water sources i.e. surface water, groundwater and seawater in the lagoon and how these water sources changed over time and space. In the wet and dry season stable isotopes of water, chloride concentration (Cl^-) and salinity were measured in two depths in the lagoon and surrounding water bodies (sea, lake, groundwater). Different components of water sources were quantified with a three component endmember mixing analysis. Differences in Cl^- and stable isotopes over time indicated the dynamic behaviour of the system. Generally, none of the groundwater samples was impacted by water of the Mediterranean Sea. During the wet season, most of the lagoon water (>95%) was influenced by freshwater and vertically well mixed. During the dry season, high Cl^- in the deeper sampling locations indicated a high contribution of marine water throughout the entire lagoon system due to salt water intrusion. However, a distinct

layering in the lagoon was obvious from low Cl^- and depleted isotope contents close to the surface supporting freshwater inflow into the system even during the dry season. Besides temporal dynamics also spatial heterogeneities were identified. Changes in water sources were most evident in the main lagoon channel compared to more isolate lagoon lakes, which were influenced by marine water even in the wet season, and compared to side branches indicating slower turnover times. We found that environmental tracers helped to quantify contributions of different water sources in the ~~Köyceğiz~~Köycegiz-Dalyan Lagoon which is a highly dynamic and heterogeneous groundwater dependent ecosystem.

1 Introduction

Lagoons are important ecosystems occupying 13% of the coastal areas worldwide (Barnes, 1980). Along the Mediterranean coastline, more than 100 lagoons are found but only little hydrological and biological data of most of these ecosystems are available (Perez-Ruzafa et al., 2011a). Generally, lagoons are shallow, coastal water bodies with marine water influence. Mostly they have limited connectivity to the open sea through coastal barriers or connecting inlets. Further freshwater input can come from upstream rivers or groundwater. Lagoons are important ecosystems being a habitat for rare species like seagrass, fishes and turtles, and with a high productivity and diversity (Alongi, 1998;Pérez-Ruzafa et al., 2011b;Remane and Schlieper, 1971). Lagoons not only are valued for fauna and flora, but also due to recreational and industrial purposes by society. These societal values are, however, difficult to quantify (Anthony et al., 2009) also due to conflicts of interest in lagoon ecosystems (fishery, aquaculture, tourism) (Perez-Ruzafa et al., 2011a). Particularly in the context of global change lagoon ecosystems require a proper management for a sustainable use and to protect the ecosystem (Kløve et al., ~~in press~~2014;Anthony et al., 2009). Here, management must not impact the quality and quantity of the lagoon water in terms of chemical and ecological status on the one hand. On the other hand, also groundwater management (drinking water/irrigation) must not impact lagoons depending on groundwater and vice versa. For example, pumping of groundwater can influence the quality of the withdrawn drinking/irrigation water due to increased marine water influence or due to the mobilization of groundwater from deeper layers. In addition, groundwater withdrawal can change the fraction of freshwater source in the lagoon water body which strongly would influence its functions as a habitat for species specifically adapted to the environment. This example highlights the vulnerability of lagoon systems. It shows the strong need to protect and manage these ecosystems and to identify seawater intrusions and groundwater dependencies in the lagoon catchment area.

Here, a detailed knowledge about the water sources and water dynamics in lagoon ecosystems is fundamental before studying further ecological and chemical processes. It has been shown that lagoon systems are heterogeneous and dynamic systems. The quality of the water and subsequent seawater quality or adjacent groundwater quality strongly depends on the water flow and origin of water and nutrients (Gattacceca et al., 2009;Niencheski et al., 2007;Santos et al., 2008a;Santos et al., 2008b). Land use can impact the interaction of lagoon with surrounding groundwater resulting in lagoon infiltration processes under pine tree plantations compared to negligible interactions under natural dune vegetation (Schmidt et al., 2011). Such spatial impacts can be identified using environment tracer methods. Further, they can also be used to study temporal dynamics of water sources and hydrological processes like seasonal changes in evaporation and seawater contribution (Lecuyer et al., 2012;Schmidt et al., 2011). Salinity and stable isotopes of water were used to identify spatiotemporal changes of water in the Akayatan lagoon, Turkey (Lecuyer et al., 2012). Assuming two different end members, river and seawater, it was found that in the wet season the contribution of freshwater and seawater was 62% and 38% on average. Throughout spring to autumn, progressively evaporation of lagoon water results in hypersaline conditions with strongly enriched isotope values suggesting limited input of freshwater in the system (Lecuyer et al., 2012). Still, it remains unknown in many lagoon systems what the contribution of different water sources is and how they change not only over time i.e. wet and dry seasons but also over space i.e. both horizontal, spatial locations in the lagoon and vertical, depth locations in the lagoon; the latter is of particular interest in wetland type lagoon systems or lagoons with stratification expecting a not well mixed hydrological systems. Therefore, the objective of the current study was (i) to identify and quantify different water sources in a lagoon, (ii) how they change over time and space, and (iii) thus how heterogeneous and dynamic the hydrology of the lagoon and adjacent groundwater was. We achieved these objectives by applying environmental tracer methods and developing a three component endmember mixing approach. Different sources of water (seawater, groundwater, lake water) were identified at different locations in the lagoon, including top and bottom water column depths, for wet and dry season. Thus, the novelty of this study is to present an environmental tracer method identifying and quantifying both temporal dynamics (wet and dry season) and spatial heterogeneities (depth of the water column and distance to coastline) of water sources in a wetland type lagoon system. With improved, detailed understanding of heterogeneous and dynamic hydrological processes in groundwater dependent lagoon ecosystems, targeted strategies to better manage may be developed.

2 Material and methods

2.1 Study area

~~Köyceğiz~~Köycegiz-Dalyan Coastal Lagoon is located at the southwest of Turkey on the Mediterranean Sea coast within the province of Mug~~ğ~~la (Figure 1a). The geology in this region is mainly composed of allochthonous and authochthounous Flysch and karstic facies overlain by plio-quaternary sediments (Garciansky 1968). Due to tectonic activities, several faults were formed in this area. Details about the geology and more maps can be found in Bayari et al. (1995).

The total area of the watershed of Köycegiz Lake is approximately ~~960~~ 830 km^2 and of the lagoon is 130 km². The upstream located ~~Köyceğiz~~ Köycegiz Lake (2 m asl.) is directly connected through surface water with the lagoon and further to the Mediterranean Sea by the lagoon and its various branches (Figure 1b). The discharge from the Köycegiz Lake is 33 m³/s on average with up to 110 m³/s during winter times (Bayari et al. 2001). During winter, most of the branches in the wetland areas in the lagoon are connected. In summer, ~~Köyceğiz~~ Köycegiz Lake water level decreases (-0.9 m) reducing the hydraulic gradient to the Mediterranean Sea considerably. The depth of the main Dalyan channel decreases from 5 m upstream near the lake to about 1 m downstream near the Sea. In addition to the Dalyan Channel and its branches, the lagoon also includes the lakes Alagöl and Sülüngür. Maximum depths of these lakes are 4 m and 13 m, respectively.~~-~~ Aquaculture activities are conducted in Sülüngür Lake. Both, ~~Köyceğiz~~ Köycegiz Lake and the ~~Köyceğiz~~Köycegiz-Dalyan Coastal Lagoon are part of the area declared as a Special Protection Area in 1988, as it is a unique and important ecosystem with a high diversity of species. It hosts one of the rare breeding and nesting sites for endangered sea turtles, *caretta caretta*, and possesses the ruins of Ancient City of Caunos and 4th century BC Lycian rock tombs that are found near the seaside by the river (Gurel et al.~~,~~ 2005). Groundwater is used as irrigation and drinking water in the area. We expect that the groundwater is mainly recharged locally from the surrounding forested mountains (up to 565 m asl.; Figure 1) of the karstic areas. The main sectors driving the economy in the watershed are agriculture, tourism and forestry. Aquaculture and capture fishing are among the important beneficial uses of the lagoon together with recreational activities.

The area is under the influence of typical Mediterranean climate characteristics, with a hot, dry summer season and a warm, rainy winter season with mean annual air temperatures of 18.3°C and mean annual precipitation of 1083 mm. These data were taken in the study area from the State Meteorology Services of Turkish Republic for Köycegiz Meteorology Station covering the period 1976-2010~~. Although the region is controlled by the terrestrial, marine or semi-mar~~, and monthly averages are presented in Figure 2. ~~ine, and semi-terrestrial low-and high-pressure systems, the high-pressure system is more effective.~~ Thus, precipitation usually occurs during the cold winter period and drought condition prevails during the hot summer period.

An environmental isotopic and hydrochemical study was conducted by Bayari et al. (1995) for determination of the dynamics of the upstream ~~Köyceğiz~~ Köycegiz Lake. ~~Köyceğiz~~ Köycegiz and Sultaniye are the two major basins that comprise ~~Köyceğiz~~ Köycegiz Lake. According to their statements the important sources that feed the lake are mainly alluvial groundwater, streamwater (Namnam and Yuvarlakçay), and rain. The main components of outflow from the lake are discharge to Mediterranean Sea through the Dalyan Channel and evaporation from the lake surface. Their environmental isotopic data and chemical data indicate that rainfall and stream flow are low density waters and thermal groundwater is the high density water; complete annual mixing cannot be observed due to the density effects. The main geothermal inflow at the southern lake coast (Sultaniye Basin) is the Sultaniye spring. It is located at a depth of 8-10 m and about 4 km north-west of the lake exit into the Dalyan channel which is shallow (0-6 m) (Bayari et al., 2001); too shallow for receiving any geothermal influenced water from the Sultaniye Basin. ~~Their environmental isotopic data and chemical data indicate that rainfall and stream flow are low density waters, and thermal groundwater inflow at the southern coast (Sultaniye) is the high density water that controls the mixing dynamics of the lake. Complete annual mixing cannot be observed, and the major factor that controls the lake dynamics is the continuous high density thermal water input to the Sultaniye Basin.~~

2.2 Conceptual Model

Identifying different water sources in the lagoon we set up a conceptual model distinguishing between dry (Figure 3a) and wet season (Figure 3b). For the dry season our hypothesis was that evaporation results in low water tables in the lagoon favouring both fluxes from Köycegiz Lake and the Sea into the lagoon. However, higher water levels maintain in the main Dalyan channel with freshwater flow from Köycegiz Lake to the Sea. Thus, we expected a density driven layering in the lagoon with (i) freshwater input from the lake in the top layer which is influenced by evaporation and (ii) saltwater input in the bottom layer mixed with groundwater (Figure 3a). We further expected that the seawater influence decreases with distance to the coastline. For the wet season our hypothesis was that freshwater input, mainly from groundwater and lake during baseflow conditions and additionally from precipitation during events, results in high water tables in the lagoon favouring freshwater flow from the lake through the lagoon into the Sea. We expected the lagoon water to be well mixed without distinct density driven layering (Figure 3b). For both season, we excluded any direct influence of the geothermal Sultaniye spring to the lagoon, because the spring's influence was found only for the bottom layers of the Köycegiz Lake (Bayari et al. 1995) not outflowing into the shallow Dalyan channel and the lagoon but discharging northwards. Still, other unknown geothermal springs in the lagoon cannot be excluded.

