XXXVIII
IAH Congress

Groundwater Quality Sustainability
Krakow, 12–17 September 2010

Extended Abstracts

Editors:
Andrzej Zuber
Jarosław Kania
Ewa Kmiecik

University
of Silesia
Press 2010

IAH 2010
Krakow

abstract id: **136**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **Development of pedotransfer functions to estimate annual groundwater recharge rates in countries of the Arab region**

author(s): **Volker Hennings**
Bundesanstalt für Geowissenschaften und Rohstoffe, Germany,
volker.hennings@bgr.de

Johannes Wolfer
Bundesanstalt für Geowissenschaften und Rohstoffe, Germany,
johannes.wolfer@bgr.de

keywords: percolation rate, groundwater recharge rate, pedotransfer functions, soil water balance, Arab countries

INTRODUCTION

Within the framework of the technical cooperation project "Management, Protection and Sustainable Use of Groundwater and Soil Resources" between the Arab Center for Studies in Arid Zones and Dry Lands (ACSAD, Damascus/Syria) and the Federal Institute for Geosciences and Natural Resources (BGR, Hannover/Germany) a Decision Support System (DSS) for water resources management was developed and applied in two pilot areas, the Zabadani Basin in Syria and the Berechid Basin in Morocco (Droubi et al., 2008). The DSS has been built by the combination and linkage of three components, a project database, a groundwater flow model (MODFLOW2000; Harbaugh et al., 2000) and a user-friendly water evaluation and planning software (WEAP; Stockholm Environment Institute 2005). For running the MODFLOW model water flows from soil to groundwater have to be determined because the percolation rate from the soil acts as one of the main input variables.

On a regional scale reliable estimates for annual values or long term means of the percolation rate from the soil are needed for quantitative water resources management. Conventionally precise information about movement of water in the unsaturated zone can only be obtained from lysimeter data, soil-hydrological measurements or process-based simulation models such as SWAP (Kroes et al., 2003). To avoid high costs of field measurements and limitations in the availability of model input parameters robust methods such as empirical equations and nomograms are needed. To characterize this kind of approaches Wessolek et al. (2008) use the term "hydro-pedotransfer functions" (HPTFs). They are based only on input variables that can be determined easily or are available from existing databases.

Exemplary for Germany HPTFs to predict long term means of the percolation rate from soil were developed by Wessolek et al. (2008). The authors used a simulation model of the soil water balance to calculate actual evapotranspiration and percolation for different climatic regions, soils and land use classes. The spectrum of site variations included four soils with different water storage capacities, six groundwater levels, sixteen climate stations whose climate parameter values can be viewed as representative of the climate regions of Germany, and four land use types [cropland (with the typical succession of grain and root crops), grassland, coniferous forest, and deciduous forest]. These conditions resulted in simulation runs for 57,600 years on a daily basis. The results of all the scenarios were analyzed by multiple regression statistics and equations were derived, from which reliable estimates of the target variable can be calculated. These HPTFs were used to compile a nationwide map of the annual percolation rate from the soil within the framework of the new Hydrological Atlas of Germany (HAD) (BMU 1998, 2001, 2003). A goal of this investigation is to adapt this methodology to semi-arid climatic conditions so similar results can be obtained for locations in a Mediterranean environment.

MATERIALS AND METHODS

The same methodology as described above was used to develop similar nomograms or empirical equations for countries of the Arab region. For simulating the soil water balance the CROPWAT model (Clarke et al., 1998) was used. CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements. Additionally CROPWAT offers plant physiological coefficients for 36 agricultural crops (crop coefficient Kc, rooting depth, depletion fraction, and yield response factor). All calculations are based on a daily soil water balance using various options for water supply and irrigation management conditions. From the soil scientist's perspective percolation beyond the lower boundary of the root zone equals groundwater recharge.

