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# Quantity and quality of groundwater of intermountain basin of Korça in Albania and implication for sustainable management

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*Korça intermountain basin is the largest of its kind in Albania and from the hydrogeological point of view represents a semi-closed intermountain basin developed in Pliocene-Holocene granular unconsolidated deposits, which maximal thickness is about 300 m. The aquifer consists of intergranular gravelly to sandy layers containing artesian groundwater and the drilling wells are free flowing on most of the basin surface. The main recharge of the intergranular aquifer comes mainly from the rivers and torrents flowing from mountain gorges around the Korça Plain. The natural groundwater drainage of Korça basin is realized through the vertical leakage in the area of the former Maliq marsh. Hydrochemistry of the aquifers show the presence of four main hydrochemical facies which are related mainly to the hydrochemistry of the recharge sources and to the solution processes and ion exchange. In the central part of the basin the water supply wells of the cities Korça and Maliq are located. The natural renewable groundwater resources of the basin are relatively restricted, but the volume resources (or static water resources) are abundant (about 1.1 × 10–9 m*$^3$*). The perspective of their exploitation is very important, but respecting the "basin yield" concept that is defined as the maximum rate of withdrawal that can be sustained by the hydrogeological system of groundwater basin without causing unacceptable changes to any other environmental component of the basin. To face the problems related to the intensification of the groundwater pumping systematic observations of the hydraulic reaction of the basin and of the possible groundwater quality deterioration and other negative environmental impacts must be organized. The purpose of the present study is for the first time to analyze the abundant basin wide hydrogeological data and to evaluate: (1) geometry and hydraulic parameters of the aquifers: (2) groundwater hydrodynamic conditions; (3) their chemical composition and (4) the natural groundwater resources and the possibility to intensify the groundwater pumping in close relation to the environmental impact.*

***Keywords:*** *groundwater; groundwater quality; groundwater management; Korça intermountain basin; Albania.*

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## Introduction

Groundwater is a vital resource for Albania; it covers about 90% of the total drinking and industrial water consumption of the country. According the calculations, the total exploitable groundwater water-supply resources of Albania are calculated at about $4.4 \times 10^9$ m$^3$/year (Eftimi, 2010), the carbonate aquifer is the most important and in the second place comes the Pliocene-Holocene intergranular aquifer. More of 85% of the distribution surface of intergranular aquifers of Albania outcrop in the western Adriatic Lowland and the remaining smaller portion is developed along the river valleys crossing the country, as well as in the inner intermountain basins. The biggest and most important intermountain basin of Albania, that of Korça is situated in south-eastern periphery of the country (Fig. 1, 2).

Groundwater is more desirable than surface water because of some higher quality indicators which make it much more convenient than the surface water (Davis, De Wiest, 1970) and due to its lower cost. The groundwater, also is more resilient to degradation than surface water, but if degraded, effects can last for decades or centuries (Dochartaigh et al., 2015). Korça City with the population of nearly 80,000 inhabitants is one of the biggest cities of Al-

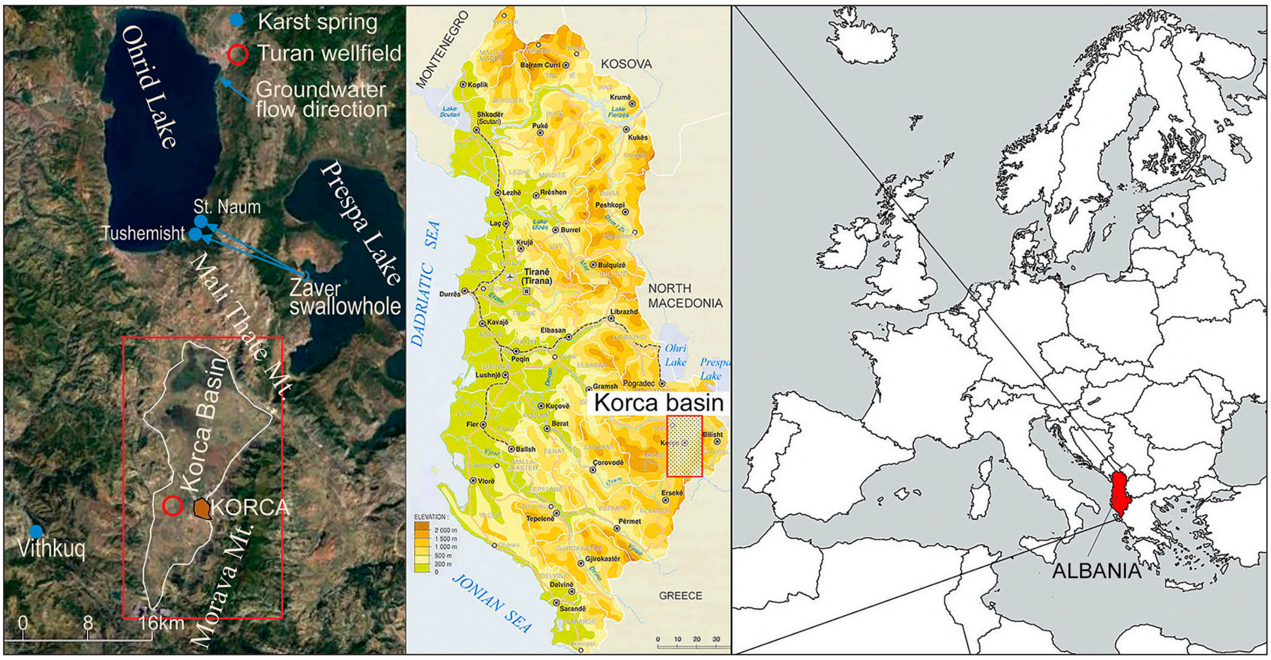

**Fig. 1.** Location of Korça intermountain basin

**Fig. 2.** Korça intermountain basin as seen from the North (Zvezda pass) to the South

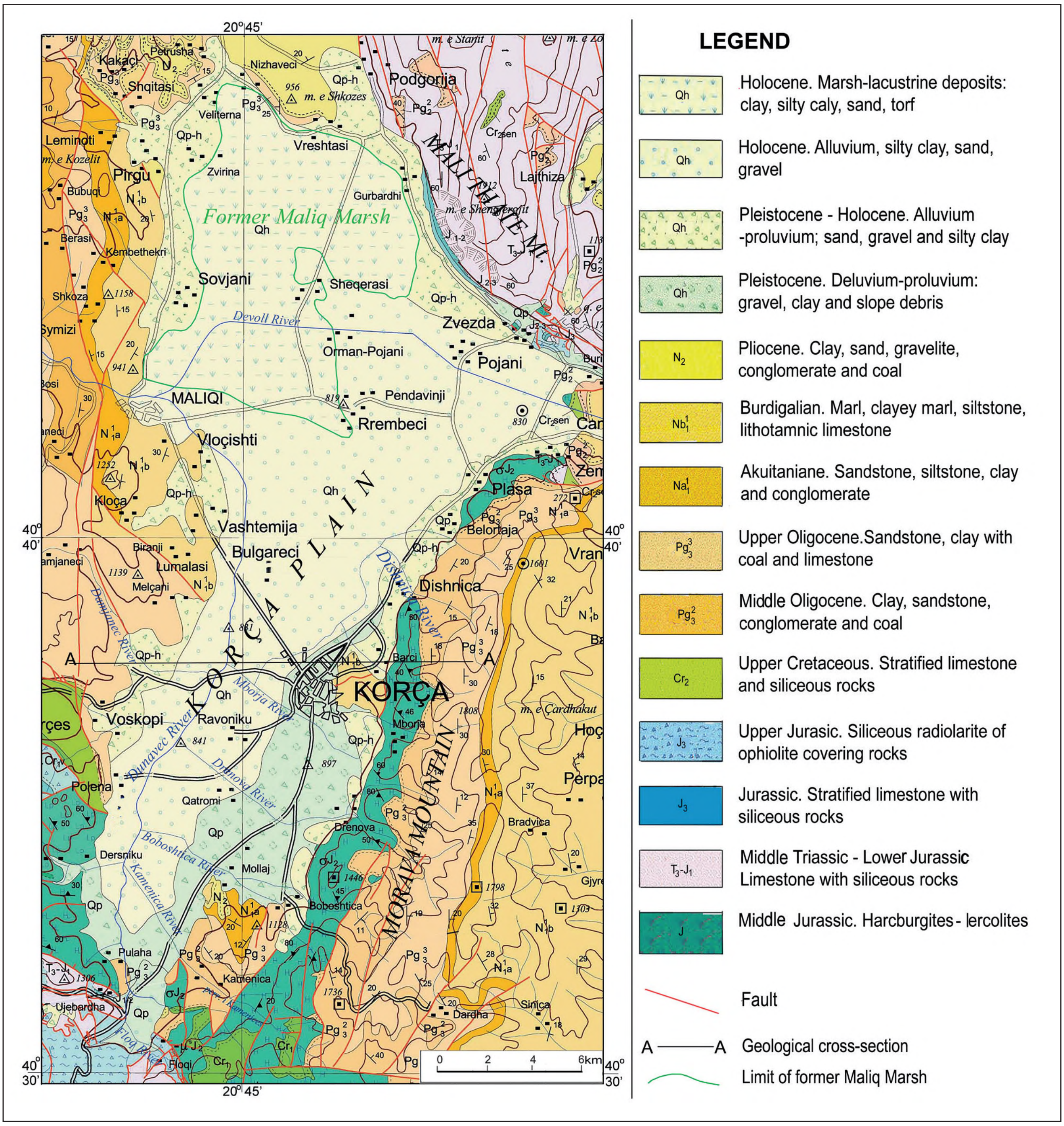

**Fig. 3.** Geological map of Korça intermountain basin (after Geological Map of Albania, sc. 1:200.000) (Xhomo et al., 2002)

bania. The importance of Korça is related also to the development of the industry, as well as to the tourism, while Korça plain is one of the areas with most intensive development of agriculture in the country.

The first drinking water supply system of Korça City, capacity about 30 l/s built in 1935 diverted by gravity to the city from a distance of about 20 km the water of Vithkuq karst spring (see Fig. 1). During the period from 1966 to 2005 some drilled water wells tapping the intergranular aquifer, located in Turan wellfield (see Fig. 1), about 3.5 km west to the city and total capacities about 200 l/s, are used for the city water supply. In 2005, based on a detailed hydrogeological project (Eftimi, 2002), the water supply system of Korça was reconstructed and the capacity increased to 400 l/s.

