ESTIMATION OF DISCHARGE OF THE SHALLOW SUBMARINE SPRINGS BY MEANS OF HYDROCHEMICAL TECHNIQUES. CASE STUDY: OVACIK SUBMARINE SPRINGS ALONG THE MEDITERRANEAN COAST OF TURKEY

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Abstract

Unfortunately most of the available groundwater discharges throughout/via highly developed karstic (burried channels) towards the mediterranean sea before interception for certain domestic and agricultural uses. This phenomenon takes place in Ovacık-Silifke village which is considered as one of the most intensive touristic places on the Mediterranean coast of Turkey. Thus, the present study indicates the hydrochemical tests and dye tracing techniques that were used for measuring the amount of water discharges along the Ovacık coastline on the southern Mediterranean coast of Turkey. Comparison of the Electrical Conductivity (EC) of the karst springs which have a background concentration of 500mS/cm, with the EC of the coastal and submarine discharges is also considered as an important tool for identifying the percentages of the fresh-water available in a certain volume of saline water discharge from the shallow submarine springs.

Hydrochemical Principles

Several approaches that use chemical and environmental isotope determinations jointly with the hydrodynamic study of a coastal aquifer may help in finding reasonable answers to the question of the sea water intrusion problems taken place in most of the Mediterraenean Countries. Saline water has a chemical composition that varies in a narrow band for open oceans and major seas. Whereas, freshwater has much less salinity (total dissolved solid TDS) oftenly in the range 0-1 to 2-0 g/l. Water in the range 2 to 5 g/l TDS are generally called brackish and up to the salinity range of 30-60 g/l are called saline of saltwater; and above this limit brines. When salts in freshwater are of marina origin some chemical ratios are close to that of sea water. The marine airborne salt reach farther into the continent or island, showing an exponentially decreasing concentration. Rain-water leaches these salts from the atmosphere jointly with other soluble matter. It is concentrated after-wards by evaporation in the soil, especially under more arid climate conditions.

In low turnover time aquifer under oxidizing conditions further chemical changes are generally small. Major changes can be produced if the redox potential is reduced. Remnant soluble salts are incorporated due to the ion exchange against the sorbed cation complex derived from the equilibrium with groundwater of a different chemical composition. Therefore, it is very important to monitor the chloride contents, salinity and electrical conductivity (EC) of the saline water and its background contents in the coastal aquifer against depth. The consideration of other ions may help in
understanding the origin of Cl$^-$ content increase. The clearest indication that sea water intrusion may be occurring is the increase of the Cl$^-$ content. Although other phenomena may lead to a Cl$^-$ increase as well, this has to be established against the Cl$^-$ background, which generally reflects recharge salinity of the karstic springs in the inland side.

If P is precipitation and R recharge, when surface runoff is a small fraction of P, chlorid content of local recharge water is: $Cl_R = Cl_P (P/R)$, in which Cl$^-$ is the chlorid concentration of precipitation, including the contribution of airborne salts. Sometimes, a chloride increase can be also due to soil salinity leaching, return irrigation, flows, saline waters aquitards. Salinity changes due to mixing of fresh-water with saline water or to leaching of marine sediments are accompanied by clear cation exchange, but these also may be produced by other saline waters as well. For example, if the Cl$^-$ increases above the background value in the coastal aquifer, the Na$^+$/Cl$^-$ ratio will decrease, and the aquifer is subjected to increase salinity due to saline water intrusion.

Moreover, in the case that the ratio $(Mg^{2+} - Ca^{2+})/Cl^-$ or $Ca^{2+}/Cl^-$ are more indicative. When Cl$^-$ increases due to saline water encroachment, the ratio also will increase. If this ratio decreases, marine sediments are being leached. So, the ratio of the saline water can be checked against the volume of brackish water that discharges from the shallow submarine springs. Thus, it is important to recall that the long turnover time of the aquifer means long processes of the past situation in the form of the chemical and environmental isotopic contents even after large head changes occurred during groundwater exploitation. The dispersion rate of freshwater through sea water based on its density. Since the velocity of shallow submarine discharges is also related to density differences between fresh and salt waters. In the freshwater-saline water mixing zone, degree of mixing in coastal aquifer can be obtained through the chloride balance;

$$X_f = \frac{Cl_{S} - Cl_{m}}{Cl_{m,s} - Cl_{f}}$$

Where;

$X_f$ : Freshwater fraction, (1-X is salt-water fraction)
$Cl_{m,s}$ : Chloride concentration in mixed and saline waters.
$Cl_f$ : Chloride concentration in fresh groundwater (background concentration)

The same expression can be used for total dissolved solid TDS and EC, since the chloride is the dominant anion. This relationship had been used for the Ovacik submarine springs and the freshwater springs in the inland side. Series of hydrochemical measurements were carried out in the field and in the laboratory in order to find out the most accurate result from the performed salinity curve.

