IMPACT OF CLIMATE VARIABILITY ON GROUNDWATER RECHARGE IN BULGARIA (AN EXAMPLE OF KOTLENSKI SPRINGS REGION)

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Abstract: Groundwater resources in Bulgaria are important sources for rural and industrial water supply. Some of the existing scenarios for future climatic development of the country predict more frequent droughts. The last drought period 1982-1994 observed in Bulgaria had negative impact on groundwater resources in the country.

This paper presents the first attempt to quantify the recharge fluctuation to a karstic aquifer in Bulgaria in response to climate variability. The estimates are based on previous studies and observations on spring flows made in the frames of National Hydrogeological Network located in NIMH-BAS. More than 40-year time series are available for the most important aquifers in Bulgaria. During the 1982-1994 drought period increased air temperatures were registered, reduction in precipitation amounts and in river runoff, as well as reduced spring discharges and declining of groundwater levels.

Estimate of regional recharge and its variations is made on the base of the spring flow data. The application of the method requires good knowledge of hydrogeological background and hydrological data on springs draining the massive. An example for quantifying groundwater recharge is given for the Kotelski springs region that is well studied although very complicated.

Groundwater in Bulgaria is vulnerable to drought. Nowadays the groundwater management should take into consideration possible impact of climate variability and climate change on groundwater resources.
Keywords: groundwater recharge, general hydrogeology, limestone aquifer, spring discharge, drought, Bulgaria.

AUSWIRKUNG DER KLIMA-VERÄNDERUNGEN AUF GRUNDWASSERNEUBILDUNG IN BULGARIEN (EIN BEISPIEL VON KOTLENSKI ENTSPRINGT REGION)

Zusammenfassung: Grundwassermängen in Bulgarien sind wichtige Quellen für landwirtschaftliche und industrielle Wasserversorgung. Die meisten vorhandenen Drehbüchern für zukünftige klimatische Entwicklung des Landes sagen häufigere Dürren voraus. Die letzte Dürreperiode zwihsen Jahren 1982-1994, die in Bulgarien beobachtet worden war, hatte negative Auswirkung auf Grundwassermängen im Land.

Dieser Artikel stellt den ersten Versuch dar, die Grundwasserneubildungsfluktuationen zu einem karstic GW-Leiter in Bulgarien in Erwiderung auf Klimabedingungen quantitativ zu bestimmen. Die Schätzungen basieren auf vorhergehenden Untersuchungen und Beobachtungen über die Quellen Entladung, für die das nationale Hydrogeologische Netz verantwortlich ist, das in NIMH-BAS gelegen ist. In Bulgarien sind Daten für die wichtigsten GW-Leiter im mehr als 40-järigen Zeitverlauf vorhanden. Während der Periode der Dürre 1982-1994 wurden erhöhte Lufttemperaturen, Verringerung in den Niederschlagmengen und des Flußabflusses, sowie verringerte Quellenentladungen und das Sinken des Grundwasserniveaus registriert.

Die Schätzung des regionalen Grundwasserneubildung und seine Veränderungen werden nach den Qelleentladungs daten gebildet. Die Anwendung der Methode erfordert ausführliches Wissen des hydrogeologischen Bedingungen und der hydrologischen Daten bezüglich der Etwässerung des Massives. Ein Beispiel für die Quantitativbestimmung des Grundwasserneubildung wird für das Karstgebiet von Kotel gegeben. Wegen des komplizierten Bedingungen im Karstgrundwasserkörpern gibt es viele Messungen und daraus erfolgliche Daten für die Quelleentladungen.

Das Grundwasserniveau in Bulgarien ist sehr von Dürre abhängig. Das Grundwassermanagement muss heutzutage die zukünftige Auswirkung der Klimaänderung auf Grundwassermängen Betrachtung nehmen.
Schlüsselworte: Grundwasserneubildung, allgemeine Hydrogeologie, Kalksteingrundwasserleiter , Quelleentladung, Dürre, Bulgarien.

1. Introduction

Groundwater in Bulgaria is important resource that is widely used for domestic, agricultural and industrial water supply. It is however vulnerable to droughts.

According to recent research, climate variability influences surface and groundwater. Last drought period 1982-1994 had strong negative impact on river runoff and aquifers. Hydrogeological time-series showed unambiguous vulnerability of groundwater in Bulgaria to drought that was indirect evidence for the recharge variability.