~~2.2~~2.3 Sampling campaigns

To quantify the different contributions of potential water sources like surface water, groundwater and seawater in the lagoon and how these water sources change over time and space, two sampling campaigns were conducted one representing the dry season (July 2011) and the other one representing the wet season (March 2012). Sampling in both seasons was without major antecedent rain events. Consequently, precipitation as major source in the lagoon can be neglected. Particularly in the wet season, water residence times in the lagoon are short due to high outflow rates from the lake (up to 110 m³/s; Bayari et al. 2001) and which is also supported by modeling results of Ekdal (2008) indicating residence times <2 days for the wet season in the main lagoon channel.

Water samples were taken in the lagoon along the main channel (L1, L2, L3, L22, L4, L7, L33, L10, L29, L9, L8), surrounding lakes (L5, L13, L14) and their inflow/outflow connections to the lagoon system (L6, L11, L12, L15) as well as in the ~~Köyceğiz~~ Köycegiz

Lake and Mediterranean Sea in two depths at the top (T), just below the surface, and at the very bottom (B). The samples were taken by boat used for transportation from Dalyan town to Iztuzu Beach, except for Sülüngür Lake. Since aquaculture activities are conducted in this lake boat of the fishing cooperative was used for sampling. Further samples were taken from surrounding groundwater wells. Groundwater samples were taken with the pump of the well, which is used for abstracting water. In total, samples were taken at 18 lagoon, 11 groundwater, 1 sea and 1 lake locations (Figure 1b) which were further analysed for chemical analysis.

~~2.3~~2.4 Water isotopes and chemical analysis

Water samples were analysed for $\delta^{18}O$ (± 0.15 ‰) and $\delta^{2}H$ (± 1 ‰) contents without any pre-treatment of the samples using a water isotope analyser (L2120-i, Picarro Inc., Santa Clara, CA, USA). The contents are given in the delta notation as δ-value (‰), which is the relative deviation of the sample from the V-SMOW (Vienna-Standard Mean Ocean Water). The results of the stable water isotope analysis from the observation area were compared to public available isotope contents in precipitation accessible through the IAEA (International Atomic Energy Agency) web database WISER (http://www-naweb.iaea.org/napc/ih/IHS_resources_isohis.html; 2014). Here, Antalya is the closest location of the Global Network of Isotopes in Precipitation (GNIP) having long-term isotope records in precipitation, which is 200 km east of the studied lagoon and 49 m asl. Based on these data, the Local Meteoric Water Line (LMWL; $\delta^{2}H = 8\ \delta^{18}O + 14.3$) and the annual weighed average isotope contents in precipitation ($\delta^{18}O$=-4.9‰; $\delta^{2}H$=-24.9‰) were calculated; monthly long-term weighed averages are shown in Figure 2.~~The results of the stable water isotope analysis from the observation area were compared to the Local Meteoric Water Line (LMWL; $\delta^{2}H=8\delta^{18}O+14.3$) and the annual average isotope contents in precipitation from Antalya ($\delta^{18}O$=-4.9‰; $\delta^{2}H$ =-24.9‰), 200 km east of the lagoon. Antalya is the closest location having long-term isotope records in precipitation which are accessible through the IAEA (International Atomic Energy Agency) web database WISER (http://www-naweb.iaea.org/napc/ih/index.html; accessed 19.05.2014).~~

Chloride concentrations (±0.22 mg/L) were measured by using Merck test kits (catalog number 1.14897.0001). NaCl stock solution, which has 1 mg Cl^- in 1 mL, was used in order to prepare standard solutions for controlling the reliability of chloride measurements carried out

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with Merck test kits. Salinity measurements (±0.1 mg/L) were conducted *in-situ* with YSI 6600V2 Multiparameter Water Quality Sonde.

~~2.4~~2.5 Endmember mixing analysis

Calculating different water fractions in the lagoon system (top and bottom), three endmembers were defined that differed in isotopic composition and chloride concentrations/salinity: (i) ~~Köyceğiz~~ Köycegiz Lake water, (ii) groundwater, and (iii) Mediterranean Seawater. The concentrations (C) of the endmembers were defined for both seasons separately. For lake (C_{LW}) and seawater (C_{SW}), the surface near water samples were taken and for groundwater an average concentration (C_{GW}) was calculated from all groundwater wells without considering GW011 due to increased chloride concentrations compared to other groundwater locations. Thus, the isotope contents (^{18}O) and chloride concentrations (Cl^-) or salinity (S) in the lagoon (C_{Lag}) were calculated from the three component mixing analysis:

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$$C_{Lag_{18O}} = f_{GW} \cdot C_{GW_{18O}} + f_{LW} \cdot C_{LW_{18O}} + f_{SW} \cdot C_{SW_{18O}} \qquad (1)$$

$$C_{Lag_{Cl}} = f_{GW} \cdot C_{GW_{Cl}} + f_{LW} \cdot C_{LW_{Cl}} + f_{SW} \cdot C_{SW_{Cl}} \qquad (2)$$

$$C_{Lag_S} = f_{GW} \cdot C_{GW_S} + f_{LW} \cdot C_{LW_S} + f_{SW} \cdot C_{SW_S} \qquad (3)$$

$$1 = f_{GW} + f_{LW} + f_{SW} \qquad (4)$$

where f refers to the fraction of groundwater (GW), lake water (LW), and seawater (SW), respectively. Getting information about the uncertainty of the method, we calculated the mixing ratios based on two different approaches considering simultaneously $\delta^{18}O$ (Eq.1) and Cl^- (Eq.2) or $\delta^{18}O$ (Eq.1) and salinity (Eq.3), both in combination with Eq.4.

3 Results

3.1 Stable isotopes of water

Results of stable isotope analysis are presented in Table 1. All analyse~~s~~d water samples plotted close or below the LMWL for both the dry (Figure ~~2a~~4a) and wet season (Figure ~~2b~~4b). Groundwater samples were the most depleted samples ranging from -6.2 to -5.7‰ for

$\delta^{18}O$, and were even lower compared to average precipitation contents (-4.9‰ for $\delta^{18}O$). Assuming only negligible differences in isotopic composition of precipitation between Antalya and our observation area due to close proximity and similar location on the Mediterranean Sea, these differences support our assumption of winter and/or higher altitude precipitation from surrounding mountains is suggested as major recharge source of groundwater. Average differences in elevation (400 m) and isotope contents (1.17‰ for $\delta^{18}O$; 9.9‰ for $\delta^{2}H$) give an altitude gradient of 0.29‰/100 m for $\delta^{18}O$ (2.5‰/100 m for $\delta^{2}H$). These gradients are in accordance with values reported for Southern Adriatic region (0.24‰/100 m; Vreca et a. 2006), the global and Italian gradients (0.2‰/100 m; Bowen and Wilkison 2002, Longinelli and Selmo 2003) and simulated values for the Mediterranean Sea region (Lykoudis and Argiriou 2007).

On averageIn groundwater, more depleted contents were generally observed in the wet season compared to the dry season; however, the absolute differences between seasons awere within the analytical uncertainty range and therefore, not significantsmall (0.21‰ for $\delta^{18}O$; 2.8‰ for $\delta^{2}H$). These differences can either result from a fraction of local seepage water with short residence times, from influence of seawater or from uncertainties of groundwater sampling. Well screening depths were unknown and therefore we expected some minor uncertainties when taking groundwater samples, i.e. water from same depths and taken with same flow rates during sampling.

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Isotope contents of seawater were positive with more enriched contents in dry (1.5‰ for $\delta^{18}O$) compared to wet seasons (0.5‰ for $\delta^{18}O$). All Köyceğiz Köycegiz Lake water samples plotted below the LMWL (Figure 4) indicating enrichment due to evaporation and mainly potential geothermal water origin as found in previous studies (Bayari et al., 1995; 2001). When considering isotope contents of reported geothermal origin in the area (-0.81‰, -4.87‰, -4-76‰ and -2.9‰, -30.0‰, -27.2‰ for $\delta^{18}O$ and $\delta^{2}H$, respectively; Bayari et al. 1995), it is evident that the geothermal origin is hidden in the evaporation signal and therefore these two sources cannot be distinguished considering isotope contents only.In both seasons more enriched values were found in samples at the bottom of the Köyceğiz Lake compared to more depleted values in samples at the top. Additionally, a Local Evaporation Line (LEL) was determined considering the top lake samples for both seasons only. The resulting LEL ($\delta^{2}H$ = 5.40 $\delta^{18}O$ - 0.3) is similar to another Turkish lagoon ($\delta^{2}H$ = 5.29 $\delta^{18}O$ - 0.55; Lecuyer et al. 2012). It intersects the LWML in -5.85‰ $\delta^{18}O$ (-31.9‰ $\delta^{2}H$) which is also close to the average groundwater contents (-6.08‰ $\delta^{18}O$ and -34.84‰ $\delta^{2}H$) supporting assumption of higher elevation recharge area for the catchment.

