Salinization of the Vrana Lake in Dalmatia within the context of anthropogenic influences and climate changes (situation in 2008)

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Abstract: Vrana Lake is a coastal lake in Dalmatia (Croatia), protected as Nature park. Although it is by its surface of about 30 km2 the largest lake in Croatia, its volume comprises only about 82.5 mil m3. The lake is a cryptodepression (with maximum level depth -3m) separated from the sea by a 0.8 – 2.5 km wide limestone ridge within which the coastal karst aquifer interacts with both the sea and the lake. Therefore this lake is a very sensitive karst coastal system with a close interaction with the sea - a direct interaction through the 800 m long Prosika canal and the indirect interaction through the karst aquifer. The period of a few recent years (particularly 2007-2008) has been characterized by pronounced draughty hydrological conditions. Evidence of the lake critical condition is the total volume of water flowing out into the sea through the Prosika canal of only about 0,19 mil. m3 in the year 2008 which is minor as compared to the average of about 31,8 mil.m3 for the analyzed period 2000-2008. Consequently, during the summer of 2008, the water level of Vrana lake fell under the sill level of Prosika canal and in specific conditions of daily sea level fluctuations even below the sea level. That caused the sea to flow into the lake directly through Prosika canal and also through numerous springs on the lake shore. The result was an enormous increase in lake water salinity. Chloride concentration values in southern part of the lake where Prosika canal and a large number of salty inshore springs is situated increased up to 6500 mg/l in 2008, compared to the average of 590 mgl-1 for the previously analyzed period from 2000 to 2006.. Within the context, the sill level of the constructed Prosika canal, which was once sufficient for the stabilization of Vrana lake, can be a problem which generates an increase in lake salinization.

Keywords: water salinization, karst, Vrana lake, Dalmatia

1 Introduction

Coastal aquifer management is one of the largest contemporary water management challenges in the Mediterranean. Negative anthropogenic influences with increasing pressure on water resources, combined with the general trend of sea level increase (Lambeck et al. 2004, Lambeck and Purcell 2005, Orlic 1995, Pirazzoli 2000, 2005) and air temperature increase which occurs simultaneously with the precipitation volume decrease and catchment area outflow balance trends (Bolle 2003, Gajic-Capka and Zaninovic 2006, Svensson et al. 2005, Svonja et al. 2003) make coastal karst aquifers particularly sensitive. Salty water intrusions into deeper parts of coastal karst aquifers, mostly caused by an excessive exploitation of coastal water resources, occur in a large part of the Mediterranean coastal area (Benblidia et al. 1996, Custodio and Bruggeman 1982, Custodio 2002, Margat 2004).