An attempt to quantify the recharge variability is made in this paper. The combination of climate variability and available time-series on spring discharge proposes good possibilities for quantifying the groundwater recharge for different time periods.

2. Climate variability and major consequences of the 1982-1994 drought period

Climate in Bulgaria is moderate for the largest territory of the country. Significant climate variations were registered during last century. Several drought periods were registered. One of the strongest and the most long-lasting droughts occurred in Bulgaria during 1982-1994 (Drought in Bulgaria, 2003).

Since 1980 in Bulgaria long lasting decrease in the precipitation combined with increase in the air temperature were observed, which led to deep depression in the river runoff. Recent studies (Gerassimov et al., 2001) shown that during 1982-1994 the runoff and precipitation in Bulgaria were below the norms; 31% decrease in runoff for Bulgaria with comparison to the norms to the period 1890-1996 was registered. This period is characterized with very low probability of occurrence.

During 1982-1994 increased air temperatures and reduction in precipitation amounts were observed. The drought had serious impact on groundwater as well. Declining groundwater levels and reduced spring discharges were registered during the drought period (Orehova et al., 2001).

3. National Hydrogeological network and data base

National Hydrogeological Network (NHGN) in Bulgaria was found in 1958-1961. It comprises observations of discharges for springs and groundwater levels in observational wells. In the frames of the Danube and Black sea basins, the most of karstic springs included in NHGN are related to elevated massives of Triassic, Jurassic and Cretaceous limestone aquifers. For the Aegean basin some important karstic massives are built from Proterozoic marbles; other karstic springs drain Triassic limestones and dolomites. The major part of observational wells refer to alluvial and proluvial deposits.

The frequency of measurements is mainly once-twice in a month. Measurement of spring discharge (using a current meter) is 12 times annually as usual. At some springs the water level recorders are operating, at other stations water level is measured every day by observers. Using rating curve, the daily data for spring discharge are obtained. Water level in observational wells is measured usually once in a month. Water level recorders are available only for part of stations.

The groundwater quality is determined 4 times per year for selected springs and pumping stations. Basic components, nitrates and some others are defined.

National Institute of Meteorology and Hydrology is responsible to hydrogeological data collection, processing, maintenance of stations and archives, supplying of the state institutions and consumers with data from NHGN, and dissemination of information. Data from NHGN are used for national and international projects and analyzed in many studies.

Time series of discharge for springs and groundwater level for observational wells give important information on groundwater regime in Bulgaria. Some of the time series are with 40-year long observational period and reflect the influence of climate variability on groundwater.

4. Methodology for estimates

It is known that the goal of any study is important in choosing a technique. This refers completely to the recharge study. “Relative explosion” of recharge studies since the mid 1980s was reported by de Vries et al. (2002). Application of different methods depends on various spatial scales and time periods (Scanlon et al., 2002).

Typical study goal includes water resources evaluation, which requires recharge estimates over large space and long time scales (Scanlon et al., 2002). These regional recharge estimates are based on the assumption that average recharge equals the average discharge (de Vries et al., 2002). Choosing appropriate period of time (1 year and more) and localized karstic aquifers in mountainous areas to avoid possible long transition periods, we ensure correct application of the technique. Good knowledge of the hydrogeological background of the region is of primary importance.

Many techniques for estimation recharge are based on the water budget equation. The most common way is the indirect or “residual” approach, whereby all other of the variables in the water-budget equation are measured or estimated. The major limitation of the residual approach is that the accuracy of recharge estimate depends on the accuracy with which other components in the water budget equation are assessed (Scanlon et al., 2002).

The aim of the paper is estimation of regional recharge from the available data. This is low cost technique that requires good knowledge of hydrogeological background and time-series data.

During droughts the springflow shows lower annual and multiannual values. We suggest that the recharge (*R*) for the period of one or several years is equal to discharge (*Q*), and the variations in the springflow are due to (and therefore equal to) the variations in the recharge to karstic aquifer:

$$\Delta R = \Delta Q. \tag{1}$$

5. An example of the Kotlenski springs region

The regional recharge assessment was applied to Kotelski springs region (Figure 1) that is well studied although very complicated.