Water samples from the lagoon mainly plotted on/below the LMWL and between groundwater and seawater samples. Distinct differences in isotopic contents were found (i) for the dry (Figure ~~2a~~4a) and wet season (Figure ~~2b~~4b) indicating a seasonally dynamic water body and (ii) for samples close to the surface (open squares, Figure ~~2~~4) and the bottom of the lagoon (closed square, Figure ~~2~~4) indicating a layered vs well mixed system in the dry and wet season, respectively. Particularly in the dry season, differences between top and bottom lagoon samples were obvious. Here, most interestingly, water samples at the bottom of the lagoon were more enriched compared to top water samples. This clearly indicates that the enrichment was not caused by evaporation but rather by mixing with enriched seawater which is more pronounced at the bottom due to salt water density effects. In the wet season, similar isotope contents were found for top and bottom samples except for samples from Alagöl (L5; -2.7‰, $\delta^{18}O$) and Sülüngür Lake (L13, L14; +0.64-0.68‰, $\delta^{18}O$) which had more enriched isotope contents at the bottom only. Here, top water samples showed similar ranges in isotope contents (-4.5 to -4.0 ‰, $\delta^{18}O$) compared to other lagoon samples (-5.0 to -4.0‰, $\delta^{18}O$).

3.2 Chloride vs. stable isotopes of water

Results of geochemical analysis are given in Table 1. Chloride and salinity showed similar spatiotemporal results and therefore, chloride results are discussed in more detail only. Chloride concentrations were in line with the results of stable isotope of water. Chloride was lowest in groundwater samples for ~~both season~~both sampling timess~~s~~ suggesting no or negligible seawater influence for most of these groundwater locations. Only one sampling site (GW11) showed increased chloride concentrations (460 mg/~~l~~ L in wet season and 2300 mg/~~l~~ L in dry season), which~~, however, were~~was ~~not~~ also accompanied by ~~increased~~ higher water isotope contents in the dry compared to the wet season (Table 1). If this was caused by mixing with seawater, it would result in an increased seawater contribution of 7±5% for the dry season in GW11. ~~Therefore~~Another reason could be short residence times of recharge from the unsaturated zone. Consequently,~~, we assume that~~ chloride originating from agricultural activities (irrigation, pomegranates) ~~was~~ would be leached ~~from the unsaturated zone due to agricultural activities (irrigation, pomegranates)~~and diluted by winter precipitation with low isotope contents in the wet season~~ rather than mixing with seawater~~.

Chloride concentrations were similar during both sampling campaigns in the dry and wet season at the bottom of the Köycegiz Lake (4500 and 4800 mg/L), but differences were measured at the top (2200 and 920 mg/L). High chloride concentrations were measured in seawater with 21700 mg/lL and 20800 mg/Ll during the wet and dry season, respectively. Chloride concentrations were similar during both sampling campaigns in the dry and wet season at the bottom of the Köyceğiz Lake (4500 and 4800 mg/l), but differences were measured at the top (2200 and 920 mg/l).

In the lagoon, chloride concentrations were generally higher in the dry season compared to the wet season (Figure 35, Table 1). In the wet season, high chloride concentrations were only measured in the lagoon lake systems that also had enriched isotope contents. In the dry season, a clear layering was also supported by the chloride concentrations which were higher at the bottom of the lagoon compared to its top. When looking at the chloride isotope relationship, lagoon samples were mainly plotting in the triangle of groundwater, Köyceğgiz Lake water and seawater samples suggesting three main endmembers in the system (Figure 35a). One sample (L2 bottom, dry period) had enriched isotope values even though chloride was quite low which we attributed either as erroneous analysis or the water was influenced by another source with geothermal origin which is also one major water origin of the upstream Köyceğiz Lake (Bayari et al., 1995). Further, other lagoon samples, particularly from bottom taken during the dry season, showed chloride and isotope data with higher concentration or more enriched values than expected. In the wet season, high chloride concentrations were only measured in the lagoon lake systems that also had enriched isotope contents (Figure 5b). All other lagoon samples had chloride concentrations lower than 5000 mg/L plotting in the triangle of groundwater, Köycegiz Lake water and seawater samples suggesting three main endmembers in the system (Figure 5b).

3.3 Endmember mixing analysis

The three component endmember mixing analysis was calculated for (i) the wet and dry season and (ii) for the top and bottom layer. The selected endmembers are given in Table 1 (asterisks) and the resulting source fractions for each location and season are given in Table 2.

For the wet season, average fractions of water sources were similar in the top and bottom of the lagoon (Figure 4b6b). The arithmetic average (median) of groundwater, lake and seawater contribution was 0.24 (0.25), 0.72 (0.73) and 0.04 (0.04) for the top and 0.21 (0.22), 0.62

(0.74), and 0.17 (0.02) for the bottom layer, respectively. Thus, the entire lagoon contained little seawater, and the main source was freshwater, either from the ~~Köyceğiz~~ Köycegiz Lake or the groundwater. Certainly, we cannot exclude direct influence from precipitation having similar chemical composition compared to groundwater which will be further discussed below. High fractions of seawater were mainly found in the bottom of the lagoon lake systems (Figure ~~5d~~7d, Table 2). The more shallow Alagöl lake (L5; 3.3 m) contained about 34% seawater and 98% seawater were calculated for the deeper Sülüngür lake (L13, L14; 3.6-5.4 m) (Table 2). The branches of the lagoon showed slightly increased salt water contributions (9% top layer, 10% bottom layer) compared the Dalyan channel locations (2% top layer, 3% bottom layer) (Figure ~~5c~~7c,d). Besides, no variability in seawater and freshwater contribution was found with distance from the shore line (Figure ~~5c~~7c,d); the error bars in Figure ~~5~~ 7 indicate the variability of the results when using $\delta^{18}O$ and Cl^- or $\delta^{18}O$ and salinity as signatures for the endmember mixing analysis.

For the dry season, average fractions of water sources were different compared to the wet season, and more variability was found within the lagoon and when comparing top and bottom of the lagoon (Figure ~~4a~~6a). The arithmetic average (median) of groundwater, lake and seawater contribution was 0.03 (0.01), 0.54 (0.43) and 0.43 (0.57) for the top and 0.09 (0.00), 0.20 (0.18), and 0.71 (0.83) for the bottom layer, respectively. Particularly the contribution of groundwater was little during the dry season (Table 2, Figure ~~4a~~6a). The lagoon contained more seawater in the dry season compared to the wet season and at the bottom compared to the top layers. Further, there was a gradient of salt water contribution in the lagoon with nearest distance to the shoreline (Figure ~~5a~~7a,b). The closer to the sea, the higher is the fraction of seawater. Still, the lagoon lake systems contained on average higher fractions of salt water (60%, top; 88%, bottom) compared to the Dalyan channel locations (35%, top; 69%, bottom) (Figure ~~5a~~7a). The branches of the lagoon seem to be more mixed compared to lake and channel locations (Figure ~~5a~~7a,b) containing on average 51% and 67% of seawater on top and bottom, respectively.

4 Discussion

The results clearly indicated differences in contribution of various water sources in the dry and wet season. We proved that it is an extremely dynamic system dominated by seawater in the dry season (>55%) and freshwater in the wet season (>95%). Lecuyer et al. (2012) also found higher contribution of freshwater (62%) compared to seawater (38%) in winter (wet season) assuming seawater and stream water as sole endmembers. Still, their open water lagoon on the Turkish coast was generally more dominated by seawater throughout the rest of the year; particularly in summer and autumn freshwater contribution seemed to be mostly absent and hypersaline conditions formed due to evaporation of seawater. In contrast, our study site had freshwater influence even in the dry season. Here, the freshwater mainly came from the upstream lake and groundwater contribution was minor. Thus, the lagoon is groundwater dependent only in the wet season. In addition, we cannot exclude direct precipitation as additional water source for the wet season; due to little precipitation in summer (3 mm in average) its influence during the dry season was assumed to be negligible. We expect that winter precipitation has similar isotopic composition compared to the local groundwater and therefore, any contribution of direct precipitation is was hidden in the groundwater term. However, this hidden precipitation is suggested to be little when looking at the upstream Köyceğiz Köycegiz Lake water balance and the size of the entire catchment (960 km^2) compared to the lagoon size (130 km^2). In the Köyceğiz Köycegiz Lake precipitation is for example more than 15 times smaller compared to its outflow into the lagoon (Bayari et al., 1995). Additionally, we sampled during a period without precipitation and therefore, our results are representative for base flow conditions in the lagoon system.

We found different dynamics for the bottom and top layers and also for the different locations in the lagoon. Particular seasonal changes were dramatic in the main Dalyan channel closer to the coast and at its bottom (Figure 5b7b,d). We assume that the terrestrial water levels (groundwater, lake, lagoon) declined in the dry season influencing the hydraulic gradients and also density driven flow of the seawater further inland. Here, the intrusion reached up to 4 km inland at the bottom of the lagoon. A 50:50 mixing of salt and freshwater is expected for bottom layers at 4.9 km distance from the coast (Figure 5b7b) and for top layer at 1 km. The freshwater (seawater) mixing relationship with distance from the shoreline was best approximated by logarithmic (exponential) function (Figure 57). Still, the salt water intrusion was mainly restricted to the lagoon system itself as the groundwater wells were unaffected by seawater influence in the dry season. Our findings are in agreement with previous studies on hydrodynamic modelling in this area (Ekdal et al., 2005;Erturk et al., 2003;Gönenc et al., 2004). In these studies, similar spatial and temporal dynamics were obtained concluding that intrusion causes strong stratification throughout almost the entire lagoon especially in the dry season. The flow direction in the upper layer was from Köyceğiz Köycegiz Lake towards the Mediterranean Sea, while flow in the bottom layer was from the Mediterranean Sea towards the Köyceğiz Köycegiz Lake. Barotrophy was found to be the driving force of the surface flow, whereas the bottom flow was baroclinic (Gönenc et al., 2004).