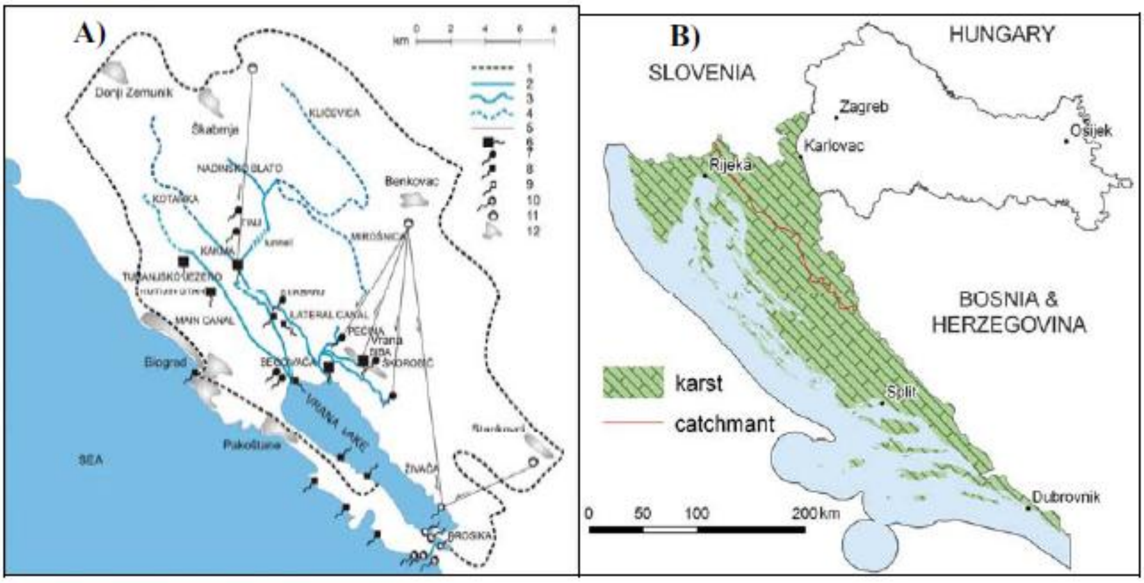

Figure 1 Position of Vrana Lake in Dalmatia: A) Catchment area overview – supplemented according to Fritz (1984) Key: (1) – hydrogeological catchment area border, (2) regulation canal, (3) permanent natural water flow, (4) periodical natural water flow, (5) underground hydrogeological link, (6) source intercepted for water supply, (7) non-intercepted more important source, (8) brackish water source, (9) submarine spring, (10) estavelle, (11) sink hole, B) broader situation of the analyzed area

Vrana Lake in Dalmatia (Figure 1) is one of the most sensitive water resources of large biodiversity which is pointedly affected by all the previously mentioned influences. In 1999 the lake with its adjacent onshore territory was declared a Nature park covering an area of 57 km2. The area in question is an extremely valuable coastal lake site covering an area of about 30.8 km2 and comprising a volume of about 82,5 mil. m3. Vrana Lake is a cryptodepression, up to 5 m deep, with its bottom situated at about 3 m below sea level. The lake runs along the sea coast in its full length of about 13.6 km. It is separated from the sea by a 0.8 – 2.5 m wide limestone ridge within which the coastal karst aquifer dynamically interacts with both the sea and the lake and through which the lake also interacts with the sea. Already in 1770 the lake was directly connected to the sea by a 800 m long Prosika canal which has later been widened and deepened on many occasions in order to improve the drainage of a constructed hydrotechnical melioration system. The canal bottom level is at only 0.43 m above sea level (m a. s. l.) while the water level of the lake varies from 0.03 m a. s. l. (in 1990 and 2008) to 2.24 m a. s. l. (in 1974 and 1994), mean value being 0.81 m a. s. l. The lake-sea interaction is performed in two ways. Direct interaction occurs through Prosika canal with water mostly flowing out, except during long-term dry periods when the sea uplevels the lake, allowing sea water to flow directly into Lake Vrana. Indirect interaction occurs through the karst aquifer where salinization of the lake takes place through several spring groups. Therefore the lake is characterized by great variations in and chloride concentration (from about a 100 mgl-1 up to over 6.000 mgl-1). In the recent years, 2007 and especially in 2008, Vrana Lake suffered extremely unfavourable hydrological conditions of increased salt-water intrusion into the lake (Rubinic and Cuze 2009). Should the started negative processes of salinization continue, lowering of biodiversity together with trophy grade increase and rapid lake degradation is to be expected.

In order to develop measure to prevent such negative scenario, an analysis of the existing mhydrological conditions is a prerequisite condition. This paper therefore analyzes some of thebasic hydrological interrelations of the lake catchment area, its karst aquifer and the surrounding sea.

2 Vrana Lake characteristics and its hydrological dynamics

Vrana Lake gets watered through numerous canals of the constructed hydromelioration system which, apart from the surface waters, also partly gather overflow waters from several karst springs as well as waters from their immediate karst aquifer (Figure 1). The complete potential catchment area surface is about 470 km2 (Fritz 1984). However, hydrological monitoring in the catchment area is not organized in a way that appropriate lake inflow control is applicable. Only in the past 7 – 8 years there are partial data about flow capacities at some of the more important lake inflow sites with a total of 1.8 m3s-1 of the lake inflow balance.

