EARTH SCIENCES
RESEARCH JOURNAL

Earth Sci. Res. SJ. Vol. 17, No. 2 (December, 2013): 115 - 118

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HYDROGEOLOGY

An approximate method for estimating nutrient loads in drainage water from a coastal irrigated area

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ABSTRACT

In this work, an estimation of nutrient loads, expressed as Dissolved Inorganic Nitrogen (DIN) and Inorganic Phosphorous (IP), in drainage water from a coastal irrigated area was undertaken. The procedure is based on the calculation of drainage discharge with the use of data from the drainage pumping station and the assessment of the concentrations of nutrients in drainage water. The case study examined is the cultivated land of Agoulinitsa (Peloponnese - Greece). The results of this study could be useful for taking the necessary measures for environmental protection.

Key words: drainage water, nutrient loads, cultivated land

RESUMEN

En este trabajo, se emprendió una estimación de las cargas de nutrientes (expresados como Nitrógeno Inorgánico Disuelto y Fósforo Inorganico) en las aguas bombeadas desde una área de irrigación costera. El procedimiento está basado en el cálculo de descarga de la cuenca con el uso de datos desde la estación de bombeo y con la medida de concentración de nutrientes en el agua bombeada. El caso de estudio propuesto es la región cultivada de Agoulinitsa (Peloponeso - Grecia). Los resultados de este estudio podrán ser útiles para tomar las medidas necesarias para la protección del medio ambiente.

Palabras clave: Bombeo de agua; carga de nutrientes; tierra cultivada.

Record

Manuscript received: 26/01/2013
Accepted for publication: 10/09/2013

Introduction

Nutrients and heavy metal inputs from drainage water and surface water to the sea environment has been a major environmental concern in many regions of the world; both agricultural practices as well as land use practices are among the main factors that control the nutrient concentration and quality of water (Alexakis 2011; Brindha and Elango 2011; Gamvroula et al. 2013). In recent years, environmental studies have revealed elevated contents of nutrients in drainage water, surface water, groundwater and soil (Alexakis et al. 2014; Brindha and Elango 2011; Golekar et al. 2013). In this work, an effort was made in order to estimate both drainage water quantities and transported nutrients in an agricultural area of Greece adjacent to the sea, which suffers seriously from pollution problems of this type. The findings of this work could be useful for planning the necessary protection measures by the local authorities.

Study area

The study area is the Agoulinitsa irrigation district, the downstream part of the Alfeios river basin in the north-west Peloponnese peninsula in Greece. The irrigation network was constructed between 1960 and 1970, after the artificial draining of the Agoulinitsa lagoon. The study area lies between latitudes 37°32΄-37°37΄N and longitudes 21°26΄-21°36΄E and is located 7 km southwest of Pyrgos city. It is surrounded by the Ionian Sea in the west, with elevations ranging from 0.5 to -1.5 m below sea level, and covers approximately 35 km^2 (Fig. 1). The district is irrigated using the water of the Alfeios River. Water from the main irrigation channel is distributed to three pumping stations (A1,A2,A3), which supply sprinkler irrigation. The drainage network consists of 1st, 2nd and 3rd class drainage ditches that drain excess water from the cultivated land to the sea through a drainage pumping station (E). The net irrigated area of the Agoulinitsa network is 24 km^2. According to the local management authorities, the cultivated land is approximately 80 % of the net area.

The irrigation season begins in April or early May and generally ends in September or October. The most common agricultural crops are corn, cotton, alfalfa, cereals, vegetables and citrus. There is no detailed information about the amount of commercial fertilizers applied by farmers in the Agoulinitsa district. The most common type of fertilizer applied in the study area is NPK (14 % of N, 28 % of P and 14 % of K).

Soils are derived from Quaternary alluvial deposits. The Quaternary alluvial deposits cover the study area, which includes lagoonal deposits, recent delta deposits, red clays, gravel and sandy materials. Soil infiltrability varies between 0.04 and 118 mm h^{-1} (Gotsis, 2007).