Hydrogeologic investigations in this basin begun since 1959 and continue with secession till today. The investigations have been focused on drilling wells for population and industrial water supply of

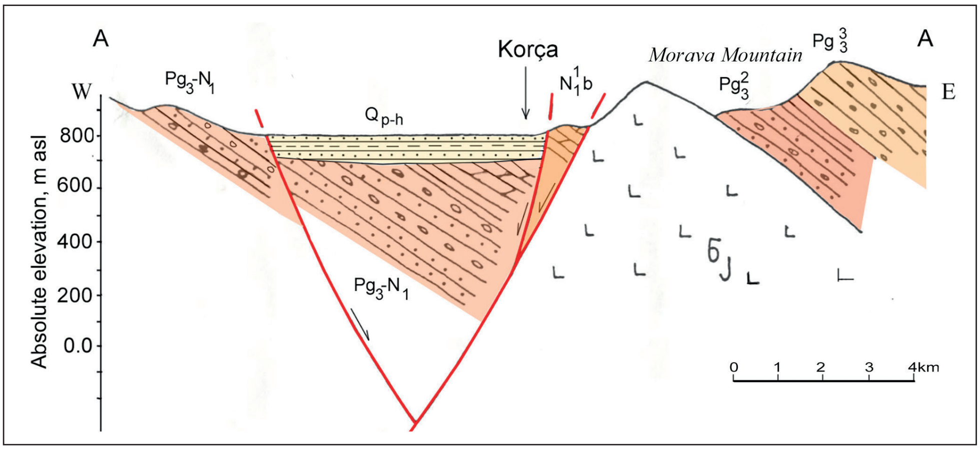

**Fig. 4.** Hypothetic cross-section through Korça intermountain basin after (Aliaj, 2012)

Korça, as well as of the numerous villages located in Korça plain. Though, numerous hydrogeological works carried out at Korça basin have been documented in a large number of technical reports, but no generalization studies have been carried out for the entire territory of the basin. The technical reports have documented the great quantitative and qualitative variety of hydrogeological data, but these very reach technical documents for the first time are generalized in this paper.

Korça basin is identified with the homonymous plain, the length of which in south-north direction is about 35 km long and maximal width is about 16 km (see Fig. 1, 2), while the total plain surface is about 300 km$^2$ (Qirjazi, 2019). Korça plain gently slopes to the north; In the southernmost edge the absolute elevation is about 880-860 m above sea level (asl), in the central part it is about 835–825 m asl, while in the northernmost edge, in the area of the former Maliq Marsh, the elevation of the plain is about 815 m asl. The elevation of the mountain slopes surrounding Korça plain varies about 900–1000 m asl. The plain at all directions is bordered by hills and mountains with altitudes up to about 2000 m asl.

Based on sufficient meteorological information the climate of the area is Mediterranean mountainous (Jaho et al., 1975), characterized by dry and fresh summers and wet and cold winters. The average annual temperature is about 10.7°C, but during the summer the average temperature is about 19 to 20°C and in winter about 4 to 5°C. Average rainfall is about 720 mm/year of which about 70% falls in the winter season, minimum yearly precipitations is about 600 mm and maximum is about 1100 mm.

There are two main rivers crossing the Korça basin, Dunavec and Devoll (Fig. 3, 5). Dunavec River crosses the basin in south-north direction for about 15 km, and near the town of Maliq joins the river Devoll. It is fed by numerous high energy creeks flowing from the surrounding mountains to Korça basin. During the summer they often totally loose the water in alluvial fan deposits, but during the wet season their flows increases to some tenths of m$^3$/s. The river Devoll is the largest of the Korça basin and its yearly flow is about 6.72 m$^3$/s (Pano et al., 1984).

The goal of this research is the conceptualization of the hydrogeological functioning of the Korça intermountain basin, through collection, analyses and generalization of the hydrogeological data of the area. The first necessary step is to evaluate the quantity and quality status of the aquifers, and to assess the groundwater recharge, movement and drainage characteristics at the basin wide scale. This could help the plan of sound actions for groundwater operating (groundwater pumping intensification), protection and safety.

## Geological settings

The Korça basin is located in the southern part of the Burrel-Mokra-Kolonja inner Albanian depression structure in which several smaller graben structures filled with molasses deposits of Oligocene-Miocene to Pleistocene age (Fig. 3, 4), transgressively placed on different rocks; their total thickness is estimated about 3000–3500 m (Meco, Aliaj, 2000; Xhomo et al., 2002; Aliaj, 2012).

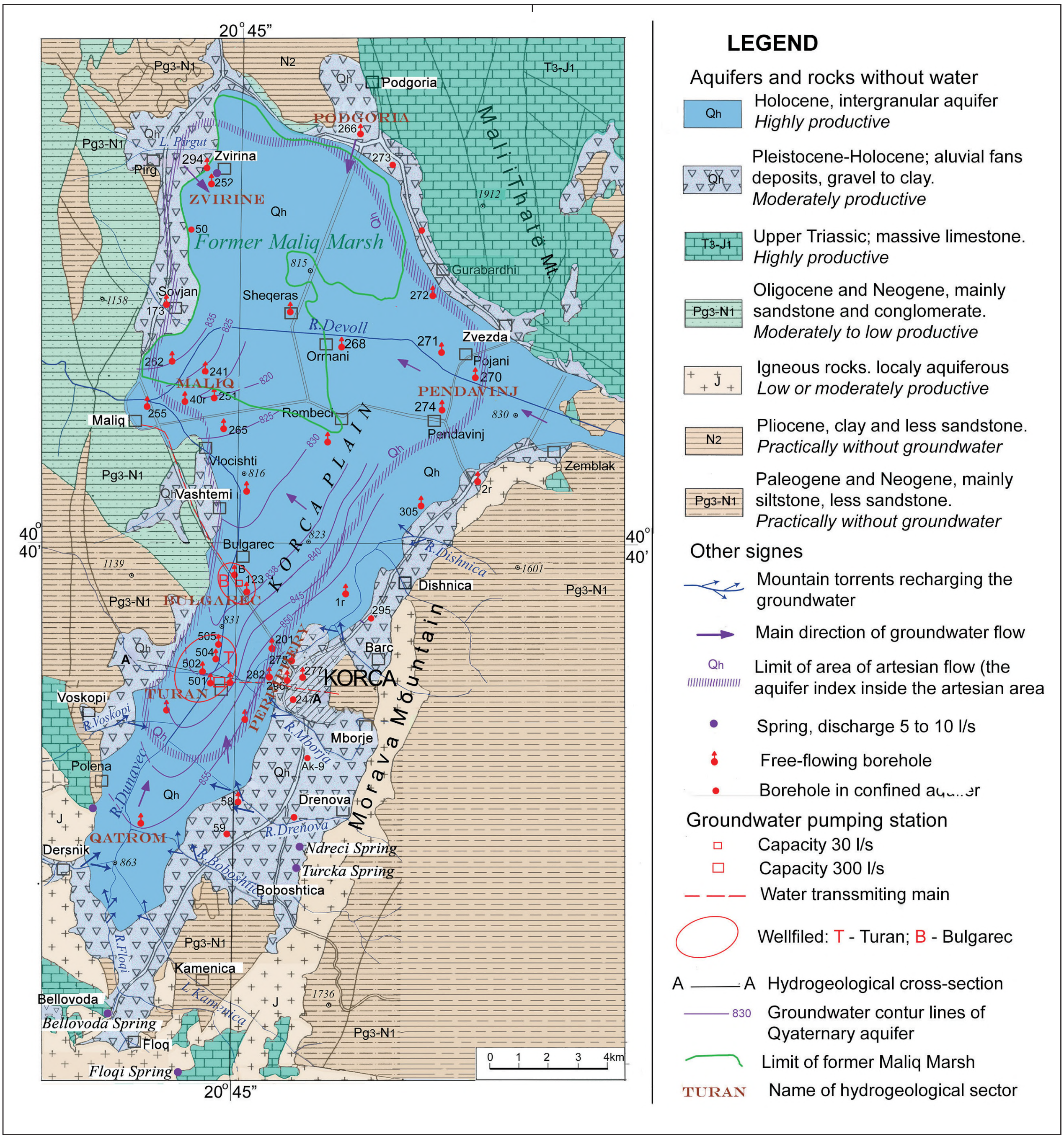

**Fig. 5.** Hydrogeological map of Korça basin (adopted from Hydrogeological Map of Albania, sc. 1:200.000) (Eftimi et al., 1985).

These structures, initially transformed into lakes, inherited various development history, some have returned to intermountain plains such as that of Korça, while some others continue to be lakes, such as Ohrid and Prespa (see Fig. 1). The fault tectonics is developed mostly in the bordering areas with Morava and Mali Thate Mountains respectively located in south-east and north of the basin. The north flank of Korça half graben (Xhomo et al., 2002; Aliaj, 2012), in the contact with the Mali Thate horst structure has a vertical displacement of over 2000 m, while the western branch of the structure deeps to the east with angles 20–30°. Korça basin continues to the south-east to Thessalian basin in Greek territory.

### Pre-Quaternary deposits

The basement of the Korça plain, as well as the hilly-mountain area surrounding it, consists of Pre-Quaternary formations, mainly magmatic and sedimentary, of Triassic-Jurassic to Pliocene age (see Fig. 3). Magmatic formations are of Jurassic and consist mainly of ultrabasic intrusive rocks such as harzburgites and serpentinite outcropping in Mount Morava and the southern periphery of the Korça basin. Among the sedimentary rocks, the oldest are the massive Triassic-Jurassic limestone consisting of the Mali Thate Mountain horst which separates the Korça basin from the basins of the lakes Ohrid and Prespa located north to this horst (see Fig. 1). Some other stratified limestone formations of limited surface outcrop in the southern edge of the study area, near to the villages Kamenica and Belovoda. Most of the hilly-mountain area surrounding the Korça basin from the west consists mainly of Paleogene and Neogene molasses such as differently intercalated of sandstone, clay, siltstone and conglomerate. At the northern edge of the Basin Pliocene deposits such as sandstone, gravel, clay and coal outcrop.