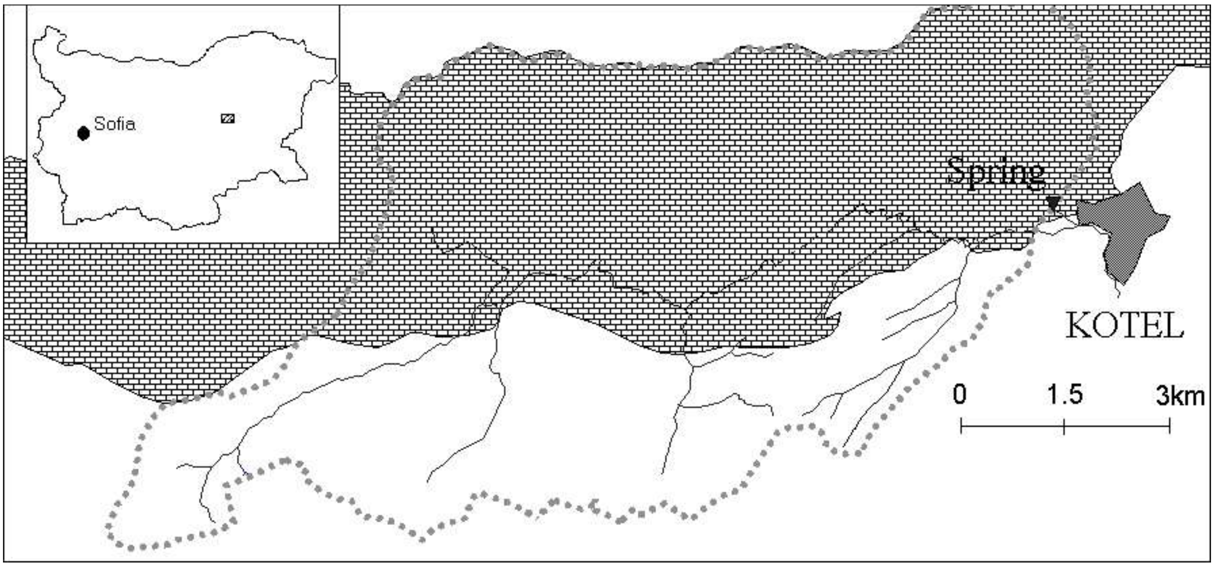

Fig. 1. Catchment area of Kotlenski springs (limestone formations are shown).

Bojilova (2004) evaluated the applicability of method of composition for specifying frequency curves of empirical distribution for selected karstic springs in Bulgaria. One of the chosen examples referred to Kotlenski springs (N: 48). According to Bojilova the method of composition is very powerful for extending probability curve of the annual spring distribution.

5.1. Geological settings and hydrogeological background

The Kotlenski springs are located near Kotel town at an elevation of 504 m above sea level and drain western part of the Kotlenska mountain. Its several peaks reach altitudes between 900 – 1000 m a.s.l. and more. Northern slopes are more steep and craggy. Spring waters join main river in the region - Suhojka.

The region of Kotlenska mountain is characterized with very complicated tectonic structure. It is situated within the boundary between Forebalkan and East Balkan tectonic zones, named dislocation “Wonderful walls”. The Western part of the Kotlenska mountain is built from upper Cretaceous and Paleogene sediments, with Jurassic flysh sediments in the south part.

Kotlenski springs are basic source for water supply of the Kotel town and neighborhood villages. From 1959 they are included into National Hydrogeological Network as station N: 48 with water level recorder that operated up to 2000. Since then daily water stages are available. Measurements of spring discharge are made 10-12 times per year, and rating curve is drawn up. Daily data of spingflow are available for the 43-year period.

From hydrogeological point of view the region refers to Kotlenski karst basin (Boyadjiev, 1964; Antonov et al., 1980). This is well drained mountain massive with two karst aquifers. The basic one is presented by widespread *Carbonate formation*, and the other is locally developed and includes *Formation of white limestone* and *Limestone formation.* The main discharge of the basin is to the east by Kotlenski springs (about l’ from the total resource), and the rest – to the north due to Kipilovski springs.

The recharge area of the Kotlenski springs, on the base of geological and geomorphological conditions covers approximately 65 km^2. Major part (43 km^2) of it is built from *Limestone formation*. The rest of the catchment area is formed by non-karstic low permeable rocks, which form mainly surface runoff. This runoff is lost fully or partly after reaching uncovered carbonate rocks. Within the karstified part of the catchment area many different karstic forms are manifested. Up to now about 45 caves and schafts have been determined by Bulgarian Federation of Speleology.