Materials and methods

Data collection

Data were collected from literature sources and relevant databases (Alexakis et al. 2012; Public Power Corporation of Greece). Monthly precipitation and temperature data obtained from the meteorological station of N.M.S. (National Meteorological Service), which is located in Pyrgos city, were used in this study (Fig. 1).

This study uses all the available systematically collected data concerning water quality of the study area over the of the year 2010. Both irrigation and drainage water samples were collected during pre-irrigation and post-irrigation seasons. A location map of the water samples and a detailed description about the sampling campaign are given by Alexakis et al. (2012).

Inflow and outflow volumes

Electrical power for a pumping station is calculated from the following equation:

$$P=0.002725 \cdot \frac{Q \cdot H}{n} \qquad (1)$$

where:
P, is the electrical power (kW)
Q, is the water discharge (m^3/h)
H, is the manometric head (m)
n, is the total efficiency of the pumping station

Transforming eq. 1, the electrical energy consumption for a pumping station can be calculated from:

$$W=0.002725 \cdot \frac{V \cdot H}{n} \qquad (2)$$

where:
W, is the electrical energy consumption (kWh)
V, is the volume of discharged water (m^3)

Monthly records of electrical energy consumption for the pumping stations (A1, A2, A3 and E) were used (Public Power Corporation of Greece/Pyrgos City). By using eq. 2, the volume of water discharged each month was calculated (i.e., irrigation water using data from pumping stations A1, A2, A3 and drainage water using data from pumping station E). The monthly discharged volume of water was then expressed in mm/month according to the data reported in Table 1.