### Quaternary deposits

Korça basin is filled with Holocene mainly fluvial-lacustrine and fluvial-fan deposits consisting of alternating and discontinuous layers of gravel, sand, silty clay and clay, which are placed on older Pre-Quaternary deposits (see Fig. 3, 4). In the southern and in the central part of the basin, the maximal thickness of these deposits is about 300 m, and seems increases to about 500 m in the northern direction. They consist of intergranular unconsolidated rocks like gravel to sandy clay and clay rocks with numerous facial changes in both horizontal and vertical direction. It is worth to mention that the intergranular deposits have a very well-expressed facial changes in northward direction; the gravely deposits predominating in the southern half of the basin, gradually change to small and fine-grained gravel deposits with high mean grain sand to fine sand contents. At the periphery of the basin the fan and alluvial fan deposits are largely deposited by the numerous high-energy rivers and creeks debouching into the plain. The largest development of the alluvial fan deposits is observed in the eastern and southern periphery of city of Korça, particularly near the villages of Floq and Bellovoda where their thickness varies at about 120 m to more than 150 m (see Fig. 5). In the northern part of the basin, near Podgoria, the thickness of the alluvial fan deposits varies about 60–100 m (Sara, 1986). At the foots of Mali Thate Mountain, the slope debris are developed strip-like about 100–400 m wide (see Fig. 3). Often these deposits consist of big grain gravel deposits with high clay content sensibly diminishing their permeability.

## Hydrogeological system

The Pre-Quaternary and Quaternary formations of the Korça basin have great lithological variety, which is reflected in the variety of their hydrogeological characteristics (see Fig. 5). The intensively

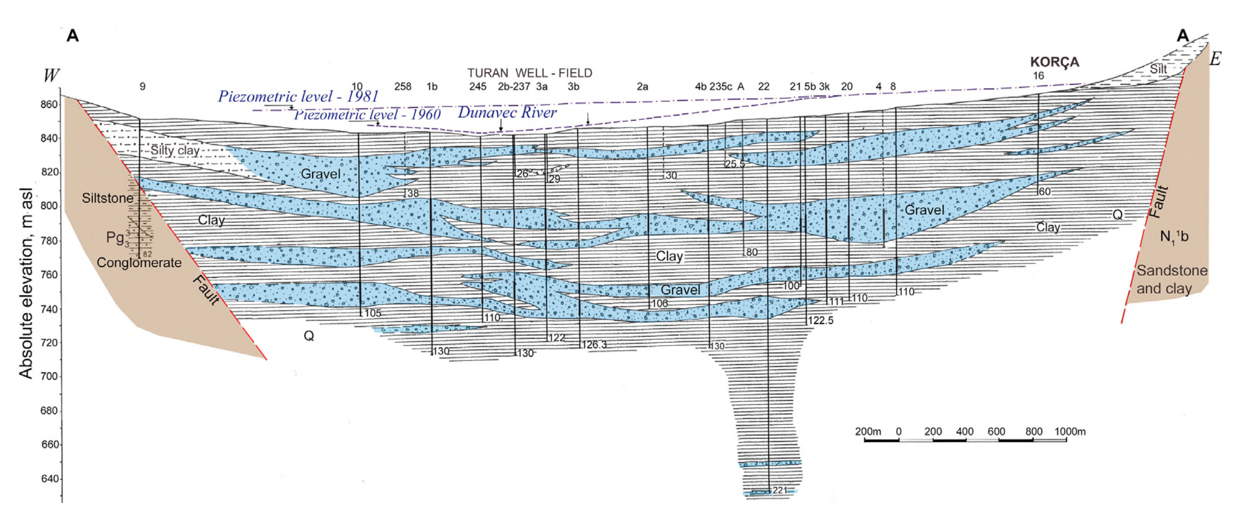

**Fig. 6.** Hydrogeological cross-section in Turan well field of Korça basin

karstified limestone rocks consisting Mali Thate Mountain, contain large groundwater resources mainly recharging the big karst springs of St. Naum and Tushemisht (see Fig. 1) issuing on Lake Ohrid shore (Eftimi, Zoto, 1997; Eftimi, Stevanović, Stoev, 2021). The limestone formations of the southern periphery of the basin, due to their relatively small outcropping surface contain limited groundwater resources; the discharge of the largest springs varies about 10 to 30 l/s. The Oligocene-Neogene and Pliocene molasses consisting most the hilly area surrounding the Korça basin, contain generally small groundwater resources. The magmatic rocks of Mount Morava are locally aquiferous with low to medium groundwater resources; the discharge of the springs usually varies about 1 to 5 l/s. The Quaternary deposits represented mainly of gravel or gravel to sandy layers consist a multi-layered aquifer system (Fig. 5, 6).

The number of the aquifer layers is more or less subjective even at relatively small distances, and the distinguish of the aquifer layers represents more or less a compromise. Nevertheless, the first four and sometime also the fifth aquifer layer, which usually are tapped down to the depth 130–140 m bgs are considered most important regarding their groundwater resources. We must also emphasize the fact that in the peripheral parts of the basin the fluvial-lacustrine and fluvial-fan deposits are intercalated and form a common aquifer. The water system in the Korça basin, at most of the surface has an artesian character, the wells are free-flowing, and only in peripheral areas the groundwater is not pressurized.

The recharge of the aquifer system occurs mainly from the outlet areas of small mountain rivers seeping the water on the alluvial fan deposits. However, another relatively important recharge source is the direct infiltration of the precipitation directly on the outcrop area of the alluvial fan deposits. As the permeability of the alluvial fan deposits generally is relatively low, and because the small recharging rivers are temporary or have small flows, Korça basin as a hydrogeological unit is classified as a semi-closed intermountain artesian basin (Rusajev, 1960).

For the organization of this paper in the alluvial-lacustrine deposits of Korça plain there are distinguished five hydrogeological sectors namely: Turan, Bulgarec, Maliq, Zvirina and Pendavinj, and two sectors in alluvial fan deposits namely: Periphery (of Korça City) and Podgoria (see Fig. 5).

## Materials and methods

Numerous, but partial groundwater studies have been conducted in the Korça basin since the beginning in 1959. In his first report Rusajev (1960) emphasized the presence of 4 to 5 most important artesian gravelly aquifers down to a depth about 140–150 m and determined that the central area of the basin consisting of Turan and Bulgarec sectors (see Fig. 3) have best hydrogeological parameters. Initially the free flow of the single water wells in the Turan sector was up to about 20 l/s, but after some time it was sensibly reduced by the depletion of elastic reserves of artesian waters (Kudelin, 1960), as well as because of interference with the other wells (Ferris et al., 1962; Krusseman, de Rider, 1990). During 1961–1965 the water supply wells for city of Korça with a total capacity about 200 l/s were built in the Turan sector (Lako, 1965; Tyli, 1971, 1975) and beside this, dozens of wells were drilled for village water supply. The overall number of well documented water supply wells drilled in Korça plain is about 300. About 275 wells are realized with rotary-drilling method with mud solution circulation. The casing of rotary-drilling wells is realized with pipes and filters which diameters varying about 89–146 mm and their depths varying from 50 to 300 m, but the mean depth was about 140–150 m. The cable-tool percussion drilling method was used for the construction of about 25 wells located mainly in the central part of the plain, in Turan sector and in the periphery of the

**Fig. 7.** The artesian well No. 292 (Sara, 1984) in Maliq hydrogeological sector free- flowing 2 l/s from the Quaternary intergranular aquifers (photo 2002)

*Table 1.* **Summarized average values of hydraulic parameters of the alluvial-lacustrine intergranular aquifers of Korça plain. H – Depth of well, M – aquifer thickness, gs – ground surface, q – specific discharge, T – transmissibility, K – hydraulic conductivity**

| Sector and year of study | No. of wells | Drilling method | H m | Aquifer layer | M m | M/H % | GW level ±gs | q l/s/m | T m$^2$/d | K m/d |
|---|---|---|---|---|---|---|---|---|---|---|
| Qatrom, 1960 | 3 | Rotary | 80–134 | 1, 2, 3 ,4 | 34.8 | 28.0 | -5-+10 | 0.4 | 60 | 1–2 |
| Turan, 1960-1965 | 8 | Rotary | 80–136 | 2,3,4 | 26 | 24 | +6.0-+11.0 | 1.4 | 255 | 11 |
| Turan, 1984 | 2 | Cable tool | 83–146 | 2, 3, 4 | 16-34 | 22 | -1.3-+6.0 | 4.0-8.6 | 2000 | 60–120 |
| Turan, 1984 | 5 | Cable tool | 29–38 | 1 | 8.4 | 27 | -5.4--0.8 | 7.45 | 785 | 98 |
| Turan, 2001–2002 | 4 | Cable tool | 110–118 | 2, 3, 4 | 37 | 32.5 | +1.5 | 27.5 | 2900 | 94 |
| Bulgarec, 1962 | 10 | Rotary | 80–210 | 2, 3, 4, 5 | 46 | 37.7 | +2.5÷+4.9 | 2.9 | 322 | 26 |
| Maliq, 1981–2001 | 8 | Rotary | 82–256 | 2, 3, 4, 5 | 33.5 | 19.3 | +4.5-+15.9 | 1.7 | 246 | 6.5 |
| Zvirin-Pendavin, 1984 | 7 | Rotary | 80-251 | 2, 3, 4 | 24 | 13.6 | +1.0-+11.1 | 0.9 | 130 | 6.5 |

*Table 2.* **Summarized hydraulic parameters of the intergranular alluvial fan aquifers. H – Depth of well, M – aquifer thickness, gs – ground surface, q – specific discharge, T – transmissibility, K – hydraulic conductivity**

| Sector and yearof study | No. of wells | Drilling method | H m | M m | M/H % | GW level ±gs | Q l/s | q l/s/m | T m$^2$/d | K m/d |
|---|---|---|---|---|---|---|---|---|---|---|
| Korça periphery | 7 | Cable tool | 61–136 | 5–12 | 4–16 | -1.6-+3.45 | 3.0–7.4 | 0.4–1.15 | 50–196 | 9–21 |
|  | 5 | rotary | 85–181 | 11–44 | 12–36 | -1.1-+8.0 | 1.3–5.5 | 0.17–0.53 | 15–70 | 1.0–5.4 |
| Podgorie | 4 | rotary | 64–85 | 3–14 | 5–21 | +2.5-+13 | 4.2 | 0.1–0.7 | 35 | 3.6 |

city of Korça. The diameter of casing pipes and screen filters of these wells is about 200 to 400 mm and their maximal depth was about 115 to 130 m (Sara, 1984, 1985, 1986, 1990; Eftimi, 2002). Some wells drilled in Turan sector have been limited to the first aquifer layer, but most have tapped the second, third and fourth and rarely the fifth one.