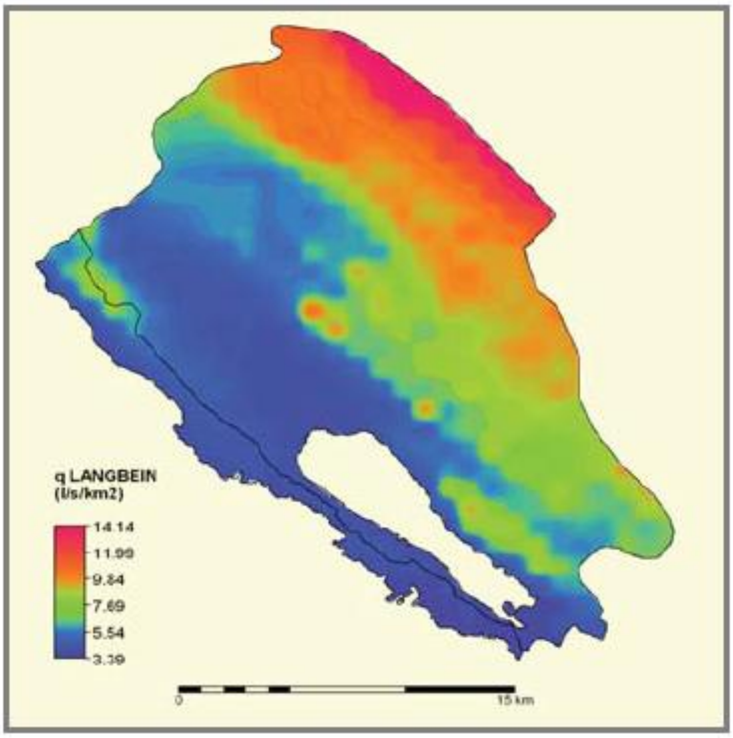

Figure 2 Distribution of annual flow capacities

Since proper inflow balance could not be calculated based on the available, relatively short and hydrologically insufficiently relevant data on flow capacities, such estimation for a referential period from 1961-1990 was conducted based on the available climatological parameters. The methodology, based on applying the Langbein method in GIS environment is developed in the paper by Horvat and Rubinic (2006).

Figure 2 shows the results of analyzing the specific flow capacity spatial distribution at which the spatial raster of the analyzed data is 1 x 1 km2. By using the latest data (Geotehnicki Fakultet Varazdin 2009) on the partially corrected surface of a potentially gravitating catchment area covering about 411 km2, the lake surface included, the balance of complete mean yearly lake inflows of 3.9 m3s-1 was calculated.

The lake also has considerable losses both in form of surface outflow from the lake through Prosika canal and due to evaporation of the lake itself, usage of water in the catchment area and sinking into subterranean passages. According to the recorded data about the flows from the Prosika profile from 1996 to 2008, the average outflow from the lake on the Prosika canal profile entrance was about 1.01 m3s-1. Since the period in question was a relatively dry one with about 20% less precipitation and higher air temperatures, the perennial average amount of canal outflow should be 20 – 50% larger, up to 1.50 m3s-1. The loss of water through evaporation is significant due to high temperatures and shallowness of the lake. Based on the analogy of the registered water evaporations from the salt-pans on the island of Pag from the paper by Berakovic (1983), it has been assessed that the losses are about 1.66 m/year. Similarly, according to the conducted empirical assessments of Meyer method (Hrvatska Vodoprivreda 1994), the average annual evaporation was assessed to 1.403 m/year. Using the mean value of the both data the balance contribution of about 1.50 m3s-1 is achieved regarding the mean lake surface. The annual usage of about 0.107 m3s-1 (Geotehnicki Fakultet Varazdin 2009) was recorded for the water supply needs from Vrana Lake catchment area. However, due to the unregistered usage of water for irrigation and local water supply, this amount is surely almost doubled – cca 0.200 m3s-1. The losses caused by sinking into subterrain passages are practically unknown and within the context of previous balance assessment closures they must be about 0.70 m3s-1. As a comparison, during the solely known water measurement of water loss from Prosika canal which was conducted on July 2nd 2009, the flow of 0.502 m3s-1 was measured at the canal entrance and up to the Prosika canal mouth the flow was just 0.055 m3s-1. This gives the loss from the canal of about 0.45 m3s-1 when the denivelation between the water level of the lake and the sea was about 0.66 m. It is quite certain that water losses at the lake perimeter depend not only on the interrelation of the lake water level and sea water level but also on the level of underground water in the karst aquifer.