In the present study, the endmember mixing analysis yielded higher lower uncertainties in the dry wet compared to the wet dry season (Figure 57), which is also obvious when looking at the endmember mixing triangles in Figure 35. For the wet season, the composition of the seawater endmember was adequate (Figure 5b). For the dry season though, higher chloride concentration as well as more enriched $\delta^{18}O$ were expected (Figure 5a) and thus, samples plot outside of the mixing triangle. This indicates that either the endmember was chosen wrongly or/and evaporation is crucial. Evaporation of surface water explains an increase in salt concentrations and isotopic enrichment like observed in a close-by lagoon (Lecuyer et al., 2012). Even though evaporation was actually considered indirectly by the lake endmember, evaporation of lagoon water could be higher due to the smaller water volume compared to the lake. Therefore, a stronger enrichment of stable isotopes explains the deviations of top surface water samples located outside of the mixing triangle in the dry season (Figure 5a). However, also enrichment of bottom samples was found in the dry season which is unusual and cannot be explained by evaporation only. Even hypersaline conditions in some of the bottom samples were found (compared to the Seawater sample). Interestingly, the slope of the Cl^{-}-$\delta^{18}O$ relationship was steeper for bottom compared to top lagoon samples. It remained unknown whether an additional water source in the system has to be considered which was of geothermal origin as found for Köycegiz Lake (Bayari et al., 1995) and as common in this area due to geology and tectonic activity (Mutlu and Gülec, 1998).

Further assessing the two discussed uncertainties (i.e. choice of endmember and evaporation) and neglecting the small contributions of groundwater to the lagoon, a two component endmember mixing analysis was additionally conducted after correction of the data due to evaporation (Figure 5a; 2 EMMA mixing line). First, the seawater surface sample was replaced by the deep lagoon sample at the very end of the Dalyan Channel exiting into the Sea (L08B). Here, chloride concentrations and also isotopes were even higher compared to the seawater sample. It was measured in the depth and we expect it to be representative to the actual seawater not influenced by any freshwater compared to the actual seawater sample from the surface. Therefore, L08B could be used as endmember for the dry season being representative for seawater too. Second, all lagoon samples were forced onto the mixing line accounting for enrichment due to evaporation. Therefore, an Evaporation Line was calculated considering the top lake sample for both seasons only ($Cl^- = 670\ \delta^{18}O + 4000$). Here, 10% increase in chloride was accompanied by 3.4% increase in $\delta^{18}O$. This regression was used to correct the lagoon data back to the mixing line. Similar procedures were done with salinity and isotope data (data not shown). The difference between measured and corrected chloride concentrations (salinity) was further used to do a mass balance calculation. Thus, relative, average evaporation were estimated at all sites (Table 3); they have to be seen as relative because the actual surface Köycegiz Lake water already comprised evaporation which was estimated to 6.8% (Bayari et al. 1995). The calculated evaporation in the lagoon ranged from 0 to 7%. There was only one outliner L2B (Figure 5a) with high chloride concentrations resulting in 54% evaporation based on chloride data; but with 0.2% evaporation based on salinity data. We attributed it to erroneous chloride analysis rather than to water influenced by geothermal origin because of differences in chemical and isotope characteristics compared to geothermal springs in this area (Bayari et al., 1995). The results of the two component endmember mixing approach yielded similar fractions of freshwater and marine water as the three component approach (Figure 8, Table 3). Considering uncertainties of the methods (Figure 7), no distinct differences in freshwater or saltwater sources were found hence. This suggested that for the dry season both groundwater and evaporation could be neglected in the system. Still, the correction of the data due to evaporation is kind of arbitrary forcing all values onto the mixing line. Only knowing the actual evaporation at individual locations and in the lake would help to adequately correct the data which even might push some results into the 3 endmember mixing triangle. Hence, fractions of groundwater even in the dry season would be underestimated by the current procedure of data correction.

~~In the dry season (Figure 3a) some of the sampling locations were outside of the triangle. Thus, other influences like evaporation, additional water sources or uncertainties of the endmember selection have to be considered additionally. For the wet season, the composition of the seawater endmember was adequate (Figure 3b). For the dry season though, higher chloride concentration as well as more enriched $\delta^{18}O$ were expected (Figure 3a). In contrast, also evaporation of surface water would explain an increase in salt concentrations and isotopic enrichment like observed in a close-by lagoon (Lecuyer et al., 2012). Even though evaporation was actually considered indirectly by the lake endmember, evaporation of lagoon water could be higher due to the smaller water volume compared to the lake. Therefore, a stronger enrichment of stable isotopes explains the deviations of top surface water samples.~~

~~A spatial heterogeneity between top and bottom water is obvious when looking at the results of the dry season (Figure 3a). Interestingly, the slope of the Cl^--$\delta^{18}O$ relationship was steeper for bottom compared to top lagoon samples. Further, also enrichment of bottom samples was found in the dry season which is unusual and cannot be explained by evaporation. Even hypersaline conditions in some of the bottom samples were found. Likely, an additional water source in the system has to be considered which was of geothermal origin as found for the Köyceğiz Lake (Bayari et al., 1995) and as common in this area due to geology and tectonic activity (Mutlu and Gülec, 1998).~~

Independent on the mixing approach, ~~In addition~~there were not only ~~to~~ spatial differences in top and bottom layers for the main Dalyan channel, ~~there were~~but also differences between different locations within the lagoon. The main channel responded quickly to changes and showed seasonal dynamics. The lake structures in the lagoon system were, however, responding differently. Here, the salt water was found in the bottom layer even in the wet season indicating maintenance of stratification; particularly in the larger and deeper Sülüngür Lake. A partial mixing was found for the smaller and shallower Alagöl Lake where salt water contribution was 34% (±20%). Also the side branches of the lagoon had less extreme changes as the main channel indicating higher water transit times in these areas and thus slower renewal. Particularly in the dry season, the contribution of fresh and salt water was about equal for the top layer and 2/3 to 1/3 for the bottom layer and independent on the distance to the coastline. These findings are in agreement with residence time calculations of a previous study (Ekdal, 2008) using the Water Quality Analysis Simulation Model. Average residence times of Sülüngür Lake (especially deeper parts of the lake) were considerably higher (16-700 d) when compared to other parts of the system (>16 d). The residence time in Alagöl (5-16 d) was also high when compared to the main channel. The main channel had a low residence time (<~~>~~5 d), which showed the dynamic characteristics of the lagoon, and which is in agreement with the results of this study.

5 Conclusion

We showed that environmental tracers can be used not only to identify but also to quantify different water sources in a lagoon ecosystem. Freshwater and marine water sources were strongly dynamic and heterogeneous in time and space. We found different water sources and mixing ratios for dry and wet seasons and for top and bottom layers in the lagoon. In the wet season, freshwater was found in all locations and all depths except at the bottom of a larger lagoon lake. Generally, the freshwater was a mixture of upstream lake water and groundwater. The groundwater dependence was, however, mainly restricted to the wet season and almost absent in the dry season. It was assumed that water levels decline and the input of seawater in the lagoon gets more pronounced; particularly in the main flow channel of the lagoon. Here, a clear stratification was observed in the dry season only, with higher salt water contributions at the lagoon bottom compared to its top. At some of these locations, the lagoon changed from a complete freshwater system to a complete salt water system which certainly has implications for the ecosystem which has to be highly adapted to such dynamic conditions. At side branches and lake structures in this wetland type lagoon, changes in water sources were less extreme and variable. From these findings, we conclude that the lagoon and the groundwater could be vulnerable to certain global change scenarios like sea level rise and decrease in precipitation. Consequently, water levels in the groundwater and lake would drop and the seawater influence would increase in the lagoon system affecting its ecosystem functions and probably also affecting the groundwater quality. In future, it needs to be analysed how the ecosystem itself reacts to changes of water sources to investigate the vulnerability of the ecosystem functions.

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References

Alongi, D. M.: Coastal Ecosystem Processes, CRC Press, Boca Raton, 1998.

Anthony, A., Atwood, J., August, P., Byron, C., Cobb, S., Foster, C., Fry, C., Gold, A., Hagos, K., Heffner, L., Kellogg, D. Q., Lellis-Dibble, K., Opaluch, J. J., Oviatt, C., Pfeiffer-Herbert, A., Rohr, N., Smith, L., Smythe, T., Swift, J., and Vinhateiro, N.: Coastal Lagoons and Climate Change: Ecological and Social Ramifications in US Atlantic and Gulf Coast Ecosystems, Ecology and Society, 14, 8, 2009.

Barnes, R. S. K.: Coastal lagoons, Cambridge University press, Cambridge, UK, 106 pp., 1980.

Bayari, S. C., Kazanci, N., Koyuncu, H., Çaglar, S. S., and Gökçe, D.: Determination of the origin of the waters of Köycegiz Lake, Turkey, Journal of Hydrology, 166, 171-191, http://dx.doi.org/10.1016/0022-1694(94)02554-O, 1995.

Bayari, C.D., Kurittas, T., Tezcan, L., 2001. Dynamics of Lake Köycegiz, SW Turkey: An Environmental Isotopic and Hydrogeochemical Study. In: Use of isotope techniques in lake dynamics investigations, IAEA-TECDOC-1206, Vienna, Austria.

Ekdal, A.: Water Quality Modeling of Köycegiz – Dalyan Lagoon, Ph.D. thesis, Istanbul Technical University, Istanbul, Turkey, 236 pp., 2008.

Bowen, G.J. and Wilkinson, B.: Spatial distribution of $\delta^{18}O$ in meteoric precipitation. Geology, 30, 315-318, 2002.

Ekdal, A., Gurel, M., Erturk, A., and Tanik, A.: Hydrodynamic and Water Quality Modeling Approach for a Dynamic Lagoon System, Environmental Hydraulics and Sustainable Water Management, Proceedings, 15-18 December, Hong Kong, People Republic of China, 2005, 621-627, 2005.

Ekdal, A.: Water Quality Modeling of Köyceğiz – Dalyan Lagoon, PhD, Istanbul Technical University, Istanbul, Turkey, 236 pp., 2008.

Erturk, A., Gurel, M., Koca, D., Ekdal, A., Tanik, A., Seker, D. Z., Kabdasli, S., and Gönenc, I. E.: Determination of Model Dimensions for a Complex Lagoon System - A Case Study From Turkey, Proceedings of XXX IAHR Congress Water Engineering and Research in a learning Society: Modern Developments and Traditional Concepts, 24-29 August 2003, Thessaloniki, Greece, 2003, 53-60, 2003.

Formatiert: Englisch (USA)

Formatiert: Hochgestellt

Graciansky, P.C., 1968. Stratigraphy of the overlapped units of the Lycien Nappes in the Teke Peninsula and their position within the Dinaro-Taurids. Bull. Miner. Res. Explor. Inst., Ankara, 71: 73-92 (in Turkish).