The process of karstification affected the entire massive – from the recharge zone to the issues of the Kotlenski springs. The locality of the issues is predetermined tectonically from the Kotlenski overthrust. They appear on the boundary between non-karstified Jurassic flysh rocks and Upper Cretaceous limestone of Carbonate Formation. The issues present 5 upward canals situated near by. All issues are below the level of artificial lake due to barrage during the largest part of the year. The karst in the region is shallow, and karstification very likely did not reach up to considerable depth (Benderev et al, 2004).

5.2. Quantification of the recharge

The recharge of the aquifer feeding the Kotelski springs is due to infiltration and influation of water from precipitation and snowmelt, as well as due to loosing of river flow of Suhojka and its tributaries. For the meteorological station Kotel (543 m a.s.l.) the annual mean temperature is 12.4°C (19.2°C for July and -1.1°C for January), with an average (for the period 1931-1985) annual rainfall of 811 mm. The precipitation amount for the region of Kotelski spring is about 910 mm and was estimated taking into consideration the elevation of the catchment area. The value of evapotranspiration was assessed using equation of Turc to be 480 mm. So, the groundwater runoff and river flow were estimated as 430 mm. Having in mind the share of areas with karstified and non-karstified rocks and hydrometric measurements, after balance calculation it was found that 70% of the total recharge, that refers to the area 65 km^2, feeds the Kotlenski springs (Benderev et al., 2004). The recharge regional value is estimated as 300 mm and should be regarded as average value for recharge of the aquifer that refers to the period 1931-1985.

The regime of Kotlenski springs is very sensitive to changes in recharge. Springs begin to respond to recharge very quickly. A sharp increase in springflow with peak discharge of one day after the highest intensity of the rainfall is followed by a less rapid drop in discharge. The flow lasts several weeks (Figure 2); from this period quickflow lasts only 3-5 days. The retention capability of the karstic basin is most probably rather low, without deep circulation. It was found that the share of quickflow is more important for wet years compared to normal and dry years. Due to low durability of quickflow for the springs, it should not be taken into account for water resources assessment. The baseflow was found to be 67 to 88% of mean yearly spring discharge. The parameters of recession curves were determined by Benderev et al. (2004).

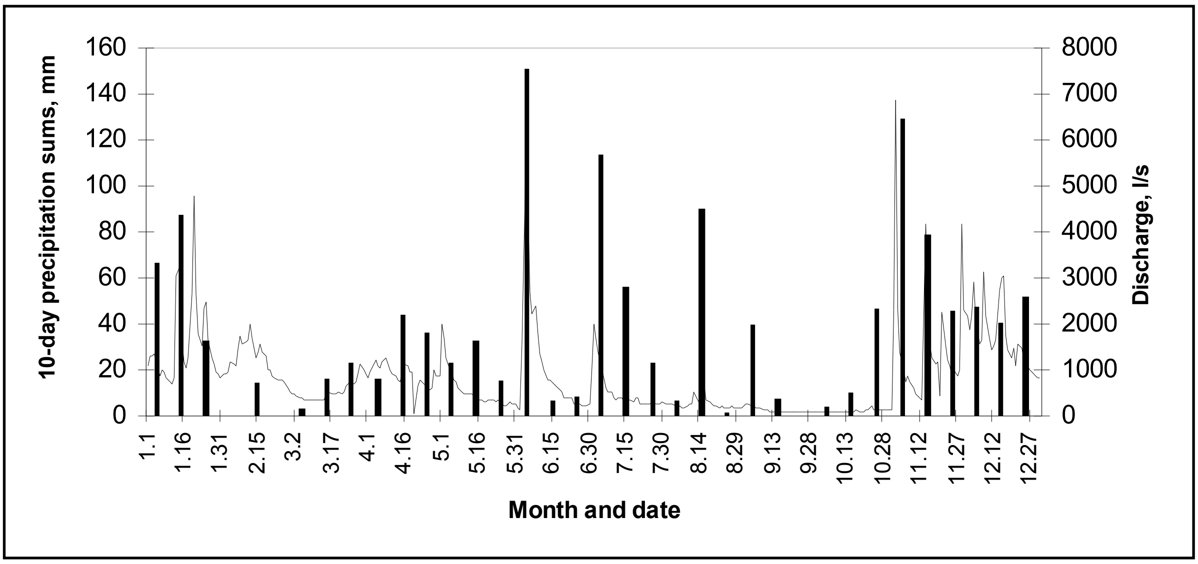

Fig. 2. Daily discharge of Kotlenski springs during the wettest year (1966) and 10-day precipitation sums for meteorological station Kotel