The obtained results of average Vrana lake inflow balance assessment are similar to those of the balance assessment conducted by Svonja (2003) which showed 4.2 m3s-1 for the same 30-year period. Somewhat lesser values were obtained by Pavic in the study of Vodotok (2008), 3.14 m3s-1 during the relatively draughtier period from 2000 – 2005. The balance assessments obtained for the period 1963 – 1980 must also be pointed out (Berakovic 1983). They relate to the 360 km2 of Vrana lake catchment area up to the formerly planned barrier profile in the very lake. The obtained mean annual flow was 2.48 m3s-1, but without counting the no quantified underground sinking losses from her paper. Even lesser mean annual Vrana lake inflows were obtained in the study of Hrvatska Vodoprivreda (1994) for the period from 1963 – 1992 in the amount of 1.96 m3s-1, which is, within the study itself, contrary to the offered assessments of lake water outflows through Prosika canal (1.5 m3s-1) and the mentioned evaporation assessments.

Regarding the relatively questionable data about flows into the Vrana lake system, the paper in question used data from other hydrological parameters at disposal. Figure 3 shows the mean annual lake water level modular value (at Prosika site), the sea level (data from the water level recorder Prosika was partly supplemented with Split-Marjan tide-gauge measurements data, based on the conducted regression analysis) and data about annual precipitation volume from Biograd and Stankovci stations (due to their position in relation to the lake the average values were used) during the last 30-year period. It is clear that despite the observed precipitation decrease trend (0.64%, 5.5 mm/year), there is a mild lake water level increase trend (0.31%, 0.34 cm/year) caused by the present sea water level increase trend (1.08%, 0.26 cm/year) (Katalinic et al. 2007).

3 Analysis of the Vrana Lake salinization during 2008

Vrana lake and its aquifer are in a dynamic balance with the sea. Dry periods with low lake water levels are followed by extreme rises in lake salinity due to inflow of sea water both through Prosika canal, or, even to a larger extent, through salty springs in the southern and northwest part of the lake area. Water from these springs flows immediately into the lake or gets collected by constructed drainage canals on the north-western part of the lake area (such as Kotarka canal). This correlation between the lake-sea water level dynamics and extreme salinization is best seen on Figure 4. It shows the mean annual water level differences of lake and sea water levels as well as the maximum annual recorded salinity values at I – Kotarka canal mouth and II – Crkvine stations (both situated in the northwestern part of the lake) starting from 1982 (with interruption during the war years). During the observed period lake salinity exceeded 2000 mg l-1 in three different occasions, all of which happened during and after extremely low lake water level periods. The first of those was recorded in 1989 – 1990 (Romic et al 1997), the second one in 2003-2004 and the most prominent one in the recent 2007 and 2008 in particular. What the extents of the unfavourable hydrological circumstances were during the year 2008 is best illustrated with the mean annual lake and sea water level difference. While the average lake water level elevation in relation to the sea water level was 51 cm during the observation period, during the year 2008 the reverse situation was noted for the first time which meant that the mean annual lake water level was lower than the mean annual sea water level for 7 cm.