The CROPWAT software as well as the CLIMWAT database is available from the FAO homepage via download. CLIMWAT 2.0 offers observed agroclimatic data of over 5000 stations distributed all over the world. CLIMWAT provides long-term monthly mean values of seven climatic parameters as required for CROPWAT applications. For this investigation data from 188 meteorological stations from eight Arabic countries (Morocco, Algeria, Tunesia, Libya, Egypt, Jordan, Lebanon, Syria) were used. Typical kinds of land use of the Mediterranean environment were taken into consideration. Five soils were compared, varying in the total available water capacity of the uppermost meter (40, 80, 120, 160, 200 mm). For all simulation runs a fixed amount of surface runoff is assumed, i.e. precipation in Fig. 1–2 means effective precipitation or net input.

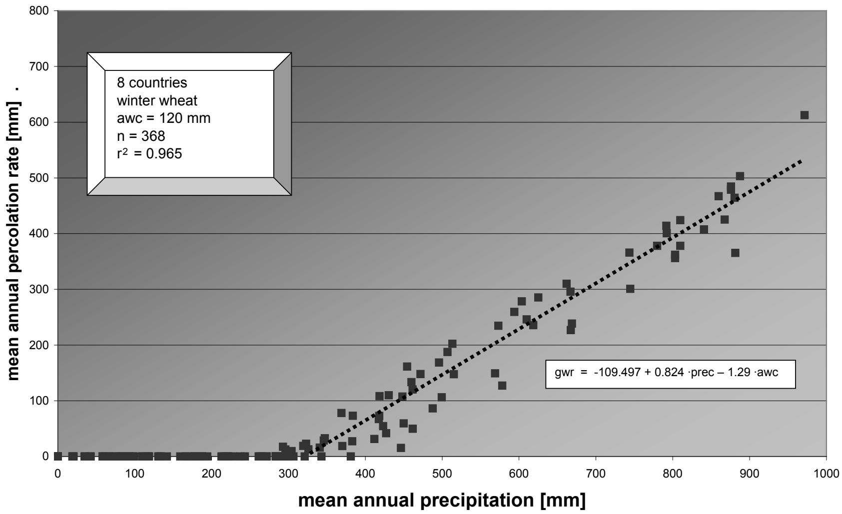

Figure 1. Annual percolation rate as a function of annual precipitation for land use type "winter wheat" and derived regression function.

First approach: preliminary pedotransfer functions derived from CROPWAT results for three kinds of land use under natural conditions

In Table 1 results for three kinds of land use (winter wheat, citrus trees, pastureland) are compared, and only natural conditions without irrigation are taken into consideration.

In order to predict mean annual percolation rates by HPTFs linear models based on precipitation and available water capacities are adequate. Based on the correlation coefficients in Table 1, the accuracy of these HPTFs is generally high. Accuracy in this context refers to correspondence between simulation model and pedotransfer function. Highly precise estimates of the target variable can be obtained on the basis of easily available soil, crop and climate information. Nomograms were developed for specific crops and varying soil properties and for specific locations and varying kinds of land use. An exemplary visualization of such a model and the derived regression equation is given in Figure 1. In the case shown, groundwater recharge from percolating water does not take place if effective precipitation is below a threshold of ≈ 300 mm.

Table 1. General conditions and summarized results of the first case study.

Land use type	Area	Target variable	Database	Statistically significant input variables	Correlation coefficient
Pastureland	8 countries	ETact	n = 940	Prec, awc	$r^2 = 0.929$
		GWR	n = 495	Prec, ETpot, awc	$r^2 = 0.930$
Winter wheat	8 countries	ETact	n = 940	Prec, awc	$r^2 = 0.912$
		GWR	n = 555	Prec, awc	$r^2 = 0.939$
	Syria	ETact	n = 220	Prec, ETpot, awc	$r^2 = 0.919$
		GWR	n = 185	Prec, awc	$r^2 = 0.968$
Citrus trees	8 countries	ETact	n = 940	Prec, awc	$r^2 = 0.922$
		GWR	n = 490	Prec, awc	$r^2 = 0.932$
	Syria	ETact	n = 220	Prec, ETpot, awc	$r^2 = 0.925$
		GWR	n = 170	Prec, awc	$r^2 = 0.960$

