GROUNDWATER FOOTPRINT: A TOOL FOR ECOLOGICAL-BASED GROUNDWATER RESOURCES MANAGEMENT ASSESSMENT

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Abstract

Over-pumping and extended drought events have raised awareness on groundwater resources management within the Mediterranean Basin. As groundwater often has an important role in sustaining certain types of aquatic, terrestrial and coastal ecosystems, water policy makers should pay special concern to maintain groundwater contribution to the environmental flow. To this aim, the present study focuses on the assessment of a newly introduced groundwater management tool, the Groundwater Footprint (GWF) (Gleeson et al., 2012). GWF represents a water balance between aquifer inflows and outflows, focusing on environmental flow requirements and expresses the area required to sustain groundwater use and groundwater dependent ecosystem services. GWF is applied to a pilot aquifer in the Mediterranean Basin, crossed by an intermittent river. Total abstraction, natural and artificial recharge, groundwater contribution to environmental stream flow are the critical parameters related to GWF estimation. In order to estimate groundwater contribution to the environmental stream flow, the assumption that groundwater contributes to the environmental flow to the same percentage as baseflow contributes to the natural flow has been made. However, the main constraint met in GWF estimation has been the estimation of the environmental flow in non-perennial river, as the quantification of the environmental flow requirements has been mainly studied for perennial rivers. For this reason, the available to the literature studies referring to environmental flow requirements have been assessed and the most appropriate method for the specific pilot area has been applied. The ratio GWF to the actual area of the aquifer (A) can be used to assess groundwater management, as GWF/A>1 indicates unsustainable groundwater consumption. Consequently, GWF/A may consist a comprehensible to the general public groundwater stress indicator and can be used to raise awareness.

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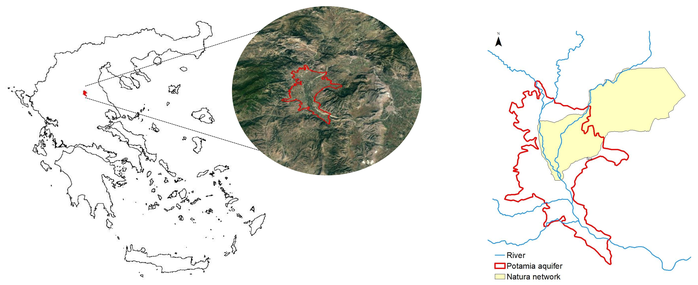
Background

- The Groundwater Footprint Concept (Gleeson et al., 2012) expresses:
  - — the **area** required to sustain groundwater use and groundwater dependent ecosystem services.
  - — a **water balance** between aquifer inflows and outflows, focusing on environmental flow requirements.
- The Groundwater Footprint to the actual aquifer size ratio (GWF/A):
  - — GWF/A < 1 indicates sustainable groundwater management
  - — GWF/A > 1 indicates unsustainable groundwater management that could affect groundwater-dependent surface water and ecosystems.
- The aim of the study is to assess the use of GWF as a tool for groundwater management assessments and to propose an easy and reliable method to estimate GWF.

Case Study: Potamia aquifer, Greece

- Potamia aquifer is:
  - — located in Central Greece and belongs in the administrative region of Thessaly (Fig. 1a)
  - — about 86.7 km^2
  - — crossed by Titarisios and Elassonitikos river (Fig. 1b)
  - — a typical rural landscape, with irrigated and non-irrigated cultivations
  - — partially covered by a Natura 2000 area
- Titarisios river:
  - — is a tributary of the Pinios river, one of the largest rivers of Greece
  - — tends to dry up during the dry period of the hydrological year (Fig. 2)



(a) (b)

Fig.1 Potamia aquifer

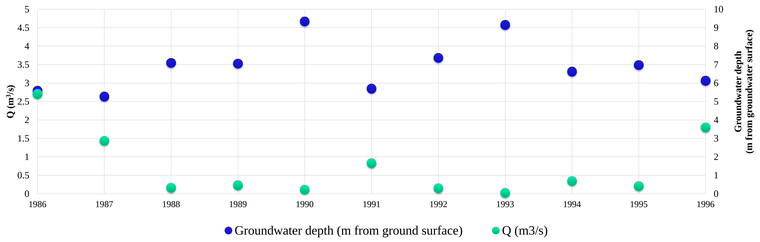


Fig.2 Titarisios flow and groundwater depth in August

Methodology

- According to Gleeson et al. (2012), the **groundwater footprint (GWF)** is defined as:

$$GWF\ (m^2) = \frac{C\ \left(\frac{m}{d}\right)}{R\ \left(\frac{m}{d}\right) - E\left(\frac{m}{d}\right)} \cdot A(m^2)$$

where, C the area-averaged annual abstraction of groundwater,
R the recharge rate (mainly from precipitation and irrigation return),
E the groundwater contribution to environmental streamflow,
A the areal extent of the aquifer of interest