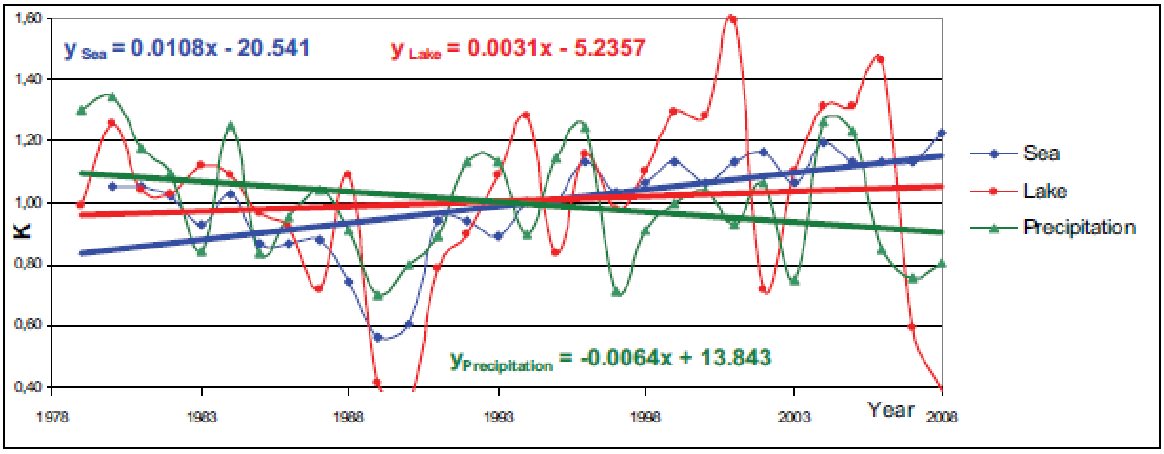

Figure 3 Modular value of lake water level, precipitation and sea level variations (1979-2008)

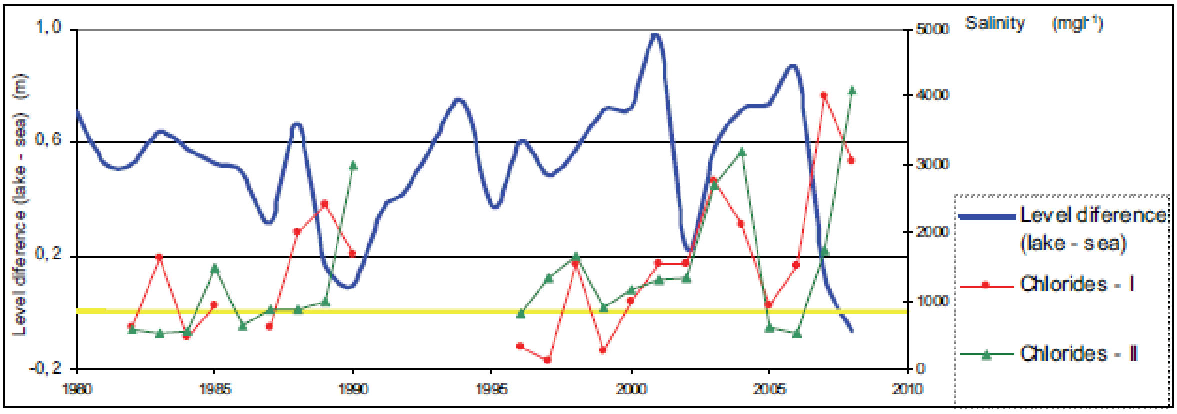

Figure 4 Annual lake water level and sea water level differences and maximum salinity recorded at the stations on Kotarka mouth (I) and Crkvina (II) in Lake Vrana (1982-2008)

Figure 5 shows hourly lake and sea water levels, and Prosika canal outflow volume from Vrana lake for the recent critical year 2008. It is clear that the lake water level was under the Prosika canal bottom level for larger part of the year. During this period not only was there no lake water spillway, but in situations when the sea water was higher than the lake water (during high tide almost on daily basis) the sea slowed down the spillway from the lake and salted the water in the canal in return. During overdrying of the lake outflow the sea flew immediately into the lake through the canal but also fed the karst aquifer. The critical conditions of the year 2008 can be best illustrated by the fact that the total annual outflow volume (from the lake into the sea) through Prosika canal was only about 0.19 mil.m3, which is neglectable in comparison to the average amount of about 31.8 mil.m3 for the observation period 2000 – 2008.

