Assessing Groundwater Resources Sustainability Using Groundwater Footprint Concept

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1. INTRODUCTION

The Groundwater Footprint (GWF), introduced by Gleeson et al. in 2012, expresses the area required to sustain groundwater use and groundwater dependent ecosystem services. GWF represents **a water balance** between aquifer inflows and outflows, **focusing on environmental flow requirements**.

As the GWF is a tool recently introduced in groundwater assessment and management, only a few studies have been reported in the literature to use it as groundwater monitoring and management tool. The present study emphasizes on a case study in Southern Europe, where awareness should be raised about rivers' environmental flow. The GWF concept is applied for the first time to a pilot area in Greece, the Chania Valley, Crete.

2. CASE STUDY: THE CHANIA VALLEY

- Important agricultural area of Greece
- Over-pumping of groundwater resources
- Tavronitis and Keritis rivers are crossing the area
- Recharge through the springs of Agyia (karstic springs at the southern boundary of the pilot area)

Fig.1 - Hydrogeological Map of the Chania Valley

3. METHODOLOGY

- 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 annual outflows from the aquifer,

R the recharge rate,

E the groundwater contribution to environmental streamflow

A the areal extent of the aquifer of interest

- **Recharge and abstraction** of the pilot area are estimated based on historical data and previous reports and a groundwater flow model, developed using **Visual Modflow** in order to diminish the uncertainty of the input parameters through model calibration.

3. METHODOLOGY

- The **groundwater quantity that should be allocated on surface water bodies** in order to sustain satisfactory biological conditions is 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 Chania Valley GWF parameters estimation procedure is presented in Fig.2.

C
- is estimated through the developed groundwater flow model.
- refers to the total outflow of the aquifer (abstraction, outflows to the sea).

R
- is estimated through the developed groundwater flow model.
- refers to the total recharge of the aquifer (rainfall, recharge from water springs).

E
- is calculated as the same percentage of the baseflow in the natural flow.
- For baseflow estimation, a HEC-HMS (USACE) precipitation-runoff model is developed.
- The total environmental flow, concerning both groundwater and surface water contribution, is estimated based on Tennant method.

Fig.2 - Steps to GWF parameters estimation

4. RESULTS

The GWF in Chania Valley, Crete is estimated for the first time with respect to the groundwater contribution to achieve **a)** good and **b)** optimum environmental conditions.

- Based on Tennant method, the total environmental flow of the rivers crossing the Chania Valley is calculated as **a)** 30% of the mean average flow to ensure fair habitat conditions and as **b)** 60% of the mean average flow to ensure optimum environmental conditions.
- The groundwater flow simulation outputs are presented in Fig.3, at the end of the wet period in 2006.

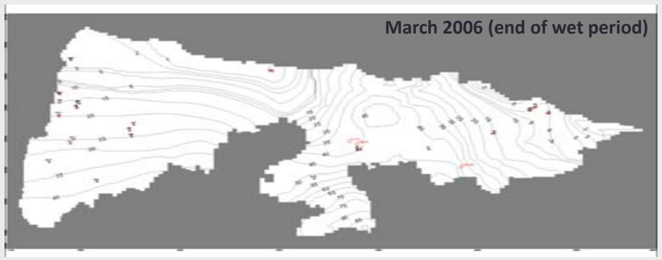

Fig.3 - Simulation of the Groundwater Flow System in Chania Valley

4. RESULTS

- The inflows and outflows of the aquifers are estimated through the water balance presented in Table 1.

INFLOW	Direct Recharge (precipitation)	Recharge (springs of Agyia)	River-Aquifer Interaction	Total Inflow
mcm/year	6,5	3,6	22,2	32,3
OUTFLOW	Pumping	Outflow to the Sea	River-Aquifer Interaction	Total Outflow
mcm/year	3,5	24,1	4,8	32,4

Table 1 - Water balance on pilot aquifer (Mean values, simulation period 2004-2008)

- **For good environmental conditions** (i.e. environmental flow equal to 30% of the mean flow), the GWF is estimated equal to 178,93Km^2, that means almost **89,4% of the actual area of the aquifer**.
- **For optimum environmental conditions**, the contribution of the groundwater to the environmental streamflow should be greater and in this case the GWF is estimated 187,69Km^2, about **93,8% of the actual area of the aquifer**.

5. CONCLUSIONS

- The GWF/A ratios computed in Chania Valley, which are lower than 1, indicate that the groundwater management in the area is sustainable.
- However, **the GWF is estimated for mean annual values, so it does not include the groundwater system response to the seasonal variability of abstraction and recharge.** In addition, **the variables used for GWF calculation are subject to uncertainty,** which should be taken into account.
- The GWF could be proved to be **a useful tool for groundwater analysis and policy** as it can raise awareness since it is intuitive to the general public. However, in order to develop the GWF method into a powerful tool, the method should be tested in changing conditions and the environmental flow requirements should be estimated with the most accurate method, based on expert consultation.

6. REFERENCES

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