Tables 1 and 2 show the summarized average values of hydraulic parameters of the drilled wells of the basin, and in Fig. 7 is shown a free-flowing artesian well located in Maliq sector. Furthermore, water samples were collected for chemical analyses, performed at the laboratory of Albanian Hydrogeological Service determined by ion chromatography, colorimetry and end-point titration (see Tables 1, 2). During the water sampling, on most of the case, electrical conductivity and temperature are measured. In all samples macrocomponents ($Na^+$+$K^+$, $Ca^{2+}$, $Mg^{2+}$, $Fe^{2+3}$, $Cl^-$, $SO^{2-}$, $HCO_4^-$, $NO_3^-$, $NO_2^-$, $NH_4^+$) and pH is measured and total mineralization, total dissolved solids (TDS) and total hardness are calculated.

The available geological (Xhomo et al., 2002) and hydrogeological maps (Eftimi et al., 1985), and a variety of other data, presented like reports realized mainly by F. Sara, N. Tyli, A. Lako and R. Eftimi have been collected and analyzed for this study.

## Hydrogeological characteristics

### Geometry of the aquifers and hydraulic parameters of wells and aquifers

Korça basin is filled with the alluvial-lacustrine deposits which have lateral and vertical transitions to the alluvial fill deposits in the periphery area, and are hydraulically interconnected with them. This is the reason that on hydrogeological point of view they could be treated as a single unit, namely alluvial deposits. Down to the depth about 250 m below ground surface (bgs), from five to eight gravel aquifer layers separated by the silty-clay layers are tapped, but the first four of them are most important (see Fig. 6). The thickness of the gravel layers varies from about 2 to 25 m and similar is also the thickness of the shale watertight layers separating them. The aquifer gravelly layers generally slope from S to N, as well as from E and W towards the center of the plain.

In Tables 1 and 2, the generalized data of both the geometry of the aquifer layers and their hydraulic parameters are given accordingly to the sectors. The sectors of Turan and Bulgarec have the best hydraulic parameters; the aquifer summarized thickness is about 37–46 m consisting about 32.5–37.7% of the investigated thickness of the Quaternary deposits. In the other sectors, the summarized thickness of the aquifer layers usually accounts for not more than 24% of the total thickness of drilled alluvial deposits down to the depth about 120 m. In the northernmost part of the Korça basin, in Zvirina and Pendavinj sectors the summarized thickness of gravel layers is significantly smaller, about 24 m consisting 13.6 % of the lithological section.

Based on the data of Tables 1 and 2 it seems that summarized values of aquifer hydraulic parameters calculated by the pumping data of cable tool percussion wells are on average over two to four times greater than those gained by the rotary drilling wells. This is mainly the consequence of the small casing diameters used in rotary drilled wells, as well as of the use for the drilling of the sealing the aquifers circulating mud. The hydraulic parameters of the wells and of the aquifer, gained by the pumping of cable tool percussion wells should be considered more realistic. There highest mean values are registered in Turan; the aquifer hydraulic conductivity is K = 100 m/d, the transmissivity T = 2000–2900 $m^2/d$, while the specific capacity of the wells vary about q = 4–27 l/s/m. Concerning the entire basin it should be noticed that values of the hydraulic parameters, both of wells and of aquifers, in the southernmost sector, that of Qatrom are lower. In the central sectors, that of Turan and Bulgarec, their highest values are registered, while in northern direction their values constantly diminish. As testified by the results of about 15 wells the lowest values of the hydraulic parameters have the aquifers of intergranular alluvial fan deposits (see Tables 1 and 2). A relatively low tritium concentration of less than 3 TU, measured during 1982–1985 in several artesian groundwater samples of the Basin, comparing to 24–50 TU measured in surface water of the area (Skende, Eftimi, 1996), reporting prior 1951 recharge of the aquifer (Fritz, Clark, 1977; Gat, Gonfiantini, 1981) could be commented also as an indication of the low permeability of the aquifer recharge area, consisting of alluvial fan deposits.

## Piezometry and groundwater level regime

The piezometric isolines for the Korça basin are shown in Fig. 5, which is adopted by the hydrogeological map of Albania (Eftimi et al., 1985). They belong to the summarized levels of the second, third and fourth aquifer layers together, based on the water level measurements performed in the water wells located mainly in the southern and central part of the plain. Although the shown map is of small-scale, it gives a general view of the piezometric conditions of the aquifer of Korça basin. As seen in Fig. 5, at most of the central and northern part of the basin the groundwater is artesian.

The main groundwater flow direction is south-north, while the elevation of the piezometric levels vary from 860–855 m asl in the southernmost part (Qatrom sector) to about 820 m asl in Maliq sector. The secondary groundwater flow direction, particularly active in southern and central part of the Korca plain, is that from the eastern and western peripheries towards the central axis of the plain. This fact emphases the main recharge of the gravelly aquifer coming from rivers and creeks flowing from mountain gorges around the Korça plain. Particularly active in this direction are the rivers flowing from Mount Morava such as Dishnica, Mborje, Drenova, Bobostica, Kamenica, etc (see Fig. 5).

Another important recharge source of the Korça basin is also the infiltration of atmospheric precipitation directly into outcrop areas of the alluvial fan deposits, which in the southern part of the plain consist about 25 $km^2$. Assuming that infiltration accounts for 20% of annual rainfall of 722 mm, the amount of infiltration constitutes about 92 l/s ($2.9 \times 10^6$ $m^3$/year). The hydraulic gradient along the main direction of groundwater movement from south to north on average is 0.0025–0.003.

The natural groundwater drainage of Korça basin is supposed to be realized in the area of the former Maliq Marsh (see Fig. 5) through the vertical leakage favored by the big groundwater pressure; in wide areas the groundwater artesian level is stabilized about 10 m ags. Actually, the artificial discharge through the pumping wells consisting about 400 l/s is the most important for the basin.

During 1973 the Hydrogeological Service built five sets of observation wells located mainly in the southern and central part of the basin where the groundwater was pumped for the water supply of the city of Korça and many surrounding villages. The observation wells were constructed to observe the groundwater level fluctuation in various aquifer layers; unfortunately, the observations were interrupted in 1991. The wells were equipped by screen filters at different depth according to the depth of the aquifer, assured the groundwater level measurements separately of five aquifer layers.

Based on the analysis of measured groundwater level the following conclusions could be made: the annual level fluctuation in the first aquifer layer is usually about 3 to 4.5 m, while for deeper layers (second to fifth) the annual level fluctuation resulted from 2 to 3.5 m. On the long-term interval, a general decrease of the piezometric level was recorded during the 1960-1991-time interval. The largest groundwater level decrease is recorded in the central part of the plain, in Turan and Bulgarec exploitable sectors. For the period of 1960-1991 the maximal groundwater level decrease of the second, third, fourth and fifth aquifer layers registered in Bulgarec sector vary about 5 m to 15 m. In Fig. 8 are shown the groundwater level fluctuation graphs registered in Bulgarec sector separately for different aquifer layers for the period of 1973–1991, which proves that the deepest layers have the largest groundwater level lowering which for the fifth layer is about 7.0, while compared with the level of 1961 it is about 12 m.

In Turan sector where the water supply wells of the city of Korça are located, the regional groundwater levels lowering compared to that of 1961 is about 14 m. The groundwater level lowering in long-term time interval are related to the intensive groundwater pumping which till now should not be considered as overexploitation.

## Groundwater resources

The concept of groundwater resources is already elaborated by numerous researchers (Todd, 1959; Maksimov et al., 1967; Davis, de Wiest 1970; Walton, 1970; Freeze, Cherry, 1979). The simplest, but in the same time more practical classification is the classification of the groundwater resources into natural and exploitable. Within the natural groundwater resources it could be distinguished two categories: volume resources (or static groundwater resources) and groundwater flow.

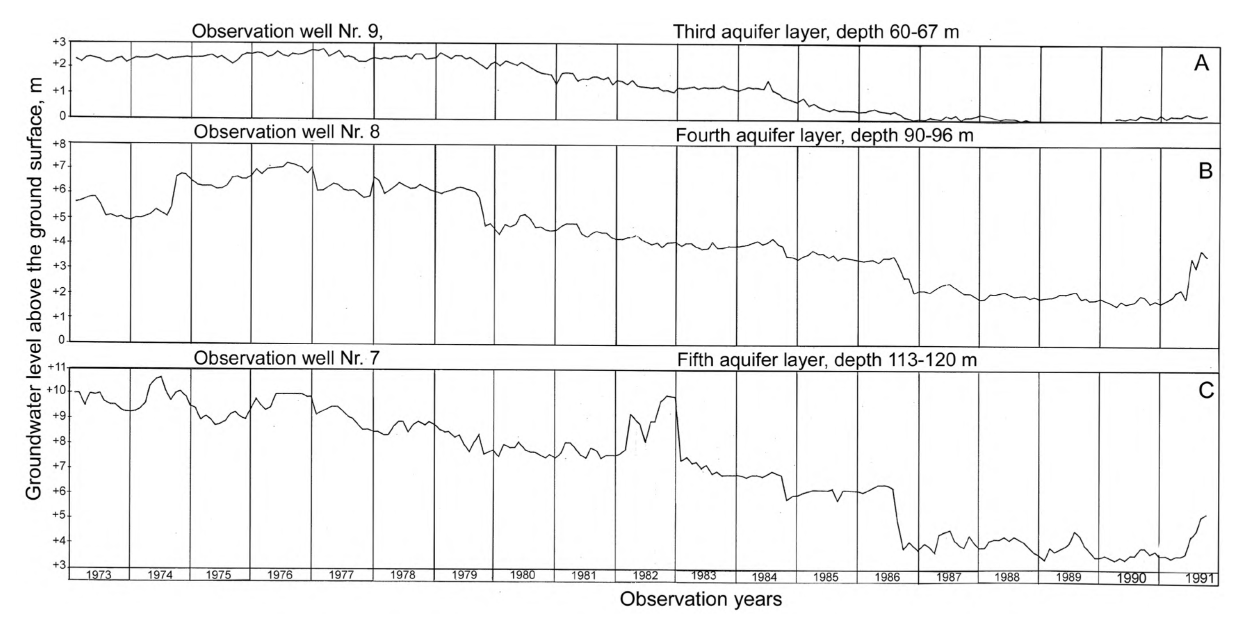

**Fig. 8.** The groundwater level observation in Bulgarec wellfield in the third (***a***), forth (***b***) and fifth (***c***) aquifer layers, for the period of 1973–1991

*Volume groundwater resources* is defined as the amount of water (volume of water) located at a certain moment in the considered aquifer, which is equal to:

$$Q_v = V \times p_e, \qquad (1)$$

where: V = groundwater saturation volume of the aquifer; $m^3$ and $p_a$ = aquifer effective porosity, fraction.