**Case Study: Ovacık Submarine Springs Along The Mediterranean Coast Of Turkey**

Although most of the touristic provinces on the southern Mediterranean coast of Turkey have great demand for domestic water, great groundwater discharges along the coastline. Ovacık is one of these beautiful touristic provinces on the southern Mediterranean coast of Turkey. Facilities in terms of transport, climate, topography, agriculture and other economic activities, has caused some problems due to the lack of reliable surface waters. Therefore, the main source for covering the water demand in this karstik region is the groundwater resources. Thus, the main purpose of this
research is focused on determining the volume water that this charges from the ovacik submarine springs towards the mediterranean coast of Turkey (Fig. 1).

Relevant hydrogeologic studies were carried out to find out the discharge volume from the hydrologic water budget of this karstic region. In order to find out the ratio of the freshwater per a unit volume of saline water discharging from these submarine springs, insitu measurements of the Cl contents and electrical conductivity (EC) were carried out at these karstic outlet points. The measurements were also carried out in several sections against the depth.

Moreover, hydrochemical experiments were carried out by mixing freshwater with saline water of different concentrations, in order to prove these objectives. The percentage of the fresh water in a certain volume of saline water can be determined from the formula which is used in used in the same conditions of the sea water intrusion problems. Thus the chemical composition of the freshwater and the saline water that discharge from the Ovacik submarine springs, have the main role in achieving this objective. Dyes were also used in order to find out the travel time of discharging a certain volume of brackish water from the outlet points of these karstic submarine springs to the surface of the Sea.

**Hydrogeological Settings**

Detailed hydrogeological investigations were carried out for evaluating different geological and structural features that affect and control the main ground water resources in such a karstic region. These studies were also related to the estimation of the hydraulic connections between the water resources in the upstream area and the coastal and submarine springs that extend along the Ovacik coastline, south Turkey (Elhatip, 1992). Most of the widespread and highly karstified carbonate outcrops in
Ovacık are belong to the Ada-Mountain. The youngest lithological units that are mainly composed of mixtures of silt, sand and gravel are cemented by porous calcareous mud, covering the whole Ovacık plain (Fig. 2).

Comparison of the field observations and the analyzed lineament map of the study area, shows that most of the intersection images are located along the eastern boundary of Ovacık plain (Elhatip, 1996). These lineaments might be the reflection or response of the NE thrust fault which crossed most of the lithological units and caused a developed fracture system (faults) in the underlying beds extending towards the sea. It is also found that there are mainly three fractures at depth range between 1.5-3m below the sea level, extending in the N75E direction. Moreover, the availability of different karstic features (sinkholes, springs) along these faultlines may reflect the main direction of the groundwater flow throughout the inland porous units (Fig. 3).

![Figure 2. Hydrogeological map of the study area](image1)

![Figure 3. lineament map of the study area](image2)

However the depth of these fault zones can not be recognized from the landsat sensors. They provide significant submarine discharges of turbid mixed water under hydrostatic pressure that causes the upward movement of the groundwater towards the surface of the sea (Fig. 4).
The hydrologic budget which was calculated for the average of ten years (1980-1990), shows that the recharge of the Ovacik basin by the Ada-Mountains (Paleozoic-Mesozoic limestone units) which cover surface area of 58 km², is about 16,3×10⁶ m³/year (Elhatip, 1988). Whereas, the recharge of the alluvium units (17 km²) is about 3,6x10⁶ m³/year. An accepted percentage of infiltration of a maximum value of 25% of the calculated surface runoff may recharge the ground-water basin with a total volume of 4,6×10⁶ m³/year within a surface area of 88 km². A total discharge of 1,2×10⁶ m³/year may occur due to the evapotranspiration and artificial pumping and from the aquifer. Then, the hydrogeological water budget of the Ovacik basin showed that the calculated average discharge of the Ovacik coastal and submarine springs is about 23,3×10⁶ m³/year (0.740 m³/s). This amount of water is discharged from mainly three submarine outlet points (Sp.1, Sp.2, and Sp.3) nearby Ovacik coastline. The discharge amount may change during the wet period up to about 1 m³/s. This of course is not only related to the amount of water recharging the coastal aquifer, but also it depends on various factors; such as the physical and chemical properties of the aquifer and the sea water intrusion.

Field Measurements:

The field measurements showed that the Ovacik submarine springs discharge from three main outlet points (Sp.1, Sp.2, and Sp.3) at different depths of about 1.5, 1.8 and 2 m below the mean sea level, respectively. Meanwhile, these outlet points discharge from cut cone-shaped outlets with circles of diameters 0.30, 0.16 and 0.1m (at the Sea floor) and 1.2, 1.4 and 1.7m (at the sea level), respectively. The EC measurements were carried out against depth, each 0.5m at these points. Where ECm values of the brackish water change from 5,000 (at the outlet point) to 30,000 µS/cm (at the sea level). The mean ECf of the karst springs, which are located in the upstream area, have maximum value of 500 µS/cm. The field measurements were carried out periodically, especially at the major submarine outlet point (Sp.1), close to the Ovacik coastline (Fig. 5).
Since the volume of this cutted-cone is; \[ V = \frac{\pi}{3}h (r_1^2 + r_2^2 + r_1r_2) \]

Where (at Sp.1, Sp2, and Sp.3),
- \( r_1 \): The radius of circles at the sea level (0.60m, 0.70m and 0.85m);
- \( r_2 \): The radius of circles at the sea floor (0.15m, 0.08m, and 0.05m); and
- \( h \): The height between two circles (1.5m, 1.8m and 2m), respectively.