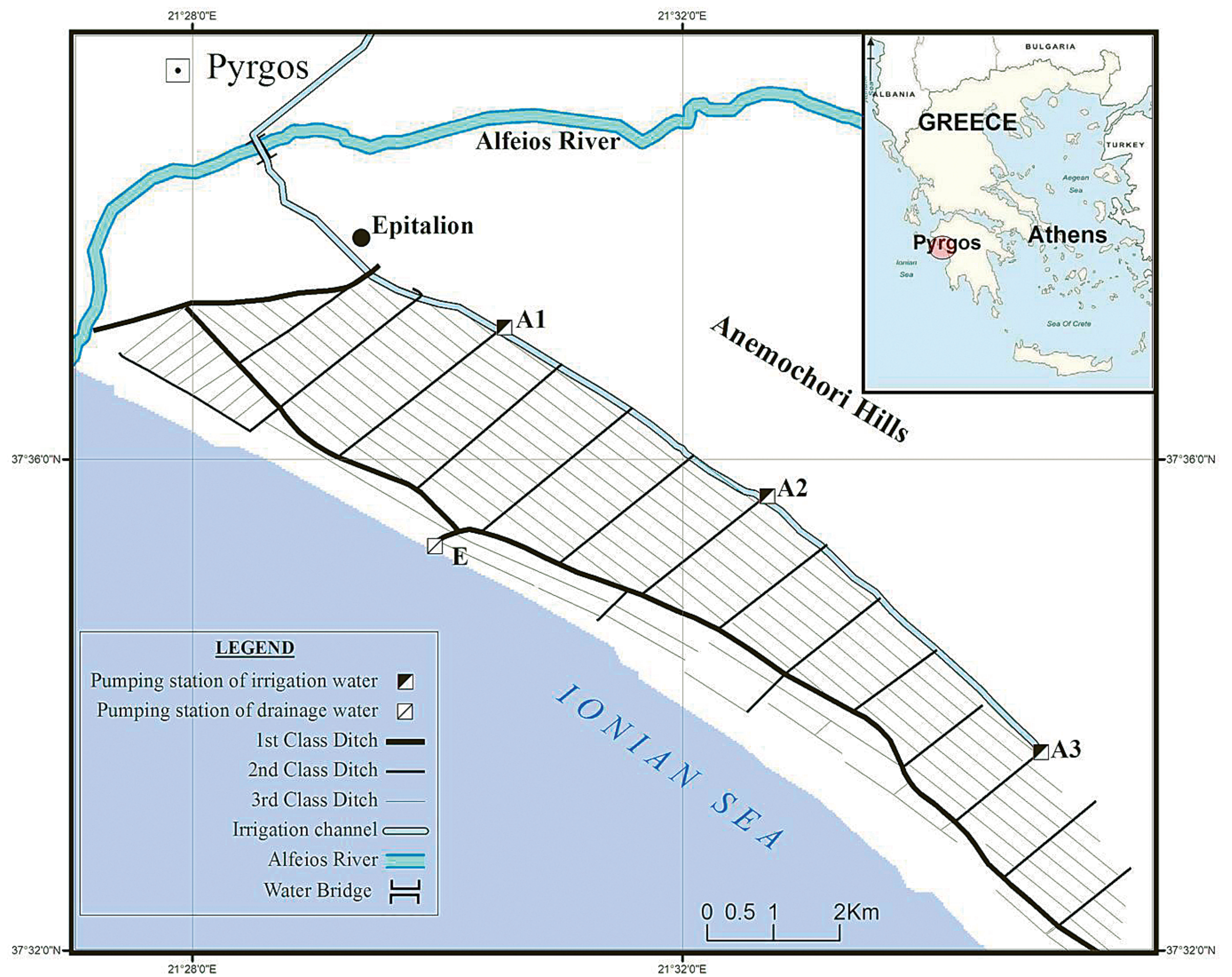


Figure 1. The irrigation district of Augoulinitsa

Table 1 Basic characteristics of the pumping stations.

Pumping Station	Irrigation			Drainage
	A1	A2	A3	E
Manometric H (m)	76	71	79	6
Motor Power (HP)	2040	2380	2040	860
Total Efficiency n	0.6	0.6	0.6	0.6
Covered Area (km²)	6.2	6.2	7.8	35.0

The estimated values of the mean monthly inflows for the period of the years 2000-2010 (precipitation, irrigation water) and outflows (potential evapotranspiration, drainage water) in the study area are presented in Fig. 2.

The potential evapotranspiration losses, also shown in Fig. 2, were estimated with the use of the modified Blaney-Criddle equation (Gotsis and Giakoumakis, 2006):

$$PET = A_B + B_B \cdot (p \cdot (0.46\,T + 8)) \quad (3)$$

where:

PET, is the potential evapotranspiration for the reference crop (clipped grass) in mm/day

T, is the mean monthly temperature (°C)

p, is the mean daily percentage of total annual daylight hours (taken from tables)

A_B, B_B: are the adjustment factors based on minimum relative humidity, sunshine duration and wind speed (taken from tables)

According to the crop and the month, the appropriate crop factor K_c was then selected.

Nutrient loads

The mean annual concentrations of DIN (Dissolved Inorganic Nitrogen), which is the sum of NO_3-N, NH_4-N and NO_2-N and IP (Inorganic Phosphorous), that were used in this study were calculated based on the NO_3-N, NH_4-N, NO_2-N, and PO_4^{3-} concentrations, respectively (Table 2). The conversions between NO_3^- and NO_3-N is the NO_3^- result multiplied by 0.226, while the conversions between NH_4^+ and NH_4-N is the NH_4^+ result multiplied by 0.777. The recorded NO_2^- water contents were below the detection limits. A conversion factor of 0.326 was applied for the conversion between PO_4^{3-} and P.

Table 2 Mean annual concentrations of nutrients in drainage water of the Agoulinitsa irrigation district.

	Mean DIN (mg L^{-1})	Mean IP (mg L^{-1})
Irrigation water	0.45	0.05
Drainage water	1.32	0.16

Because PO_4^{3-} is the most readily available form of phosphorous for uptake during photosynthesis, the study of this type of phosphorous is generally of high importance with regards to algal blooms and eutrophication (Yanagi et al. 1992).