The volume resources of Korça basin are calculated separately for the southern and for the northern areas of the basin.

*The southern area of the basin* includes the Qatrom, Turan, Bulgarec and Korça suburbs sectors with the total area of about 80 $km^2$ (see Fig. 5). The groundwater quality of the southern area of the basin is generally good, it is drinkable and is used for the water supply of the cities of Korça and Maliq, as well as of many villages. Generally, the effective porosity $p_e$ is the volume of pores that is available for transport of water, divided by bulk volume. In intergranular gravelly layers the effective porosity consists about 60 to 70% of total aquifer porosity (Todd, 1959; Freez, Chery 1979) and in the study case is accepted 0.17. The average total thickness of the aquifer layers for the lithologic section 200 m thick is 40 m, and the groundwater resources result in Qv = 544 Ml $m^3$. The large resources support the idea about the possibility of sustainable management of groundwater resources even in case of the pumping intensification.

*The northern area of the basin* includes Maliq, Zvirina and Pendavinj sectors (see Fig. 5); here is totally included also the area of former Maliq Marsh. Using the following values; active porosity 0.17, mean aquifer thickness 30 m and the total surface 120 $km^2$, the total volume groundwater resources for the northern area of Korça basin Qv = 540 $Mm^3$, which practically are equal to the calculated volume resources of the southern area.

*Groundwater flow* is the water quantity flowing in a time interval through an aquifer section perpendicular to the flow direction and could be calculated based on Darcy law (Walton, 1970; Noner, 2003):

$$Q = T \times W \times I \times 365, \qquad (2)$$

where: T = mean transmissivity of the aquifer, $m^2$/day; W = the width of a section measured perpendicular to the groundwater flow direction, m; average hydraulic gradient of the groundwater according to the map of contour lines of groundwater table; 365 = days of a year.

For the first aquifer layer (T = 785 $m^2$/day; W = 4000 m; I = 0.003) Natural groundwater flow results: Q = 4.4 $Mm^3$/year (or 109 l/s).

For the second, third and fourth layers of water (T = 2600 $m^2$/day; W = 4000 m; I = 0.0025) the groundwater flow results Q = 9.49 $Mm^3$/year (or 301 l/s).

The overall groundwater natural flow in the southern area of the Korça basin is estimated at approximately 13.9 $Mm^3$/year or 410 l/s. As for the northern sector the map of contour lines of groundwater table is missing and the groundwater flow of this sector could not be calculated.

## Reconstruction of Turan wellfield

For the improvement of the water supply of Korça City during 1995-1996 a hydrogeological investigation was finalized with the design of high-capacity wells for increasing the groundwater pumping capacity of Turan wellfield. According to the hydrogeological investigations and observations it was established that in Turan sector could be pumped about 500 l/s without creating important negative impacts (Eftimi, 2002). Instead of 13 pumping wells with a total capacity of about 300 l/s used for Korça water supply, four big diameter gravel pack wells with a total capacity of 400 l/s were constructed, located in the central part of Turan wellfield. The first, shallower aquifer layer, easier minced by the surface pollution was excluded from the water supply system. The final casing of the wells is made of stainless pipes and screens with diameter 400 mm. The installed screen filters are of shutter type of slots 1.2 mm. The filter/thickness ratio of the aquifer layers is more than 80%. According to the design, the entrance velocity of water moving into screens was calculated 1.2 to 1.6 cm/s, representing half the recommended maximum speed of 3.0 cm/s (Driscoll, 1986; Kruseman, de Ridder, 1970; Walton, 1970). Based on the results of granulometric analyses of the gravel aquifer layers the diameter of the gravel pack was determined 2.5 to 3.0 mm.

For each well there was organized a step drawdown test at four or five different rates, the last stage with the capacity at least 120 l/s. The duration of pumping test was 24 to 30 hours, each step lasting 6 hours. Fig. 9 shows the observations during the step drawdown test and the groundwater recovery for well No. 501. The estimated efficiency (Bierchenk, 1964) of new wells vary from 71.6% to 91.8%.

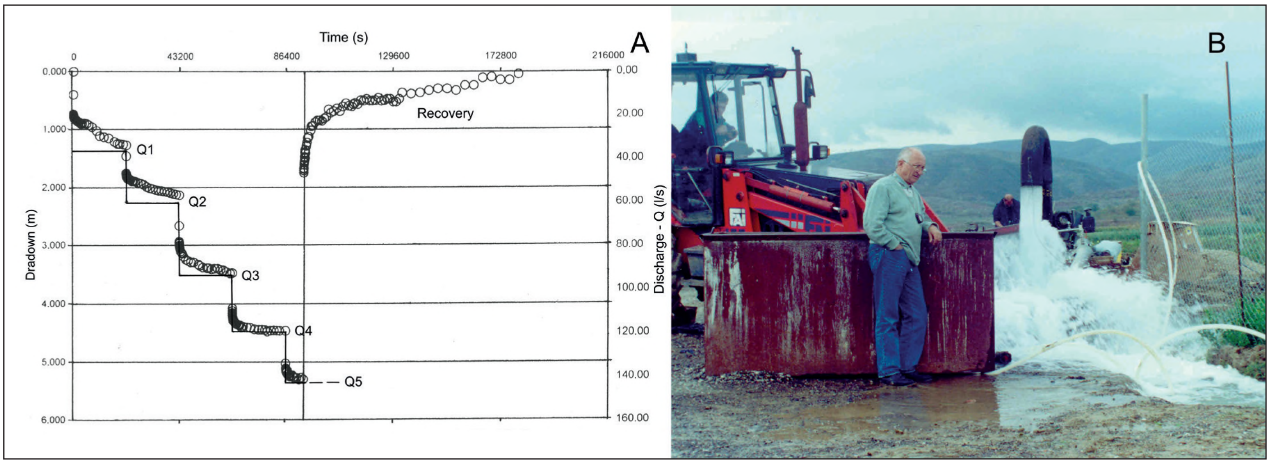

**Fig. 9.** Korça water supply wells of Korça: *A* – Graphic of step drawdown test and the recovering of the water level, well No. 501; *B* – The pumping of well No. 501 with discharge 142 l/s

The constructed wells of Turan wellfield are functioning normally during a period of about 15 years with single capacities of 100 l/s and with a total capacity of 400 l/s, but usually only three wells are simultaneously pumped with a total capacity of 300 l/s and one is left as a spare well.

The Turan wells are realized respecting the technical request for construction of high-capacity exploitable wells (Kruseman, de Ridder, 1970; Walton, 1970; Driscoll, 1986; Clark, 1988) summarized as follows: (a) Cable tool drilling technology; (b) big casing diameter of wells of 400 mm; (c) high screen length/aquifer thickness ratio of 80–83%; (d) thickness from 15 to 30 cm and well dimensioned gravel pack; (e) low groundwater flow entrance velocity in the filter calculated at about 1.2–1.6 cm/s. The main technical data of the new wells are given in Table 3, but their construction is analyzed in detail by Eftimi (2006).

## Groundwater quality

For the analysis processing was used AquaChem program, which enables the construction of the Piper diagram, and reciprocal relation of different hydrochemical components (Fig. 10, 11). For the study, the results of 84 chemical analyses of 49 wells and of two springs are used, and the results of 27 representative analyses are shown in Tables 4, 5, and 6.