Then, the calculated total volumes of the cutted cone-shaped outlets at these points, are approximately 0.74, 0.87 and 1.60m³. This volume is equal to total volume of brackish water, which is discharged from the major outlet point. Thus, during the field studies, tracers were injected into this outlet point in order to determine the exact time for discharging such a volume of mixed (brackish) water. This time \( t_x \) is equal to the time of the upward movement from the outlet points to the sea level. This tests were repeated more than 6 times to find out the most accurate \( t_x \) values at Sp.1, Sp2, and Sp.3 outlet points. The average time \( t_x \) from these outlet points to the sea level is 1.5, 2.0, 3.5 seconds, respectively.

**Laboratory Tests:**

The laboratory tests were carried out to determine the percentage of fresh water of \( \text{EC}_f = 500 \) µS/cm within mixed (saline) waters of different salinities range between 1.000-50.000 µS/cm. For applying these tests, two main water volumes \( (V_f \text{ and } V_s) \) were prepared with different Electrical Conductivity values representing the fresh water \( (\text{EC}_f) \) and sea water \( (\text{EC}_s) \).

The \( \text{EC}_m \) of the mixed solution in different volume percents (10%-90% fresh-water added to 90%-10% saline water) was measured. Then, the degree of mixing (mixing ratio) the fresh water \( (X_f) \) in the sea water, is determined as;

\[ X_f \% = \frac{\text{EC}_s - \text{EC}_m}{\text{EC}_s - \text{EC}_f} \times 100. \]

The \( \text{EC}_s \) value of the Mediterranean sea around the outlet points of the Ovacık submarine springs may reach to 45.000-50.000 µS/cm. Note that, the mixed water of submarine springs has \( \text{EC}_m \) value range between 5.000 to 30.000 µS/cm.

**Estimation of discharges of Ovacık Submarine Springs**
The calculated volumes of the cutted cone-shaped outlets at the points Sp.1, Sp2, and Sp.3, are approximately 0.74, 0.87 and 1.60 m³, respectively. Whereas, the average time \( (t_x) \) from these outlet points to the sea level is 1.5, 2.0, 3.5 seconds, respectively. Since the ratio of fresh water at Sp.1, which has EC\(_f\) value of 500 µS/cm within mixed water of average EC\(_m\) of 17.500 µS/cm is about:

\[
\frac{50.000 - 17.500}{50.000 - 500} \times 100 = 65.7 \%
\]

This value represents the percentage of the fresh water, that is mixed within a certain volume of saline water at Sp.1. Both field and laboratory measurements showed that the major submarine spring (Sp.1) discharges brachish water from cutted cone-shaped with total volume of 0.74 m³, with fresh-water percentage of 65.7 %. Then, the total volume of the freshwater \( V_f \) at this outlet point is:

\[
V_f = 0.74 \times 0.657 = 0.49 \text{ m}^3
\]

Since the discharge time \( (t_x) \), at this point is 1.5 sec. Then, the fresh-water discharges \( Q_f \) from this submarine spring (Sp.1) is;

\[
Q_f = \frac{V_f}{t_x} = \frac{0.49}{1.5} = 0.327 \text{ m}^3/\text{s}
\]

This amount of water represents about 44% of the total submarine discharges, that were calculated from the hydrogeological budget of the Ovacık basin \( (23.3 \times 10^6 \text{ m}^3/\text{year} \text{ or } 0.740 \text{ m}^3/\text{s}) \). Notes that, the laboratory and field measurements were carried out considering the tidal effects and the changes in the discharge amounts during the dry and wet periods.

By using the same method, the percentage of the fresh water, within a certain volume of saline water at Sp.2 and Sp.3 is calculated as 55.0% and 40.0%, respectively. The calculated discharges at Sp.2 is 0.240 m³/s, whereas it is 0.183 m³/s at Sp.3. Then, the total discharge of the Ovacık submarine springs is calculated as 0.750 m³/s.

**CONCLUSIONS**

The amount of fresh water that discharges through-out shallow submarine springs can be calculated from the hydrochemical investigations. This amount is bigger than the other determinant from the hydrogeological budget. This may be related to the small percentage of infiltration that were considered as the recharge ratios of different high fractured limestone units covering such coastal karstic region.

Therefore, this hydrochemical method gives more accurate results of the freshwater discharging from the Ovacık submarine springs. However, this type of hydrochemical measurement depends on maney internal and external factors including the density equilibrium between the fresh and saline waters and other physical and structural properties of the coastal water bearing formations in such karstic area.

**REFERENCES**