Gattacceca, J. C., Vallet-Coulomb, C., Mayer, A., Claude, C., Radakovitch, O., Conchetto, E., and Hamelin, B.: Isotopic and geochemical characterization of salinization in the shallow aquifers of a reclaimed subsiding zone: The southern Venice Lagoon coastland, Journal of Hydrology, 378, 46-61, 10.1016/j.jhydrol.2009.09.005, 2009.

Gönenc, I. E., Tanik, A., Seker, D. Z., Gurel, M., Erturk, A., Ekdal, A., Yuceil, K., Kose, C., Be~~z~~yazgu~~k~~l, M., and Bilir, L. Z.: Ecosystem modeling for the sustainable management of lagoons, Final Report, The Scientific and Technical Research Council of Turkey, TUBITAK YDABCAG Project No: 100Y047, Ankara ~~(in Turkish)~~, 2004.

Google Earth, http://www.google.com/earth/, access: 25.05.2014, 2014.

Gurel, M., Tanik, A., Erturk, A., Dogan, E., Okus, E., Seker, D. Z., Ekdal, A., K., Y., Bederli Tumay, A., Karakaya, N., Beler Baykal, B., and Gönenc, I. E.: Köycegiz – Dalyan Lagoon: A case study for sustainable use and development, in: Coastal Lagoons: Ecosystem Processes and Modeling for Sustainable Use and Development, edited by: Gönenc, I. E., and Wolflin, J., CRC Press, Boca Raton, Florida, 440-474, 2005.

Kløve, B., Ala-Aho, P., Bertrand, G., Gurdak, J. J., Kupfersberger, H., Kværner, J., Muotka, T., Mykrä, H., Preda, E., Rossi, P., Uvo, C. B., Velasco, E., and Pulido-Velazquez, M.: Climate change impacts on groundwater and dependent ecosystems, Journal of Hydrology, http://dx.doi.org/10.1016/j.jhydrol.2013.06.037, in press, 2014.

Lecuyer, C., Bodergat, A. M., Martineau, F., Fourel, F., Gurbuz, K., and Nazik, A.: Water sources, mixing and evaporation in the Akyatan lagoon, Turkey, Estuarine Coastal and Shelf Science, 115, 200-209, 10.1016/j.ecss.2012.09.002, 2012.

Longinelli, A. and Selmo, E.: Isotopic composition of precipitation in Italy: a first overall map. J. Hydrol., 270, 75-88, 2003.

Lykoudis, S. P. and Argiriou, A. A.: Gridded data set of the stable isotopic composition of precipitation over the eastern and central Mediterranean. Journal of Geophysical Research-Atmospheres 112, D18, 2007.

Mutlu, H., and Gülec, N.: Hydrogeochemical outline of thermal waters and geothermometry applications in Anatolia (Turkey), Journal of Volcanology and Geothermal Research, 85, 495-515, 10.1016/s0377-0273(98)00068-7, 1998.

Niencheski, L. F. H., Windom, H. L., Moore, W. S., and Jahnke, R. A.: Submarine groundwater discharge of nutrients to the ocean along a coastal lagoon barrier, Southern Brazil, Marine Chemistry, 106, 546-561, 10.1016/j.marchem.2007.06.004, 2007.

Pérez -Ruzafa, A., Marcos, C., and Pérez -Ruzafa, I. M.: Mediterranean coastal lagoons in an ecosystem and aquatic resources management context, Physics and Chemistry of the Earth, 36, 160-166, 10.1016/j.pce.2010.04.013, 2011a.

Pérez-Ruzafa, A., Marcos, C., Pérez-Ruzafa, I., and Pérez-Marcos, M.: Coastal lagoons: "transitional ecosystems" between transitional and coastal waters, J Coast Conserv, 15, 369-392, 10.1007/s11852-010-0095-2, 2011b.

Remane, A., and Schlieper, C.: Biology of Brackish Water, Wiley Interscience, New York, 372 pp., 1971.

Santos, I. R., Machado, M. I., Niencheski, L. F., Burnett, W., Milani, I. B., Andrade, C. F. F., Peterson, R. N., Chanton, J., and Baisch, P.: Major ion chemistry in a freshwater coastal lagoon from southern Brazil (Mangueira Lagoon): Influence of groundwater inputs, Aquatic Geochemistry, 14, 133-146, 10.1007/s10498-008-9029-0, 2008a.

Santos, I. R., Niencheski, F., Burnett, W., Peterson, R., Chanton, J., Andrade, C. F. F., Milani, I. B., Schmidt, A., and Knoeller, K.: Tracing anthropogenically driven groundwater discharge into a coastal lagoon from southern Brazil, Journal of Hydrology, 353, 275-293, 10.1016/j.jhydrol.2008.02.010, 2008b.

Schmidt, A., Santos, I. R., Burnett, W. C., Niencheski, F., and Knöller, K.: Groundwater sources in a permeable coastal barrier: Evidence from stable isotopes, Journal of Hydrology, 406, 66-72, 10.1016/j.jhydrol.2011.06.001, 2011.

Vreca, P., Bronic, I.K., Horvatincic, N. and Baresic, J.: Isotopic characteristics of precipitation in Slovenia and Croatia: Comparison of continental and maritime stations. J. Hydrol., 330, 457-469, 2006.

WISER, available at: http://www-naweb.iaea.org/napc/ih/IHS_resources_isohis.html, ~~http://www-naweb.iaea.org/napc/ih/index.html,~~ last access: 19~~.05~~ May~~.~~ 2014.

Table 1. Chemical analysis of water samples for the dry and wet season; asterisks indicate values used for endmember mixing analysis using either a three (3EMMA) or two (2EMMA) mixing approach.

	dry season					wet season				
Location	Depth (m)	Chloride (mg/l)	Salinity (pptg/l)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	Depth (m)	Chloride (mg/l)	Salinity (pptg/l)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)
L01T	0.1	2400	3.8	-2.90	-16.4	0.1	930	3.1	-4.70	-24.9
L02T	0.1	2600	3.8	-2.87	-16.0	0.1	930	3.1	-4.51	-26.3
L03T	0.1	2800	4.0	-2.97	-16.4	0.1	930	3.2	-4.78	-24.8
L04T	0.1	3700	7.0	-2.71	-14.9	0.1	940	3.0	-4.93	-25.4
L05T	0.1	11400	23.6	-0.15	-1.3	0.1	2350	4.6	-4.50	-22.5
L06T	0.1	14900	22.3	-0.16	-0.7	0.1	1500	4.2	-4.72	-22.8
L07T	0.1	7800	16.1	-1.86	-10.8	0.1	1050	3.2	-4.68	-24.8
L08T	0.1	18600	37.9	1.45	9.2	0.1	1300	4.2	-4.74	-23.3
L09T	0.1	14700	29.3	0.59	3.3	0.1	1300	4.5	-4.44	-24.5
L10T	0.1	14700	27.6	0.47	2.2	0.1	840	3.4	-4.76	-24.7
L11T	0.1	15800	27.6	0.30	2.4	0.1	2150	5.9	-4.95	-27.8
L12T	0.1	13200	25.7	0.20	0.6	0.1	2500	6.9	-4.28	-22.9
L13T	0.1	18200	30.6	1.00	4.2	0.1	1400	7.6	-4.17	-21.9
L14T	0.1	17400	30.6	0.95	-0.6	0.1	1350	7.6	-3.97	-21.0
L15T	0.1	13900	-	-0.33	-1.3	0.1	1200	7.3	-4.43	-22.5
L22T	0.1	8700	16.7	-1.51	-8.8	0.1	950	3.2	-4.73	-24.4
L29T	0.1	13700	29.3	0.50	3.2	0.1	750	3.3	-4.62	-25.0
L33T	0.1	12000	25.0	-0.56	-2.9	0.1	950	3.4	-4.76	-23.8
L01B	3.8	3300	26.3	-2.86	-16.4	3.8	940	3.1	-4.73	-24.7
L02B	4.4	3600	27.8	-0.12	-0.8	4.4	940	3.2	-4.7	-24.4
L03B	2.5	3700	31.8	-2.90	-16.6	2.4	950	3.2	-4.7	-24.8
L04B	2.1	20000	32.7	0.73	4.3	2.0	970	3.1	-5.01	-27.0
L05B	3.3	22300	38.2	1.43	8.1	3.2	7100	19.4	-2.7	-12.3
L06B	1.4	12800	32.1	-0.09	-0.9	1.7	1600	4.7	-4.58	-23.1
L07B	2.0	21400	35.8	1.13	7.5	1.9	1100	3.1	-4.90	-23.8
L08B*, 2EMMA	1.1	23800	39.7	1.16	7.4	1.1	1300	4.3	-4.44	-23.9
L09B	1.3	24200	39.0	1.35	7.9	1.2	1700	5.4	-4.33	-23.4
L10B	1.1	21800	33.8	1.30	7.1	1.3	930	3.4	-4.78	-24.0
L11B	1.5	17100	31.2	1.02	4.4	1.5	3500	7.5	-4.34	-21.3
L12B	1.5	14300	34.6	0.66	2.4	1.5	3600	7.3	-4.31	-21.4
L13B	3.4	18300	36.5	1.07	4.6	3.6	21600	41.2	0.64	4.9
L14B	5.4	18100	36.9	0.76	4.3	5.4	21000	41.2	0.68	3.0
L15B	1.6	16400	-	0.65	4.0	1.6	1320	8.0	-4.05	-21.9
L22B	3.0	22100	35.9	0.97	5.9	3.0	980	3.3	-4.66	-24.8
L29B	1.8	17500	35.5	0.93	5.5	1.8	850	3.3	-4.58	-24.8
L33B	3.8	19800	38.8	1.11	7.0	3.8	3400	11.3	-3.71	-18.5
GW03	-	132	0.4	-5.27	-25.8	-	-	-	-	-
GW04	-	117	0.4	-6.10	-34.7	-	111	0.4	-6.08	-34.1
GW05	-	146	0.5	-6.03	-34.3	-	88	0.4	-6.25	-34.8
GW11	-	2300	1.3	-6.39	-36.1	-	460	1.1	-6.66	-43.4
GW14	-	69	0.3	-6.35	-35.5	-	41	0.3	-6.46	-38.3
GW15	-	41	0.3	-6.32	-36.0	-	40	0.3	-6.22	-36.6
GW18	-	42	0.4	-6.02	-32.9	-	16	0.5	-5.62	-35.2
GW19	-	25	0.3	-6.63	-37.6	-	-	0.3	-6.55	-38.9
GW20	-	56	0.4	-5.77	-30.0	-	18	0.2	-6.60	-39.5
GW25	-	57	0.6	-5.24	-29.0	-	50	0.5	-5.25	-31.0
GW29	-	46	0.4	-5.87	-33.5	-	26	0.4	-6.00	-34.1
GW*	-	73	0.4	-6.00	-32.9	-	49	0.4	-6.17	-36.6
Sea*, 3EMMA	0.1	20800	40.0	1.45	9.1	0.1	21700	39.2	0.49	1.1
Lake*	0.1	2200	3.7	-2.88	-15.9	0.1	920	3.2	-4.38	-23.4
Lake	12.8	4500	11.2	-2.26	-11.5	12.7	4800	13.6	-2.27	-12.0