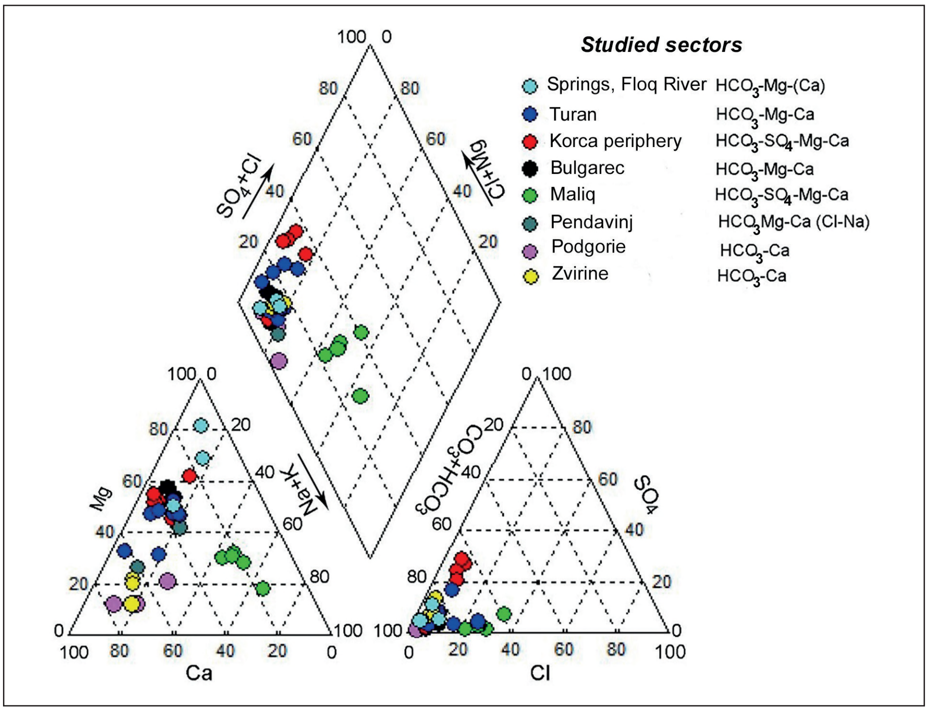

**Fig. 10.** Piper diagram for the hydrochemical data of Korça artesian basin

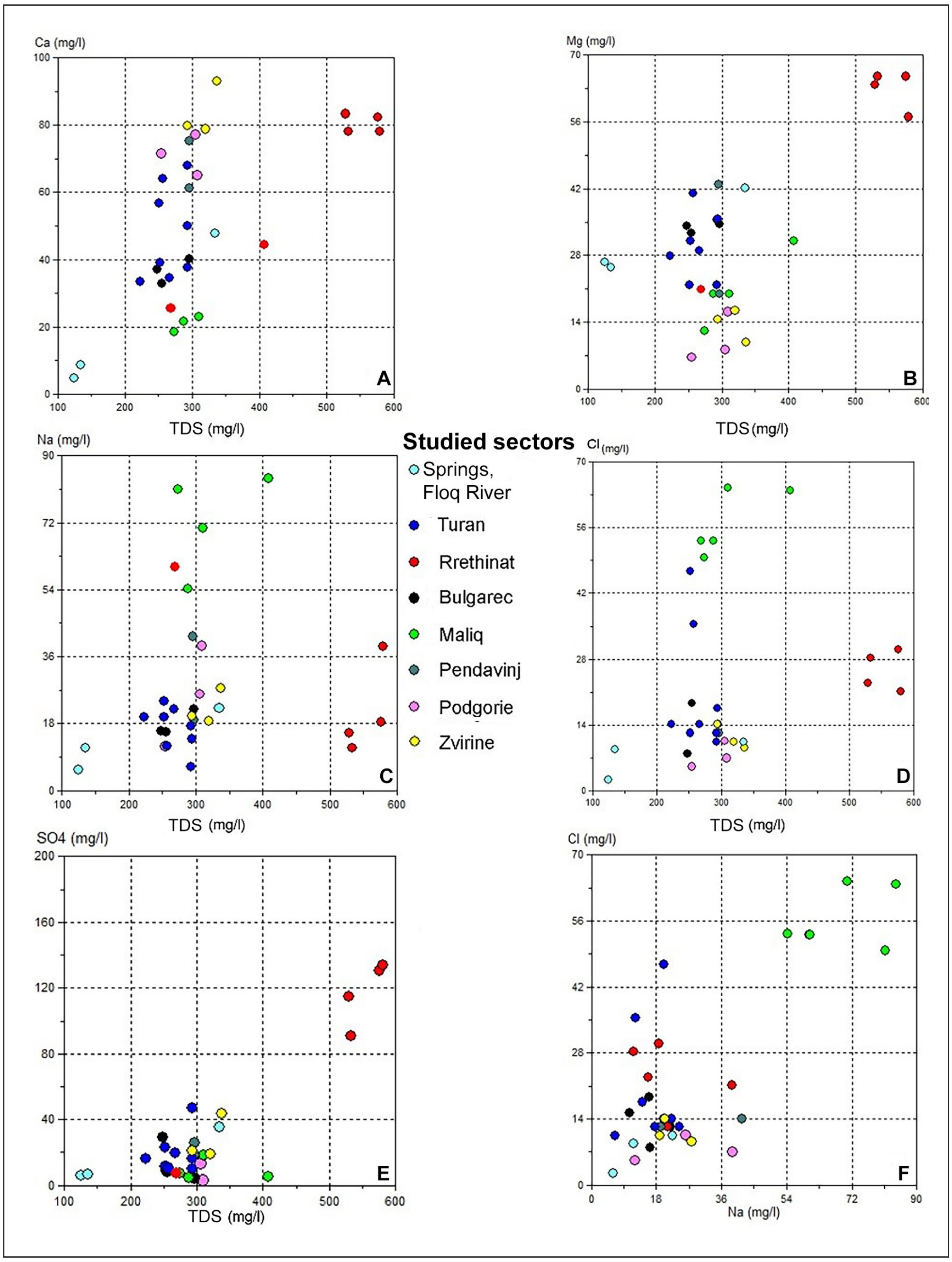

**Fig. 11.** Relation between different hydrochemical parameter: *A* – Ca vs TDS; *B* – Ca vs TDS; *C* – Na vs TDS; *D* – Cl vs TDS; *E* – $SO_4$ vs TDS; *F* – Cl vs Na

*Table 3.* **Main results of the Korça water supply wells located in Turan sector. H – well depth; M – aquifer thickness; L – filter length; θ – filter diameter; L – filter open area; V – entrance velocity; Q – pumping capacity; q – specific capacity; T – aquifer transmissibility; k – hydraulic conductivity. Calculated storage coefficient is 2 × $10^{-4}$**

| No. well | Year | Elevation m ags | H m | M m | M/H % | L m | l/M % | θ mm | F % | V cm/s | Q l/s | s m | q l/s/m | T $m^2$/d | k m/d |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 501 | 2001–2002 | 835.0 | 113.8 | 38.3 | 33.6 | 32.0 | 83.5 | 400 | 20 | 1.20 | 142.3 | 5.3 | 26.8 | 2850 | 74 |
| 502 | 2001–2002 | 835.0 | 109.7 | 29.1 | 26.5 | 24.5 | 82.6 | 400 | 20 | 1.60 | 169.3 | 6.3 | 27.0 | 2800 | 96 |
| 504 | 2001–2002 | 833.0 | 117.8 | 38.1 | 32.3 | 30.5 | 80.3 | 400 | 20 | 1.30 | 158.5 | 4.2 | 37.9 | 4000 | 105 |
| 505 | 2001–2002 | 832.12 | 115.8 | 41.9 | 33.5 | 33.5 | 80.0 | 400 | 20 | 1.20 | 135.3 | 7.4 | 18.2 | 2000 | 48 |

*Table 4.* **Hydrochemical composition of ground water of Turan sector (intergranular alluvial deposits) and of two springs and one river**

| Location | Wells | | | | | Spring | | River |
|---|---|---|---|---|---|---|---|---|
| No. well | 1B | 3A | 1v | 3v | 5v | Ndreçi | Turcka | Floq |
| Depth, m | 130.0 | 122.0 | 141.0 | 110.4 | 79.5 | | | |
| Date | 07.07.1995 | 07.07.1995 | 21.02.1989 | 21.02.1989 | 21.02.1989 | 13.05.1999 | 10.03.1988 | 21.02.1989 |
| T, °C | 12.9 | | 12.6 | 12.0 | 12.1 | 11.9 | 11.5 | 8.3 |
| pH | 7.3 | 7.2 | 8.1 | 8.1 | 8.1 | 8.25 | 8.6 | 8.3 |
| Cond. µS/cm | 502 | 488 | 438 | 415 | 515 | 407 | 238 | 546 |
| TDS, mg/l | 292 | 286 | 250 | 222 | 293 | 124 | 134 | 334 |
| TH[1], °G[2] | 14.5 | 13.9 | 12.3 | 11.1 | 12.2 | 6.8 | 7.1 | 16.4 |
| $Ca^{2+}$, mg/l | 68.1 | 64.1 | 40.3 | 33.4 | 50.1 | 4.7 | 8.8 | 47.8 |
| $Mg^{2+}$, mg/l | 21.9 | 41.1 | 29.2 | 28.0 | 35.8 | 26.6 | 25.6 | 42.2 |
| $Na^{+}$, mg/l | 6.4 | 12.2 | 17.7 | 19.8 | 14.0 | 5.8 | 11.5 | 22.3 |
| $Fe^{2+}$, mg/l | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.02 | gj | 0.2 |
| $HCO_3^{2-}$, mg/l | 256.0 | 256.0 | 252.5 | 246.4 | 266.0 | 148.8 | 139.1 | 351.4 |
| $SO_4^{2-}$, mg/l | 16.7 | 10.7 | 11.5 | 16.5 | 47.3 | 6.2 | 7.2 | 35.8 |
| $Cl^{-}$, mg/l | 10.6 | 35.5 | 21.3 | 14.2 | 17.7 | 2.5 | 8.9 | 10.6 |
| $NO_3^{2-}$, mg/l | 4.5 | 3.8 | 12.0 | 2.8 | 16.0 | 4.1 | 7.0 | 1.6 |
| Hydrochem. facie | $HCO_3$-Mg-Ca | $HCO_3$-Mg-Ca | $HCO_3$-Mg-Ca | $HCO_3$-Mg-Ca | $HCO_3$-Mg-Ca | $HCO_3$-Mg | $HCO_3$-Mg | $HCO_3$-Mg-Ca |
| rCa / rMg | 1.9 | 0.95 | 0.83 | 0.73 | 0.85 | 0.11 | 0.21 | 0.69 |
| rNa / rCl | 0.93 | 0.53 | 1.3 | 2.15 | 1.22 | 3.57 | 2.0 | 3.23 |

[1] Total hardness, [2] °G – German degree.

The Piper diagram (see Fig. 10) shows that the groundwater chemistry generally exhibits relatively little variation. The plotted points of the samples in the diagram indicate the fresh character of the water (Appello, Postma, 1994). The graphics of the relations between different chemical components (see Fig. 11) enable to understand the groundwater chemistry differentiation of the basin in support of the identification of groundwater flow patterns.

Based on the TDS concentration which is less than 1000 mg/l, the groundwater of Korça basin generally could be classified as fresh (Fetter, 1994), but the typical groundwater chemistry for a location can generally be described by the so-called "water type" (Stuyfzand, 1999). The groundwater chemical composition is classified according to the dominant chemical components, which are in quantities over 20% meq/l. In most groundwater of the basin $Ca^{2+}$, $Mg^{2+}$ and $HCO^{3-}$ make up the bulk of TDS. Despite the prevalence of these ions in some samples high content of $Na^{+}$, $SO_4^{2-}$ and rarely of $Cl^{-}$ were found. Surface water recharging the groundwaters, like Floqi River and some other small river flowing from Morava Mountain are generally of $HCO_3$-Mg-Ca type, with TDS < 350 mg/l. Some springs like Ndreçi and Turcka (see Fig. 5, Table 4) recharged by the ultrabasic rocks, are of $HCO_3$-Mg type, and TDS < 150 mg/l.

The water type $HCO_3$-Mg-Ca is characteristic for the groundwater of the southern part of the basin, including the Bulgarec sector. The groundwater chemical composition of the southern area of the basin generally very similar to that of recharging them rivers and torrents flowing from the ultrabasic rocks characterized of high $Mg^{2+}$ content. The conductivity varies about 400–580 µS/cm, TDS 220–350 mg/l and total hardness 11–17°German. It is worth to mention the fact that groundwater in the Turan sector, has nitrate content in quantities of about 5 to 15 mg/l (see Table 4). Although, this amount is still below the limit value of 50 mg/l, which composes the maximum permissible value (MPV) for drinking water, it is an indication of the groundwater pollution, probably by the polluted groundwater of alluvial fan deposits of the periphery of Korça.