Annual loads of nutrients were then calculated by multiplying the mean annual concentrations mentioned above by the corresponding volumes of annual inflowing (irrigation) water and drainage water, respectively. The total annual loads (in tn yr^{-1}) of DIN and IP discharged from the Agoulinitsa drainage network into the Ionian Sea were finally estimated by the following equations:

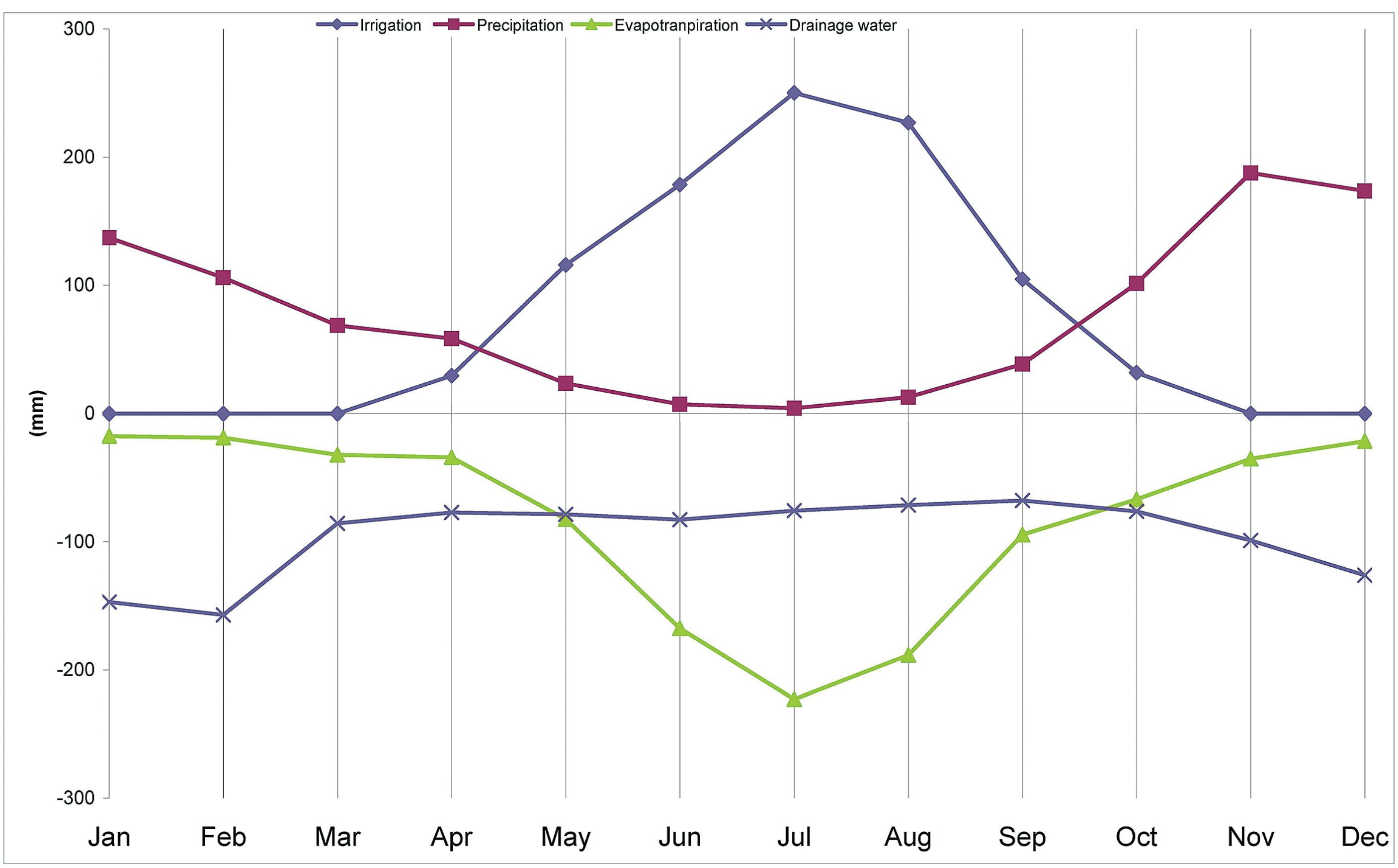
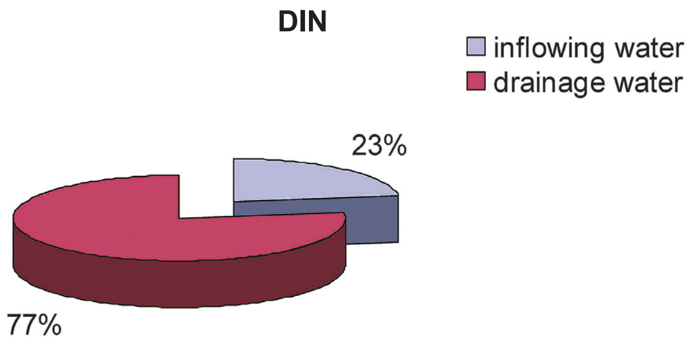