Formatiert: Hochgestellt

Formatiert: Hochgestellt

Table 2. Average results of the three component endmember mixing analysis giving the contributions of groundwater (f_{GW}), lake water (f_{LW}) and seawater (f_{SW}) in the lagoon top and bottom for dry and wet season.

	dry season			wet season		
	f_{GW}	f_{LW}	f_{SW}	f_{GW}	f_{LW}	f_{SW}
Location -TOP						
L01	0.020	0.975	0.005	0.210	0.780	0.010
L02	0.015	0.970	0.015	0.080	0.915	0.005
L03	0.070	0.905	0.025	0.265	0.720	0.015
L04	0.075	0.830	0.095	0.360	0.620	0.020
L05	0.000	0.559	0.441	0.255	0.675	0.070
L06	0.045	0.400	0.551	0.320	0.630	0.050
L07	0.140	0.530	0.335	0.210	0.775	0.015
L08	0.000	0.189	0.811	0.320	0.640	0.040
L09	0.000	0.431	0.569	0.130	0.835	0.035
L10	0.000	0.447	0.549	0.260	0.730	0.010
L11	0.000	0.335	0.665	0.605	0.290	0.105
L12	0.000	0.513	0.488	0.230	0.665	0.105
L13	0.000	0.307	0.693	0.135	0.790	0.070
L14	0.000	0.332	0.668	0.065	0.825	0.110
L15	0.030	0.650	0.320	0.250	0.665	0.085
L22	0.055	0.580	0.360	0.240	0.745	0.015
L29	0.000	0.468	0.532	0.150	0.840	0.010
L33	0.040	0.400	0.560	0.265	0.720	0.015
Location - BOTTOM						
L01	0.335	0.420	0.245	0.225	0.765	0.010
L02	0.020	0.645	0.335	0.220	0.775	0.005
L03	0.360	0.380	0.258	0.235	0.760	0.005
L04	0.088	0.140	0.772	0.425	0.555	0.020
L05	0.056	0.050	0.894	0.200	0.460	0.340
L06	0.100	0.250	0.650	0.250	0.695	0.050
L07	0.073	0.075	0.852	0.355	0.630	0.015
L08	0.145	0.000	0.855	0.115	0.865	0.020
L09	0.108	0.015	0.874	0.130	0.815	0.060
L10	0.061	0.168	0.770	0.280	0.705	0.015
L11	0.000	0.349	0.651	0.375	0.480	0.145
L12	0.030	0.305	0.674	0.350	0.505	0.145
L13	0.000	0.150	0.850	0.025	0.000	0.975
L14	0.060	0.060	0.880	0.025	0.000	0.975
L15	0.000	0.300	0.700	0.110	0.815	0.075
L22	0.107	0.055	0.838	0.205	0.785	0.010
L29	0.000	0.175	0.825	0.135	0.855	0.010
L33	0.045	0.005	0.950	0.150	0.675	0.175

Table ~~2~~3. Average results of 2 component endmember mixing analysis giving the contributions of ~~groundwater (f_{GW}),~~ lake water (f_{LW}) and seawater (f_{SW}) in the lagoon top and bottom for the dry ~~and wet~~ season; average relative percentages of evaporation calculated for dry season based on data correction (details given in text).

	f_{LW}	f_{SW}	evaporation (%)
Location -TOP			
L01T	0.993	0.007	-
L02T	0.989	0.011	0.1
L03T	0.975	0.025	-
L04T	0.913	0.087	-
L05T	0.540	0.460	5.3
L06T	0.469	0.531	3.3
L07T	0.689	0.311	-
L08T	0.179	0.821	3.7
L09T	0.389	0.611	4.7
L10T	0.412	0.588	4.7
L11T	0.376	0.624	3.1
L12T	0.472	0.528	5.0
L13T	0.292	0.708	4.3
L14T	0.312	0.688	4.5
L15T	0.472	0.528	2.1
L22T	0.671	0.329	0.7
L29T	0.413	0.587	5.0
L33T	0.483	0.517	1.6
Location - BOTTOM			
L01B	0.598	0.402	-
L02B	0.667	0.333	0.2
L03B	0.494	0.506	-
L04B	0.198	0.802	1.4
L05B	0.075	0.925	1.9
L06B	0.365	0.635	2.4
L07B	0.126	0.874	1.7
L08B	0.000	1.000	-
L09B	0.016	0.984	0.8
L10B	0.156	0.844	2.9
L11B	0.312	0.688	4.8
L12B	0.315	0.685	3.6
L13B	0.194	0.806	2.6
L14B	0.181	0.819	1.4
L15B	0.374	0.626	4.2
L22B	0.100	0.900	0.8
L29B	0.226	0.774	2.7
L33B	0.118	0.882	1.5

Figure Captions

Figure 1. Geographic location of the ~~Köyceğiz~~Köycegiz-Dalyan Coastal Lagoon (a) and sampling locations (b); source of modified satellite picture was Google Earth (2014).

Figure 2. Long-term monthly data of average precipitation (grey bars) and air temperature (solid line) from Köycegiz meteorology station (1976-2010) and isotopic composition of precipitation in Antalya (dashed line). Data from Antalya are available at the IAEA database WISER (http://www-naweb.iaea.org/napc/ih/index.html; accessed 19.05.2014).

Figure 3. Conceptual model of flow connections between the lagoon and surrounding water bodies for (a) the dry and (b) wet season.

Formatiert: Englisch (USA)

Figure ~~2~~4. Dual isotope plot for (a) dry season and (b) wet season sampling campaign; LMWL and average precipitation taken from closest station of the GNIP data base i.e. Antalya.

Figure ~~3~~5. Chloride concentrations and $\delta^{18}O$ ratios for (a) dry season and (b) wet season sampling campaign; the dashed lines connect~~s~~ the three (bold) or two (light) endmembers used for the three component mixing analysis.

Figure ~~4~~6. Fractions of different sources of the lagoon water for (a) dry and (b) wet season sampling campaign.

Figure ~~5~~7. Changing fractions of freshwater (circles) and marine water (triangles) with distance from the coastline for (a) the top layer in the dry season, (b) bottom layer in the dry season, (c) top layer in the wet season, (d) bottom layer in the wet season; closed dark symbols indicate locations at the main lagoon channel, open symbols indicate surrounding lake locations and closed light symbols indicate their inflow/outflow connections to the lagoon system; error bars were determined from variability of endmember mixing analysis using salinity and chloride data individually in combination with $\delta^{18}O$.

Figure 8. Fractions of freshwater (a) and seawater (b) contributions in the top and bottom lagoon samples calculated from two and three endmember mixing approaches; dashed line gives 1:1 line.