- To adjust the proposed methodology to the particular characteristics of the study aquifer, in the present study the parameter 'C' includes not only the annual abstraction of groundwater but also groundwater discharge through Amourio springs.
- Accordingly to parameter 'C', parameter 'R' includes river infiltration and lateral inflows besides recharge through precipitation and irrigation water infiltration. Parameters 'C' and 'E' derived from observations and water budget analysis in related reports.
- The steps followed to estimate GWF parameter 'E' are presented in Fig. 3.
- The **groundwater quantity that should be allocated on surface water bodies** in order to sustain satisfactory biological conditions was estimated under the assumption that **surface water and groundwater contribute equally both to the environmental flow** and **to the natural flow** (Sood et al., 2016).
- The **baseflow** was estimated through a freely available R package named 'EcoHydRlogy' and specifically through the 'BaseflowSeparation' function (Fuka et al., 2018).
- The **environmental flow requirements** of Titarisios river were estimated as the maximum value of environmental flows estimated based on the Tennant method (1976), a widely used method, and on the method proposed on the National Guidance for environmental flow estimation (Government Gazette of the Hellenic Republic, issue D, No. 2075/2009).

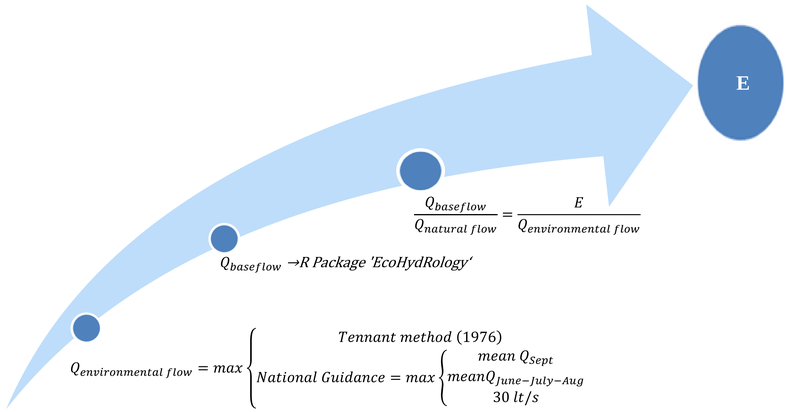


Fig.3 Steps to E parameter estimation

Results

- Following the proposed methodology, Titarisios environmental flow was estimated as the average flow observed in June, July and August of the period 1974-2018 and is equal to 1.3 m^3/s.
- The free software IHA was used to assess Titarisios flow alteration during the period of study (The Nature Conservancy, 2009). The increasing occurrence of extreme low floods should raise since according to The Nature Conservancy (2009) extreme low flows conditions can become highly stressful to many organisms (Fig. 4).
- The GWF/A ratio of Potamia aquifer was estimated to be equal to 3.1, indicating unstainable water management. However, Potamia GWF/A ratio is slightly lower than the world average ratio, which is 3.5 according to Gleeson et al. (2012).

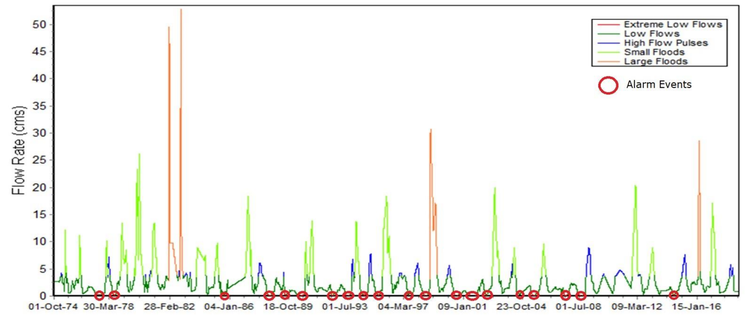


Fig.4 Titarisios flow classification via IHA software

Conclusions & Future work

- The GWF/A ratio computed in Potamia aquifer is greater than 1, indicating that a more sustainable groundwater management plan should be adopted in the area.
- Titarisios flow analysis via IHA software indicates that awareness should be raised on Titarisios environmental flow requirements.
- Uncertainty in GWF estimation will be quantified.

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