The discharge of Kotlenski springs is highly variable (from 0.04 to about 20 m^3/s). The spring flow showed its vulnerability to droughts and quick response to changes in the recharge conditions. During the 1982-1994 drought period reduction of springflow in average 20% was registered, and 25% - for the shorter 1985-1994 period (Orehova et al., 2001). The more frequent lately winter droughts caused strong reduction of recharge to aquifers (Andreeva et al., 2001). Examples of monthly distribution of springflow for normal and wet years are presented in Figure 3. Droughts during cold period for the years had strong negative influence on the discharge of Kotlenski springs (Figure 4). The reference period for average monthly data is 1961-1990.

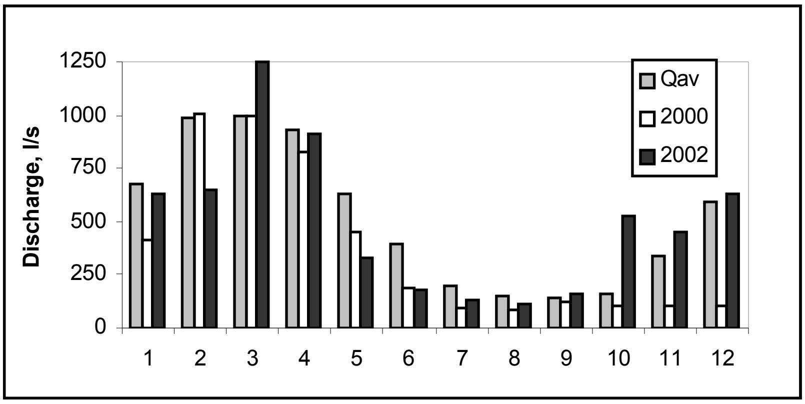

Fig. 3. Monthly distribution of springflow for normal and wet years (2000, 2002)

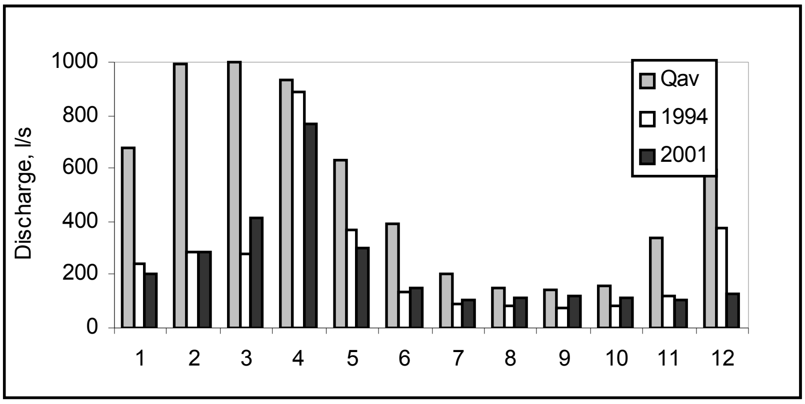

Fig.4. Monthly distribution of springflow for normal and dry years (1994, 2001)

The temperature of spring water shows variation opposite to that of variations in discharge (Orehova, 2001). The lower temperatures occur during the periods of recharge characterized with high discharge values (as low as 7.6°C); the maximal temperatures are during baseflow period (up to 10.8°C). This relatively high amplitude (above 3°C) is common for springs draining non-homogeneous massives and represent indirect evidence for low retention capability of the karstic massive and absence of deep circulation zone.

Chronological structures of discharge are presented on Figure 5 in relative deviations $\psi = \frac{X - \overline{X}}{\sigma_X}$, where $\overline{X}, \sigma_X$ are average and standard deviation, which for the observational period 1960-2002 are equal to 506 l/s and 146 l/s respectively. Due to equation 1, this graph is valid for recharge variations as well. Unknown variations in recharge are similar and approximately equal to relative variations of the discharge. The mentioned value of discharge refers to recharge to the aquifer equal to 350 mm and standard deviation 101 mm. This is another estimate of the regional recharge to aquifer feeding the Kotelski springs. The 20%-reduction of spring during the 1982-1994 drought period resulted in comparable reduction of groundwater recharge (70 mm). For the shorter 1985-1994 period the diminution of 25% means decrease of about 87 mm. The most probable variations in recharge to aquifer feeding the Kotelski springs are within the range from 250 to 450 mm per year. The recharge estimate given before (300 mm) lies within this range.