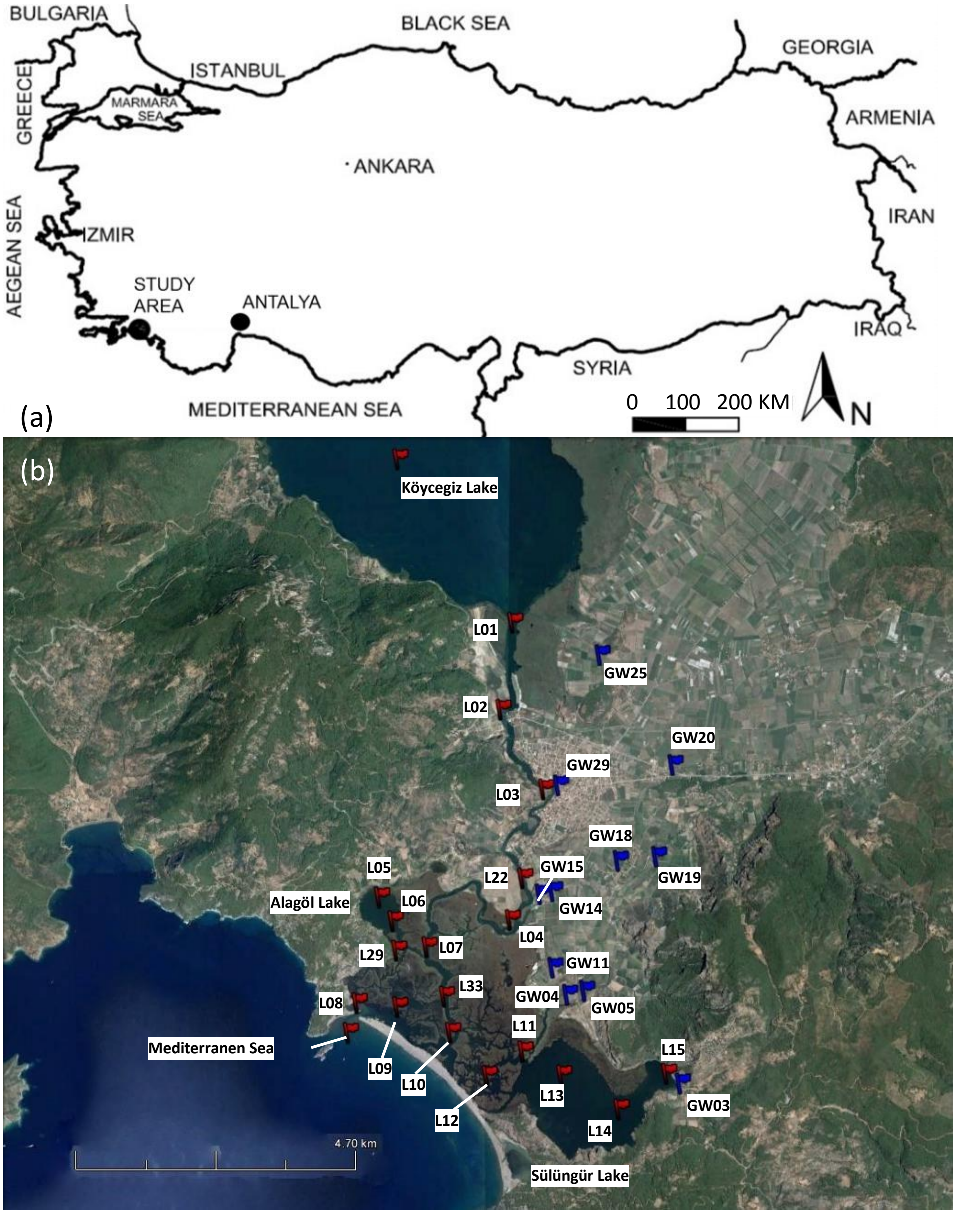
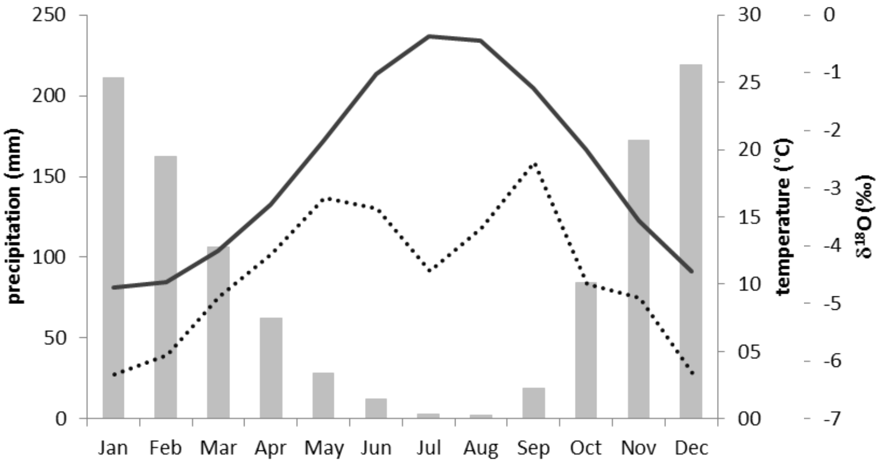

BULGARIA
BLACK SEA
GEORGIA
GREECE
ISTANBUL
MARMARA SEA
ARMENIA
ANKARA
IRAN
AEGEAN SEA
IZMIR
STUDY AREA
ANTALYA
IRAQ
SYRIA
MEDITERRANEAN SEA
0 100 200 KM
N
(a)
(b)
Köycegiz Lake
L01
GW25
L02
GW20
GW29
L03
GW18
GW15
GW19
L05
L22
GW14
Alagöl Lake
L06
L04
L29
L07
GW11
L33
GW04
GW05
L08
L11
Mediterranen Sea
L15
L09
L10
L13
GW03
L12
L14
4.70 km
Sülüngür Lake

Figure 1



precipitation (mm)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
temperature (°C)
30
25
20
15
10
05
00
δ18O (‰)
0
-1
-2
-3
-4
-5
-6
-7

Figure 2

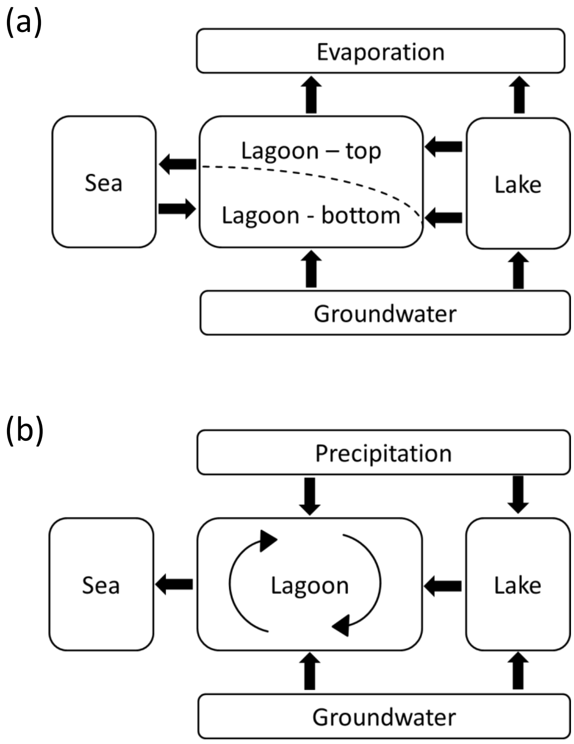

(a)
Evaporation
Sea
Lagoon – top
Lagoon - bottom
Lake
Groundwater
(b)
Precipitation
Sea
Lagoon
Lake
Groundwater

Figure 3

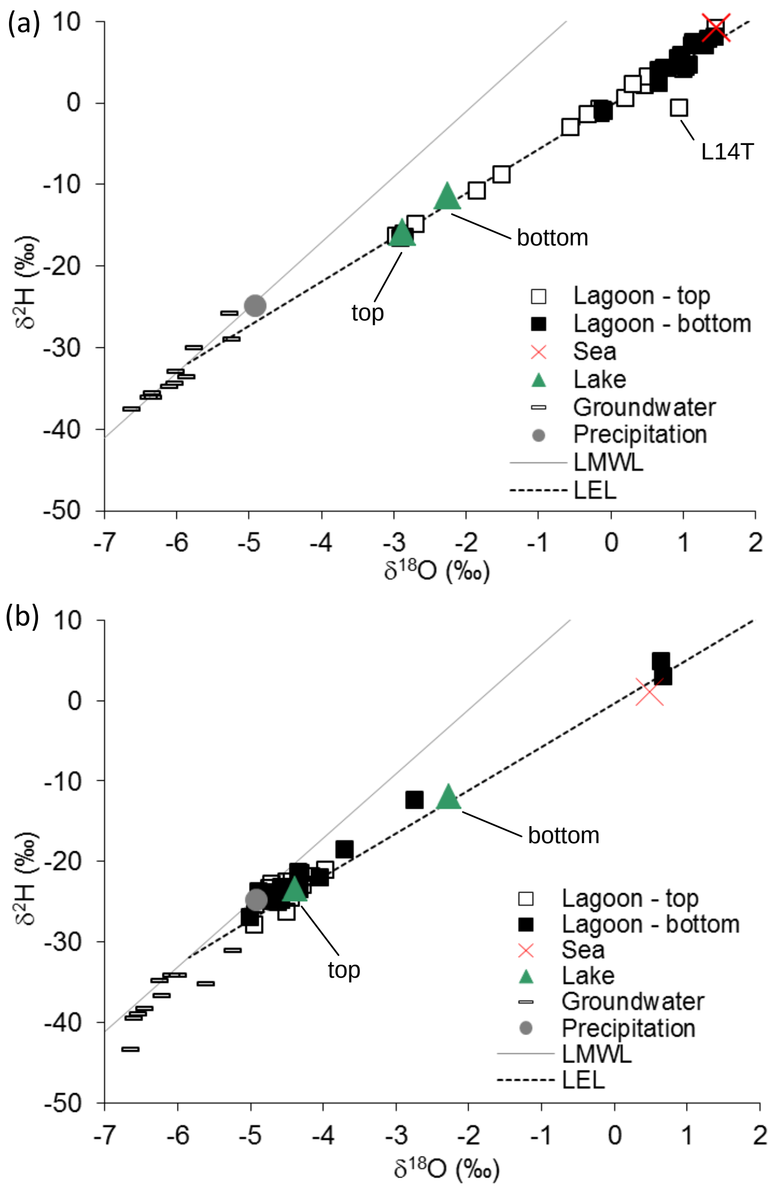

(a)
δ2H (‰)
δ18O (‰)
L14T
bottom
top
Lagoon - top
Lagoon - bottom
Sea
Lake
Groundwater
Precipitation
LMWL
LEL
(b)
δ2H (‰)
δ18O (‰)
bottom
top
Lagoon - top
Lagoon - bottom
Sea
Lake
Groundwater
Precipitation
LMWL
LEL