*Table 5*. **Hydrochemical composition of ground water of Bulgarec, Maliq and Pojan sectors (intergranular alluvial deposits)**

| Sector | Bulgarec | | | | Maliq | | | | Zvirine | | Pendavinj |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. well | 112 | 123 | 8v | 9v | 261 | 292 | 241 | 40r | 294 | 294 | 274 |
| Depth, m | 100 | 80 | 101,2 | 75 | 140 | 190 | 239 | 256 | 80 | 80 | 40 |
| Date | 14.01.76 | 14.01.76 | 21.02.89 | 21.02.89 | 20.03.89 | 13.10.87 | 06.04.89 | 17.06.01 | 30.03.89 | 05.06.88 | 17.09.83 |
| T °C | | | 12.6 | 11.5 | 14.9 | 17.1 | 17.8 | 14.1 | 11.7 | | |
| pH | 8.7 | 8.5 | | | 7.9 | 7.19 | 7.8 | 7.9 | | 7.6 | 7.7 |
| Cond., µS/cm | | | 479 | 440 | 510 | 462 | 471 | 540 | 505 | | |
| TDS, mg/l | 254 | 254 | 296 | 230 | 268 | 273 | 254 | 310 | 291 | 300 | 408 |
| TH[1], °G[2] | 12.1 | 12.8 | 12.9 | 13.5 | 7.9 | 5.4 | 7.4 | 7.8 | 14.9 | 15.2 | 18.4 |
| $Ca^{2+}$, mg/l | 32.9 | 34.9 | 40.3 | 34.4 | 25.6 | 18.7 | 23.1 | 23.1 | 80.6 | 91.2 | 61.5 |
| $Mg^{2+}$, mg/l | 32.7 | 34.5 | 29.8 | 37.6 | 20..9 | 12.2 | 20.9 | 20.1 | 16.1 | 10.5 | 43 |
| $Na^{+}$, mg/l | 15.9 | 9. 2 | 28.5 | 8.5 | 60.3 | 81.2 | 60.2 | 70.7 | 12.7 | 6.9 | 41.6 |
| $Fe^{2+}$, mg/l | 0 | 0 | 0.2 | 0.65 | 0.5 | 0.1 | 0.52 | 0.15 | 0 | 0.3 | 0 |
| $HCO_3^{2-}$, mg/l | 262.3 | 264.7 | 223.3 | 269.6 | 247.7 | 239.1 | 247.7 | 195.6 | 322.1 | 306.2 | 463.6 |
| $SO_4^{2-}$, mg/l | 8.2 | 14 | 7.8 | 25.5 | 7.1 | 7.4 | 7.4 | 18.8 | 10.3 | 7.3 | 18.5 |
| $Cl^{-}$ , mg/l | 18.8 | 11.4 | 10.6 | 8.9 | 53.2 | 49.7 | 53.2 | 64.5 | 10.7 | 8.9 | 14.2 |
| $NO_3^{-}$, mg/l | 1.4 | 2 | gj | gj | gj | 0.8 | gj | gj | 6 | 6 | 1.6 |
| $NH^{4+}$, mg/l | 0 | 0 | 1 | gj | 0.1 | 0.7 | 1.6 | >0.8 | 0 | 0 | 0 |
| Hydrochem. facie | $HCO_3$-Ca-Mg | $HCO_3$-Ca-Mg | $HCO_3$-Mg-Ca | $HCO_3$-Mg-Ca | $HCO_3$-Cl-Na-Mg | $HCO_3$-Na | $HCO_3$-Na-Mg-Ca | $HCO_3$-Na-Mg-Ca | $HCO_3$-Ca | $HCO_3$-Ca | $HCO_3$-Mg-Ca |
| rCa / rMg | 0.61 | 0.61 | 0.82 | 0.56 | 0.74 | 0.92 | 0.77 | 0.61 | 3.05 | 5.3 | 0.87 |
| rNa / rCl | 1.3 | 1.25 | 4.13 | 1.48 | 1.75 | 2.53 | 1.9 | 1.7 | 1.93 | 1.2 | 4.5 |

[1] Total hardness, [2] °G – German degree.

The water type $HCO_3$-$SO_4$-Mg-Ca is found only in the groundwater of periphery of Korça (see Fig. 10), which differ by the highest salt content, compared to the rest of the Korça basin. The conductivity varies about 900 µS/cm, the TDS is about 350 to 550 mg/l, while the total hardness varies around 20–27°German. The groundwater is characterized by the relatively high $SO_4^{2-}$ content, varying about 90 to 130 mg/l, and which could be the result of the oxidation of marcasite and pyrite (Back, Zötl, 1975), in redeposited Neogene molasses outcropping in this area. The high $NO_3^{2-}$ content in the groundwater of this sector of 20–40 mg/l is result of the pollution by the intensive industrial activity developed here.

The water type $HCO_3$-Na-Mg-Ca and less the water type $HCO_3$-Na-Mg are characteristics for the groundwater of Maliq sector. The main hydrochemical parameters in this sector vary as follow: TDS-400 mg/l, conductivity (460–540 µS/cm), while $Cl^-$ and $Na^+$ concentrations vary around 50–60 mg/l and 60–80 mg/l respectively, marking a significant increase compared to the other sectors (see Fig. 11). The groundwater of Maliq sector is characterized by relatively low concentrations of $Mg^{2+}$ and $Ca^{2+}$ and relatively higher concentrations of $Na^+$ and $Cl^-$ comparing with the other areas of the basin. Often the ion exchange between of $Mg^{2+}$ and $Ca^{2+}$ of the groundwater with $Cl^-$ and $Na^+$ ions of clay and shale layers or present in the aquifer, is an important factor for formation of the groundwater chemical composition (Freeze, Chery, 1979; Hem, 1992; Cartwright, Weaver, 2005). In the groundwater of Korça basin most of the samples have $Na^+/Cl^-$ ratios greater than 1 (see Table 4). In case of ion exchange these ratios should be decreased, usually lower than 1 (Freeze, Chery, 1979; Hem, 1992; Cartwright, Weaver, 2005; Xing et al., 2013), which is manifested in some samples irregularly scattered in the study area. The groundwater of Maliq sector is characterized also by the presence of NH + in quantities about 0.5–1.6 mg/l as well as of the $CH_4$ which are related to the decomposing of the organic material (Davis, De Wiest, 1970; Hem, 1992), present in marsh Quaternary deposit of this sector, or also to a deep water input component.

*Table 6.* **Hydrochemical composition of ground water of the sectors (intergranular alluvial fan deposits) Korça Periphery and Podgoria**

| Sector | Korça Periphery | | | | | Podgoria | |
|---|---|---|---|---|---|---|---|
| No. well | 248 | 277 | 296 | Ak-9 | 1/1r | 288 | 289 |
| Depth, m | 72 | 122 | 150 | 181 | 80 | 64 | 85 |
| Data | 11.03.88 | 21.02.89 | 30.10.88 | 08.09.88 | 20.08.11 | 05.05.85 | 08.05.85 |
| T °C | 12.8 | 12.8 | | | 13.2 | | |
| pH | 7.7 | | 7.9 | | 7.5 | 7.8 | 7.6 |
| Cond. μS/cm | 891 | 877 | | | 408 | | |
| TDS, mg/l | 575 | 528 | 530 | 315 | 279 | 308 | 305 |
| TH[1], °G[2] | 26.7 | 26.3 | 26 | 15.6 | 14.6 | 12.8 | 12.7 |
| $Ca^{2+}$, mg/l | 82.5 | 83.5 | 79.4 | 36.4 | 28.1 | 65.1 | 77.2 |
| $Mg^{2+}$, mg/l | 65.6 | 63.8 | 65 | 46.8 | 46.2 | 16.2 | 8.3 |
| $Na^{+}$, mg/l | 18.6 | 15.6 | 13.8 | 13.8 | 20.9 | 38.9 | 26 |
| $Fe^{2+}$ mg/l | 0.3 | 0.2 | 0.1 | 7 | 0.3 | 0.4 | 0.1 |
| $HCO_3^{2-}$, mg/l | 392.8 | 407.5 | 403.8 | 274.5 | 323.3 | 357.5 | 306.2 |
| $SO_4^{2-}$, mg/l | 130.9 | 114.8 | 91.4 | 43.2 | 7 | 3.3 | 13.6 |
| $Cl^{-}$, mg/l | 30.1 | 23 | 26.6 | 14.2 | 12.4 | 7.1 | 10.7 |
| $NO_3^{-}$, mg/l | 20 | 23 | 40 | 14 | 6.2 | 0 | 0.05 |
| Hydrochem. facie | $HCO_3$-$SO_4$-Mg-Ca | $HCO_3$-$SO_4$-Mg-Ca | $HCO_3$-$SO_4$-Mg-Ca | $HCO_3$-$SO_4$-Mg-Ca | $HCO_3$-Mg-Ca | $HCO_3$-Ca | $HCO_3$-Ca |
| rCa / rMg | 0.76 | 0.8 | 0.74 | 0.47 | 0.37 | 2.46 | 5.66 |
| rNa / rCL | 0.95 | 1.05 | 0.8 | 1.5 | 2.46 | 8.45 | 3.77 |

[1] Total hardness, [2] °G – German degree.