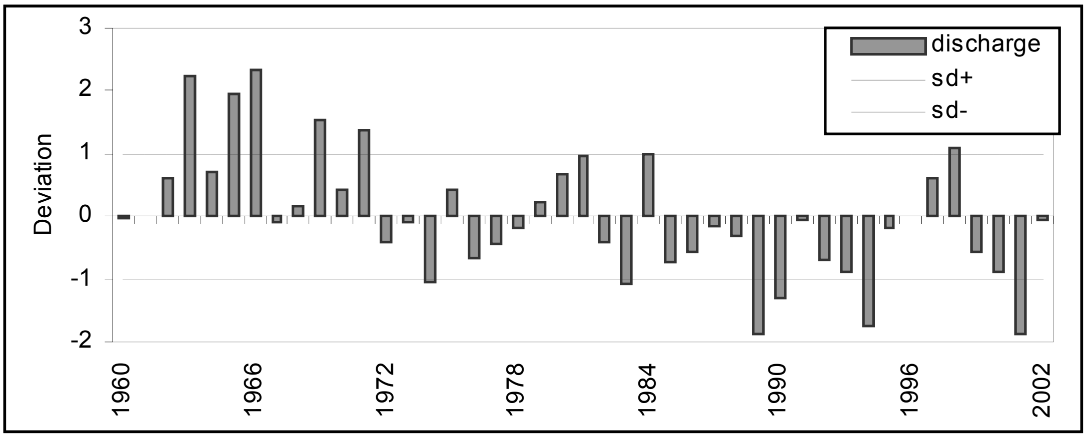

Fig.5. Variability of discharge with time

6. Discussion

The last drought period gave indirect evidence for the recharge reduction. An example for quantifying groundwater recharge is given for the Kotelski springs region that is well studied although very complicated. General characteristic of the region of Kotlenska mountain is done including geological setting, lithological description, degree of karstification and hydrogeological background.

The elements of water budget were assessed for the region. The value of the recharge was estimated by two ways: firstly, as a residual from water budget, and secondly, from data on spring discharge. The accuracy of the first method is restricted by the accuracy with which other components in the water budget equation are assessed. The estimated value of groundwater recharge (300 mm) is averaged and refers to the period 1935-1985. The second method for regional recharge estimates is based on the assumption that average recharge equals the average discharge. For the period of one year and more, we consider this approach reliable for the catchment area of Kotelski springs. The recharge estimate for the period 1960-2002 is 350 mm with standard deviation about 100 mm. The two approaches gave comparable values.

The process of recharge estimation is iterative and involves continual refinement of recharge rates as addition data are collected. Multiple techniques should be used to estimate recharge because of uncertainties associated with each approach, as was recommended by Scanlon et al. (2002).

Due to economic significance of groundwater resource, extensive research should be projected concerning impact of droughts on recharge to aquifers.

7. Conclusion

Some of scenarios for future development for Bulgaria predict more frequent droughts. This means reduction of groundwater resources, but also more anthropogeneous pressure on groundwater.

Different aspects of drought impact described in the monograph prepared in the frames of USA – Bulgarian Project (Drought in Bulgaria, 2003) are described and discussed. Our point of view is that much more attention must be paid to studies of impact of drought on groundwater. Groundwater provides strong impact on human life and is connected with many other elements of the environment (surface water, soils, vegetation, animals). Besides, one expects to use groundwater for solving additional needs in water supply during drought periods.

Estimates of regional recharge are made by two ways: firstly, as a residual from water budget, and secondly, from data on spring discharge. These approaches may be very reasonable techniques for extended areas and can be derived using readily obtained field data. The application of the methods requires good knowledge of hydrogeological background and hydrological data on springs draining the massive.

Regional estimates of recharge and its variations are presented in the paper for the region of Kotlenska mountain. This paper showed an approach to assess reduction of groundwater recharge as a result of the 1982-1994 drought period. Good groundwater management practice must take into consideration such decrease of groundwater resource.

Groundwater is valuable but vulnerable resource. Special studies are necessary to clarify the dynamics of recharge to aquifers. The society intends to rely on groundwater resources during droughts.

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