Figure 4

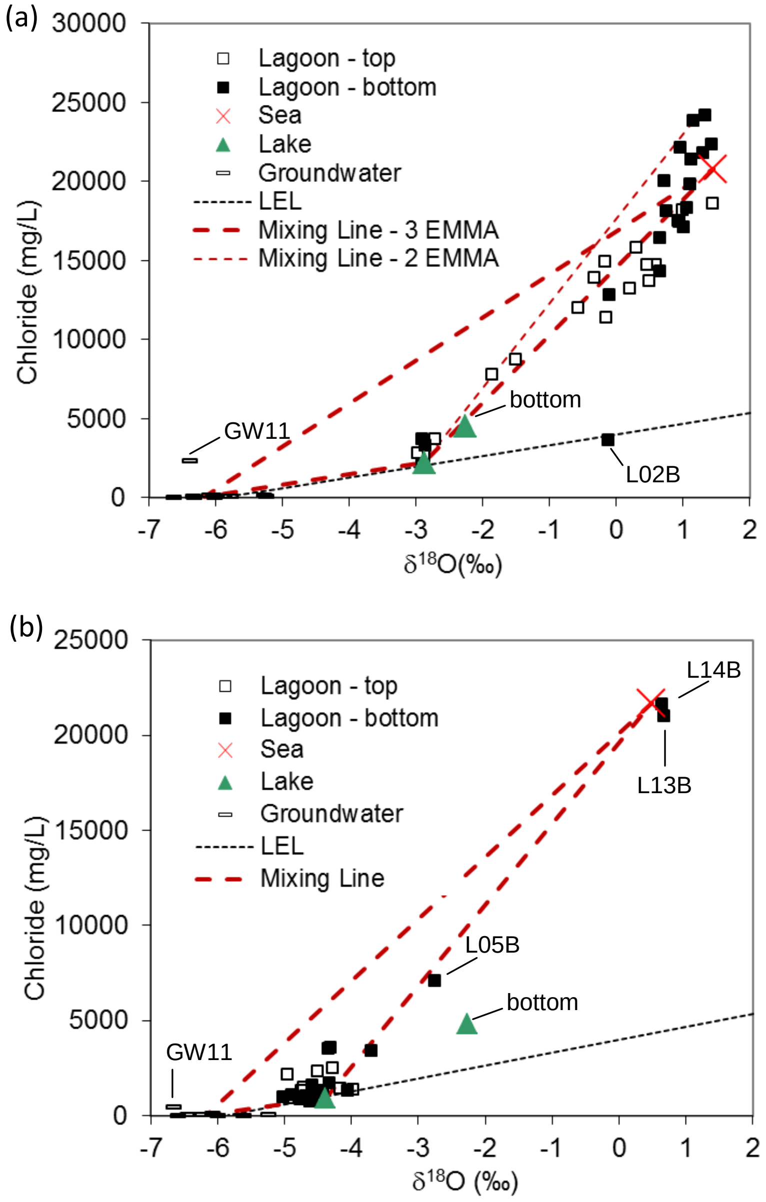

(a)
Lagoon - top
Lagoon - bottom
Sea
Lake
Groundwater
LEL
Mixing Line - 3 EMMA
Mixing Line - 2 EMMA
GW11
bottom
L02B
Chloride (mg/L)
δ18O(‰)
(b)
Lagoon - top
Lagoon - bottom
Sea
Lake
Groundwater
LEL
Mixing Line
L14B
L13B
L05B
bottom
GW11
Chloride (mg/L)
δ18O (‰)

Figure 5

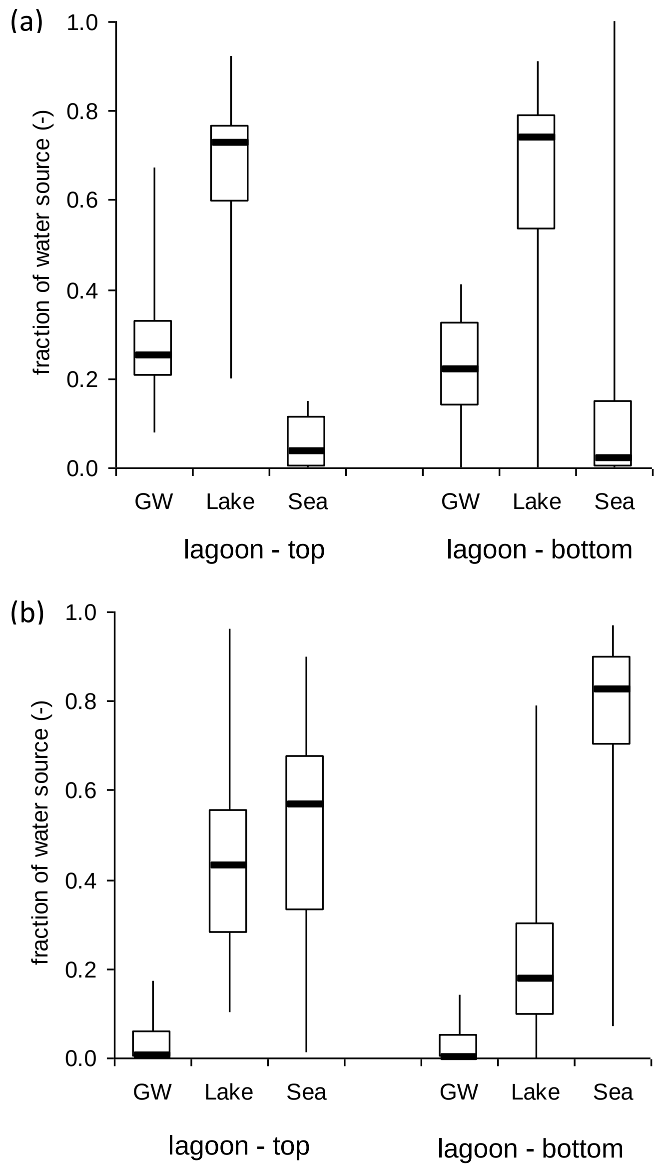
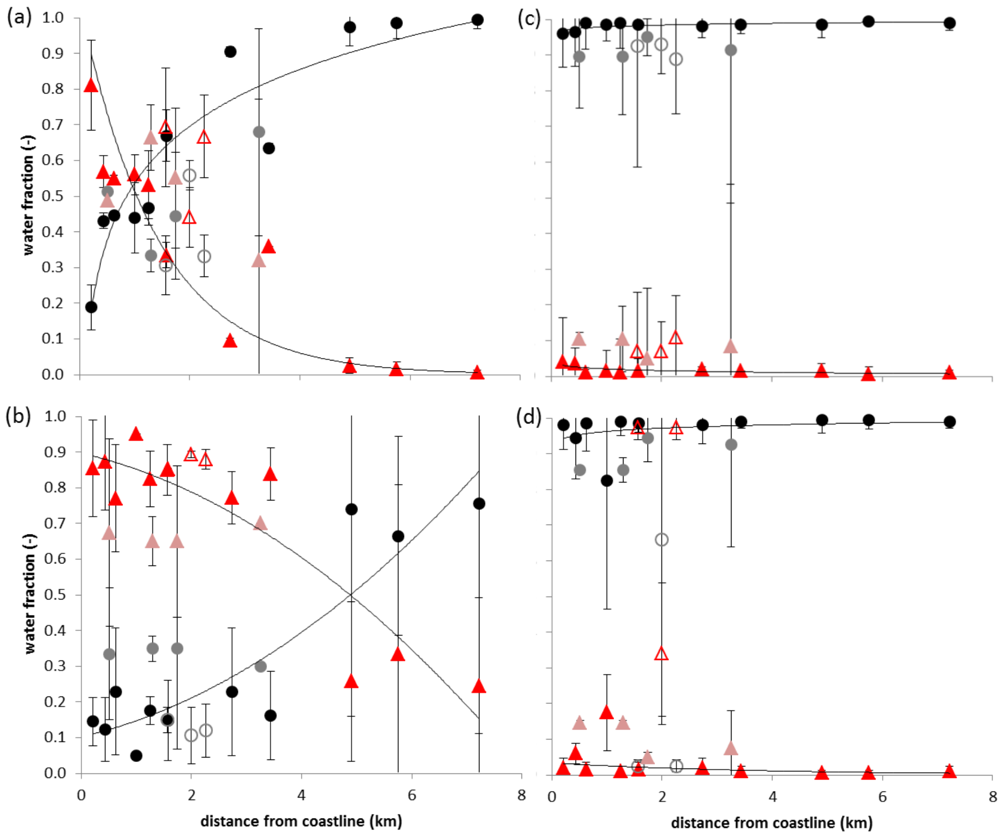

(a)
fraction of water source (-)
1.0
0.8
0.6
0.4
0.2
0.0
GW
Lake
Sea
GW
Lake
Sea
lagoon - top
lagoon - bottom
(b)
fraction of water source (-)
1.0
0.8
0.6
0.4
0.2
0.0
GW
Lake
Sea
GW
Lake
Sea
lagoon - top
lagoon - bottom

Figure 6



(a)
(b)
(c)
(d)
water fraction (-)
distance from coastline (km)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8

1

2 Figure 7

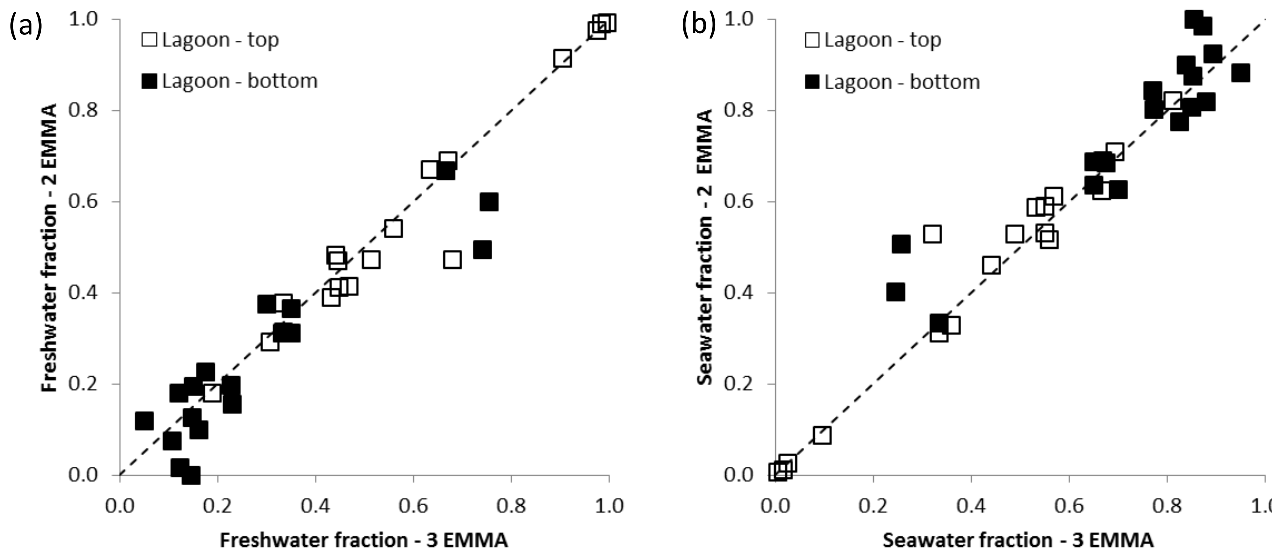

(a)
Lagoon - top
Lagoon - bottom
Freshwater fraction - 2 EMMA
Freshwater fraction - 3 EMMA
0.0
0.2
0.4
0.6
0.8
1.0
(b)
Lagoon - top
Lagoon - bottom
Seawater fraction - 2 EMMA
Seawater fraction - 3 EMMA
0.0
0.2
0.4
0.6
0.8
1.0

Figure 8