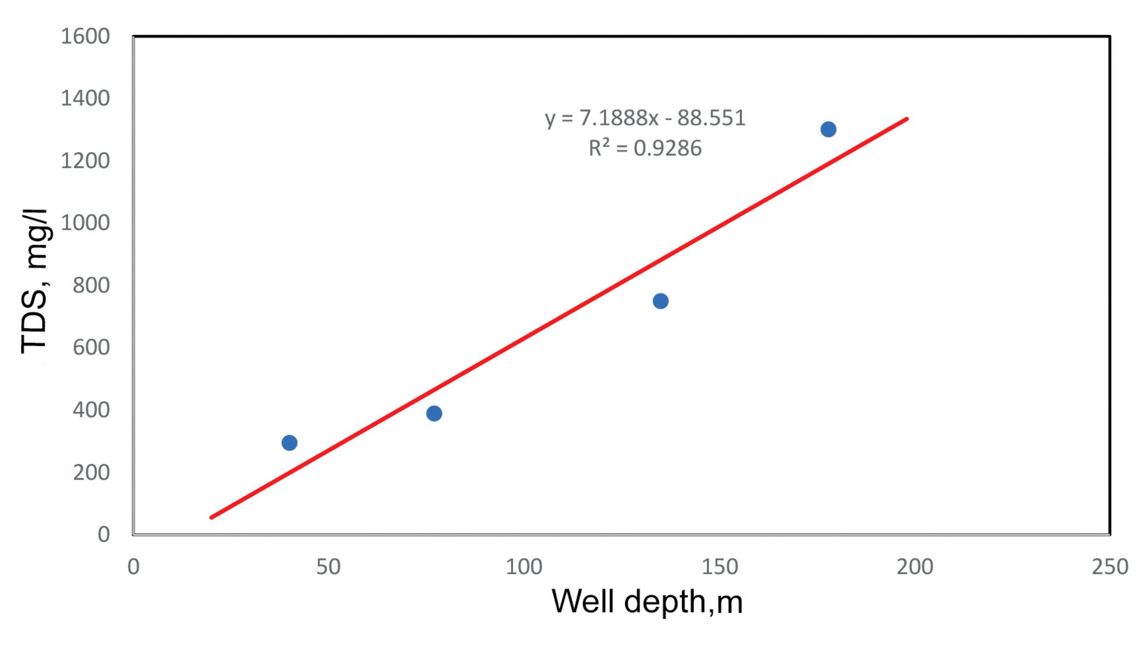

**Fig. 12.** TDS vs the depth of the well No. 277 located in Pendavinj (Sara, 1984)

Water type $HCO_3$-Ca is characteristic for the groundwater of two northernmost peripheral sectors of the basin, that of Zvirina and Podgoria. In both sectors there are widely developed the alluvial fan deposits consisting mainly of carbonate materials deposited by small streams flowing from the surrounding mountain area. The groundwater in both sectors is good, low mineralized with $NO_3^-$ – concentration about 1 to 6 mg/l.

Regarding the groundwater composition changes with the increasing aquifer depth, there are not important evidences, as appears from the data shown on Tables 4, 5 and 6. The only evidence is the groundwater chemical composition at the well No. 274 of Pendavinj sector (Sara, 1984), where a "normal" increase of the salt concentration with increasing depth is observed (Fig. 12). This phenomenon is also associated with the change in dominant ions from $HCO_3$-Mg-Ca at a depth of 40 m, to $HCO_3$-Cl-Na at a depth of 77 m and to Cl-Na at the depth of 135 m. This phenomenon seems to be present in the wide area of the northern part of Korça basin, but for this area the hydrogeological data are scarce.

## Discussions and conclusions

Korça intermountain basin is the largest of this kind in Albania consisting of Pliocene-Holocene intergranular unconsolidated alluvial deposits. The gravel-sand aquifer layers contain artesian groundwater and from the hydrogeological point of view Korça basin is characterized as a semi-closed intermountain artesian basin. The main recharge of the gravelly aquifer comes from rivers and streams flowing from mountain gorges around the Korça plain, as well as, by the infiltration of atmospheric precipitation directly into outcrop areas of the alluvial fan deposits.

The groundwater of the Korça basin is of low mineralization; TDS usually is lower than 600 mg/l, and the ions prevalent in the chemical composition of the groundwater of the basin are $HCO_3^-$, $Mg^{2+}$ and $Ca^{2+}$, but there are also areas of high content of $Na^+$, $SO_4^{2-}$ and less $Cl^-$. Based on the predominant ions in the groundwater of the Korça basin, four hydrochemical water type are distinguished, which change in the direction of the groundwater flow. Particularly indicative is the presence in groundwater of $Mg^{2+}$ which originates from the igneous rocks largely outcropping in the southern main recharge area of the basin. Moving towards the north the groundwater chemical composition is transformed through solution and ion exchange processes which result in the increases in the groundwater of the $Na^+$ and $Cl^-$ ions content, and diminishing of $Mg^{2+}$ and $Ca^{2+}$. In former Maliq marsh area, in the northern part of basin, ammonia ($NH^{4+}$) appears also, and methane gas ($CH_4$) resulting by the decomposing the organic matter present in the deposits of former Maliq Marsh, but is not excluded the deep-water input. Regarding the drinking water quality, the groundwater of southern part of the basin is good, but in most of the northern part of the basin it is disputable or bad (non-drinking).

The natural (static) groundwater resources of Korça basin are very large, they are estimated at about 1.1 × 107 m$^3$, more or less belonging half to the southern area and half to the northern area of the basin. The natural groundwater flow estimated for the southern area is about 400 l/s and actually there are pumped just about 400 l/s, mainly in the Turan sector (wellfield) and consequently a regional groundwater cone of depression of about 14 m is created there. Actually, groundwater requested to be supplied by the basin are related to the drinking water supply of city of Korça including the industrial water supply, as well as of many villages, and the second request consists for irrigation water.

The main problem regarding intensification of the groundwater use in Korça basin is the sustainability which must be established between the pumped groundwater quantity and the eventual negative environmental impacts on the groundwater and on the environment in general. Given the recharge from the wide outlet's areas of alluvial fan deposits, groundwater of the basin is susceptible to contamination from the surface. Potential contamination sources include agricultural activities (pesticides, fertilizers, food processing plants), urban disposals and numerous small-scale industries scattered throughout the area. Safe yield is traditionally defined as the attainment and maintenance of a long-term balance between the amount of ground water withdrawn annually and the annual amount of recharge (Sophocleous, 1997). Often the management policies based on the safe yield are accompanied with some negative consequences, like as loss of ecosystems (drying up of streams, springs and wetlands) contamination of groundwater by polluted streams and eventual depletion of the aquifers. As a result, the aquifer development based upon the concept of safe yield is not safe and sustainable (Sophocleus, 1997, 2002; Bredehoeft, 1997; Sakiyan, Yazicigil, 2004). The concept of safe yield often represents an unjustified restriction of the groundwater resources exploitation. Any determination of safe yield is based upon specific conditions, either existing or assumed, and any change in these conditions will change the safe yield.

Most valuable is to assess the exploitable resources of groundwater representing their amount which can be taken (can be pumped) from an aquifer, or from a sector of it, for a predetermined period of time, without causing significant negative impacts, which would question (compromise) their exploitation for the intended purpose. Since the natural groundwater flow results practically equal to the total infiltration, one could say that actually the groundwater exploitation in Korça basin is respecting the basin safe yield (pumping=total recharge).

The additional groundwater pumping should be accompanied by the intensification of induced infiltration of the surface waters, as well as the partial extraction of static groundwater resources stored in intergranular aquifers (Todd, 1967; Walton, 1970; Freeze, Cherry, 1979). This can lead also to negative environmental impacts like drying up of small rivers and torrents and withdrawal of eventually polluted ground and surface waters. Such situations could be accepted up to a certain level proven by detailed quantitative and qualitative monitoring of groundwater and environmental elements eventually affected by intensive groundwater pumping. Understanding the hydrological and biological processes that define the relationship between the surface and subsurface waters, the landscape connection of riverine or aquatic habitats, and human-induced changes is essential if one is to understand the environmental effects of water-resources management rulings in a basin (Bredehoeft, 1997; Sophcleous, 1997, 2000, 2002).

If the groundwater pumping should be limited within the natural groundwater flow for respecting the so-called aquifer "safe yield", should be difficult, if not possible to face the constantly increase of demands for the groundwater. Most appropriate is to respect the "basin yield" concept that is defined as the maximum rate of withdrawal that can be sustained by the hydrogeological system of groundwater basin without causing unacceptable changes to any other environmental component of the basin.

Obviously, the respect of the concept of the "basin yield" practically means a sustainable groundwater management of Korça basin. Realization of such a goal must be accompanied obligatorily by detailed observations and control of the aquifer, water inspection of the wells, annual water use reports, water conservation measures, groundwater quality deterioration, observation of possible negative environmental impacts like drying up of the rivers, sealing of the groundwater recharge areas, pronounced changes in wetlands including their habitats etc. The enactment of a new water law is also necessary that will improve the current legislation regarding groundwater and surface waters. However, to predict the effects of the groundwater exploitation and for minimizing the possible negative effects it is very important to develop a groundwater model of the basin.

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## Кількість та якість підземних вод міжгірського басейну Корча в Албанії та застосування для сталого управління

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Міжгірський басейн Корча є найбільшим у своєму роді в Албанії і з гідрогеологічної точки зору являє собою напівзамкнутий міжгірський басейн, утворений у пліоцен-голоценових зернистих неконсолідованих відкладах, максимальна потужність яких становить близько 300 м. Водоносний горизонт складається з гравійно-піщаних шарів з міжзерновою порожнинністю, що містять артезіанські підземні води, а бурові свердловини самовиливають на більшій частині поверхні басейну. Основне живлення міжзернистого водоносного горизонту відбувається в основному від річок і потоків, що витікають з гірських ущелин навколо рівнини Корча. Природний дренаж підземних вод басейну Корча здійснюється через вертикальний витік у районі колишнього болота Малік. Гідрохімія водоносних горизонтів показує наявність чотирьох основних гідрохімічних фацій, які пов'язані головним чином з гідрохімією джерел поповнення, процесами розчинення та іонним обміном. У центральній частині басейну розташовані водопостачальні свердловини міст Корча і Малік. Природні поновлювані ресурси підземних вод басейну відносно обмежені, але об'ємні ресурси (або статичні водні ресурси) рясні (близько 1,1 × 10–9 м$^3$). Перспектива їх експлуатації є дуже важливою, але з дотриманням концепції «продуктивності басейну», яка визначається як максимальна швидкість вилучення, яку може підтримувати гідрогеологічна система басейну підземних вод, не викликаючи неприйнятних змін для будь-якого іншого екологічного компонента басейну. Для вирішення проблем, пов'язаних з інтенсифікацією відбору підземних вод, необхідно організувати систематичні спостереження за гідравлічною реакцією басейну та можливим погіршенням якості підземних вод та іншими негативними впливами на навколишнє середовище. Метою даного дослідження є вперше проаналізувати гідрогеологічні дані продуктивного басейну та оцінити: (1) геометрію та гідравлічні параметри водоносних горизонтів; (2) гідродинамічні умови підземних вод; (3) їх хімічний склад і (4) природні ресурси підземних вод і можливість інтенсифікації відбору підземних вод у тісному зв'язку з впливом на навколишнє середовище.

***Ключові слова:*** *підземні води; якість підземних вод; управління підземними водами; міжгірська улоговина Корча; Албанія.*