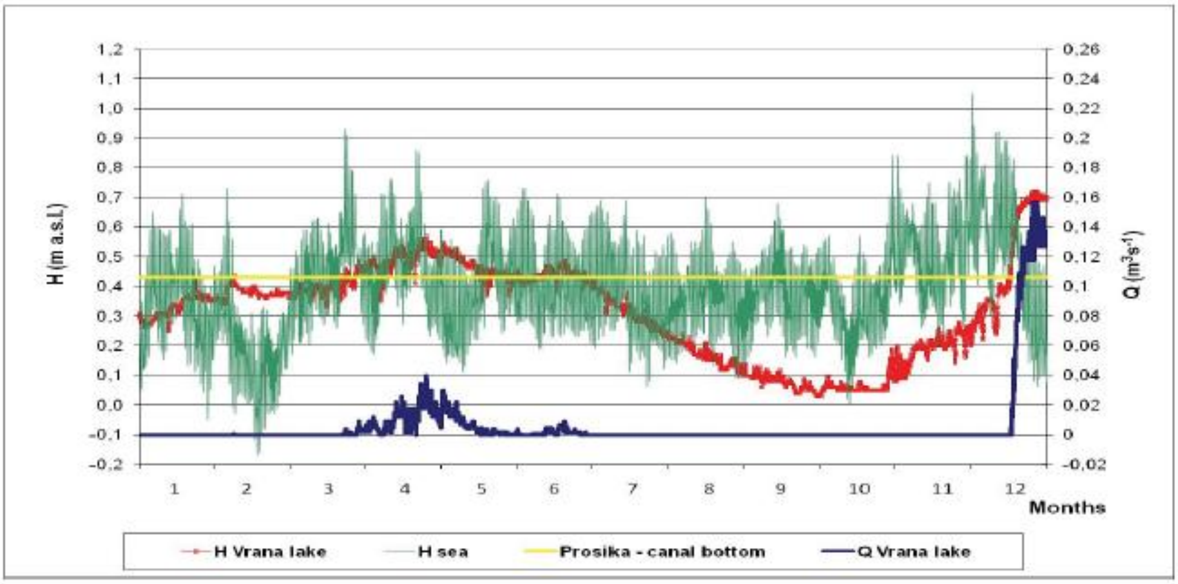

Figure 5 Observed Vrana lake water level and sea water level and outflow from the lake during 2008

Extreme salinization of the lake which was going on in 2007 and especially 2008 is shown in Figure 6. Recorded chloride concentration values at the measuring station Kotarka canal mouth in the northwest part of the lake varied from 424 mgl-1 to 4000 mgl-1 for 2007- 2008 with the average being 2007 mgl-1 in relation to the average of 590 mgl-1 for the previously analyzed period. On the nearby measuring site Crkvine the recorded values during 2007 and

2008 varied from 360 mgl-1 to 4100 mgl-1, the average being 1669 mgl-1 in relation to the average of 650 mgl-1 for the previously analyzed period. In the south-eastern part of the lake near Prosika canal there is also a large number of coastal springs through which the salty water flows into the lake. There, even higher values of salinity were recorded: in 2007-2008 chlorides varied between 395 mgl-1 and 6500 mg/l, the average being 2331 mgl-1, in relation to the average of 590 mgl-1 for the previously analyzed period from 2000 to 2006. During the analyzed period of the so far highest recorded Vrana lake salinity (2007–2008), the mean lake water level was only 0.41 m a. s. l., while the mean value for the period 2000-2006 was 1.04 m a. s. l. During that critical period the sea water level was 0.38 m a. s. l which indicates an increase of 2 cm in relation to the average value of 0.36 m a. s. l for the previous period. The average precipitation volume recorded at Stankovci station during 2007-2008 was 757.2 mm, which is ca 17% less than the measured average value for the previous 7-year period.