Fig. 2 Mean monthly inflows and outflows in the study area.



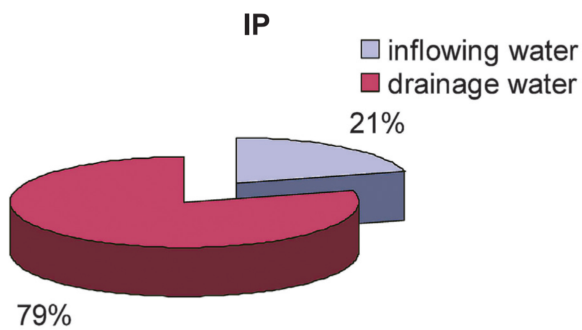


Fig.3 Pie-charts showing the contribution (%) of each type of water to the annual loads of nutrients discharged from the Agoulinitsa drainage network into the Ionian Sea.

$$L_{DIN\text{-}total} = L_{DIN\text{-}inflowing\ water} + L_{DIN\text{-}drainage\ water} \quad (4)$$

$$L_{IP\text{-}total} = L_{IP\text{-}inflowing\ water} + L_{IP\text{-}drainage\ water} \quad (5)$$

Results and Discussion

Concentrations of DIN and IP in drainage water are higher than the concentrations of DIN and IP in Alfeios surface water. This is attributed to the extensive use of fertilizers by farmers in the Agoulinitsa district. The results are shown in Table 3.

Table 3 Annual loads of nutrients for irrigation and drainage water.

	Volume (10^6 m^3 yr^{-1})	DIN (tn yr^{-1})	IP (tn yr^{-1})
Irrigation water	18.7	8.4	0.9
Drainage water	21.4	28.2	3.5
Total volume	40.1	36.6	4.4

From this table, the following remarks can be outlined:

(i) The annual volume of drainage water from the study area is greater than that of irrigation water, which is percolated into the soil by sprinkler irrigation, because drainage water is also composed of runoff from precipitation.

(ii) Annual loads of DIN and IP are far greater for drainage water than for irrigation water. Namely, the contribution of inflowing water (Alfeios River water feeding the irrigation network) in the annual DIN and IP loads are 23% and 21%, respectively, whereas the contribution of drainage water in the annual DIN and IP loads are 77 % and 79 %, respectively (Fig. 3).

(iii) Total annual loads of DIN and IP discharged from the Agoulinitsa drainage network into the Ionian Sea are 36.6 tons of DIN and 4.4 tons of IP.

To contribute to the environmental protection of the sea coast and to control the nutrient loads that are discharged into the seawater, a method of reusing drainage water and mixing with freshwater for irrigation use was proposed (Gotsis et al., 2011).

Conclusions

It was found that the drainage water of the study area contains nutrients expressed as Dissolved Inorganic Nitrogen (DIN) and Inorganic Phosphorous (IP), due mainly to the extensive use of fertilizers in the cultivated land. The annual transported loads of nutrients DIN and IP discharged into the sea were calculated to be 36.6 and 4.4 tons, respectively. These findings could contribute to the establishment of the appropriate policy measures for environmental protection (i.e., drainage water reuse after mixing with fresh water).

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