It can be stated that such an intensive salinization in the past two years was primarily caused by a coincidence of several unfavourable hydrological conditions also helped by anthropogenic influence, namely, existence of Prosika drainage canal, cut off at a level much too low for the present lake-sea water level interrelations.

The observed and extremely significant problem of sea water flow into Vrana lake during the analyzed year of 2008 brought the need for constructing a lock gate on Prosika canal into focus. This lock gate construction proposal was accentuated five years ago because the lock gate could be used to control the lake water level and ensure the elevation of the lake water level and lake system low water elevation increase during draught periods. Should that not be the case and should the extremely draughty hydrological conditions and sea water level increase continue, the consequences of once performed structural intervention by which the cultivable area around Vrana lake was enlarged would be incalculable in terms of the lake ecosystem.

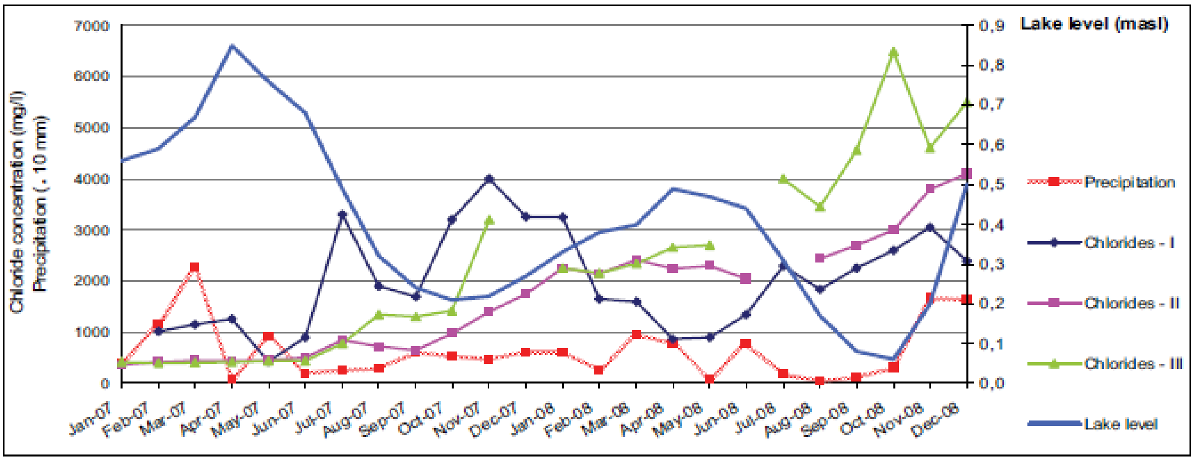

Figure 6 Overview of monthly precipitation volume, water level and chloride content

4 Conclusion

The paper has determined that the global processes in the coastal area which are characteristic for the aquatic appearances in the whole Mediterranean have been recently intensively manifested in the area of Lake Vrana and its karst aquifer. Global climate change / climate variations in the form of unfavourable precipitation trend and rise in sea water level, as well as anthropogenic interventions in Vrana Lake catchment area, influenced the lake water level variations and outflows from the lake, causing the occurrence of extremely salty water inflows into the lake system during 2007 and 2008. It is established that salinization occurs both immediately, through the Prosika drainage canal as well as through two sets of springs located in the south-eastern part of the lake round Prosika canal and in Vrana field. The risk of lake salinization is totally doubtless under given conditions. Therefore, the recommendation is to introduce a lake outflow regulation by lock gate construction which would ensure the rise in minimum lake water levels, in order to stabilize the lake system and preserve the existing ecosystem of the Vrana Lake Nature park.

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