(ETact: actual evapotranspiration; GWR: groundwater recharge; Prec: precipitation; ETpot: potential evapotranspiration; Irrig: irrigation; awc: soil available water capacity)

Advanced approach: pedotransfer functions derived from model simulations based on the dual crop coefficient concept

The CROPWAT model applied in the first case study is based on the single crop coefficient concept, where differences in the crop canopy and aerodynamic resistance relative to the reference crop of the FAO Penman Montheith method are accounted for within the crop coefficient Kc. The Kc coefficient serves as lumped parameter for the physical and physiological differences between crops. Kc integrates the relationships between evapotranspiration of the crop and the reference surface and summarizes all factors influencing evaporation and transpiration. Therefore CROPWAT's use is restricted to the period of growth. In a second, more sophisticated approach Kc is split into two factors that separately describe the evaporation (Ke) and transpiration (Kcb) components. All relevant algorithms were published as part of the FAO Irrigation and Drainage Paper No. 56 "Crop Evapotranspiration" (Allen et al., 1998). Within the framework of the second case study the dual crop coefficient concept was applied to improve derived pedotransfer functions. In particular the following modifications were implemented:

- the dual crop coefficient concept was applied to calculate evaporation from bare soil before and after the period of growth and within its initial phase,
- the spectrum of typical Mediterranean crops was extended to olive trees and vegetables,
- CROPWAT-internal parameter settings were substituted by region-specific plant coefficients,
- the effects of irrigation were taken into account; generally irrigation up to maximum demand without yield reduction was simulated,
- expert knowledge about region-specific agricultural practices (sowing dates, irrigation practices, ...) was incorporated.

The second case study is restricted to Syria (44 meteorological stations) and includes six land use scenarios. Three crops under rainfed agriculture (wheat, barley, olives) are compared with three crops under irrigation (wheat, citrus trees, peas as an example for small vegetables). Based on the correlation coefficients in Table 2, mean annual percolation rates can be predicted by HPTFs very precisely.

Table 2. General conditions and summarized results of the second case study.

Land use type	Length of growing season	Sowing/ planting date	Period of potential evaporation	Statistically significant input variables for estimating GWR	Correlation coefficient
Winter wheat	240 days	1st Nov	155 days	Prec, awc	$r^2 = 0.957$
- no irrigation -					
Barley	160 days	1st Dec	225 days	Prec, awc	$r^2 = 0.967$
- no irrigation -					
Olives	270 days	1st Mar	125 days	Prec, awc	$r^2 = 0.951$
- no irrigation -					
Winter wheat	240 days	1st Nov	160 days	Prec, ETpot, Irrig	$r^2 = 0.989$
under irrigation					
Citrus trees	365 days	(whole	60 days	Prec, ETpot,	$r^2 = 0.957$
under irrigation		year)		Irrig, awc	
Vegetables	100 days	1st Apr	285 days	Prec, ETpot,	$r^2 = 0.999$
under irrigation				Irrig, awc	

(Prec: mean annual precipitation; ETpot: mean annual potential evapotranspiration; Irrig: irrigation; GWR: groundwater recharge; awc: soil available water capacity).

Regression models for rainfed cropping use only precipitation and soil available water capacity as independent variables while regression models for irrigated agriculture additionally integrate information on potential evapotranspiration. Outside desert areas in eastern parts of the country, the negative correlation between precipitation and potential evapotranspiration in Syria is not very strong; areas with high rainfall can be characterized by low evapotranspiration rates in the Antilebanon mountains as well as by high evapotranspiration rates on western slopes of the coastal range. For that reason estimated groundwater recharge as a function of precipitation only shows more variation under irrigated conditions. The distinction between rainfed and irrigated agriculture can also be found in Fig. 2: thresholds for the beginning of groundwater recharge in terms of annual precipitation are generally higher for non-irrigated crops than for crops that depend on irrigation in summer.

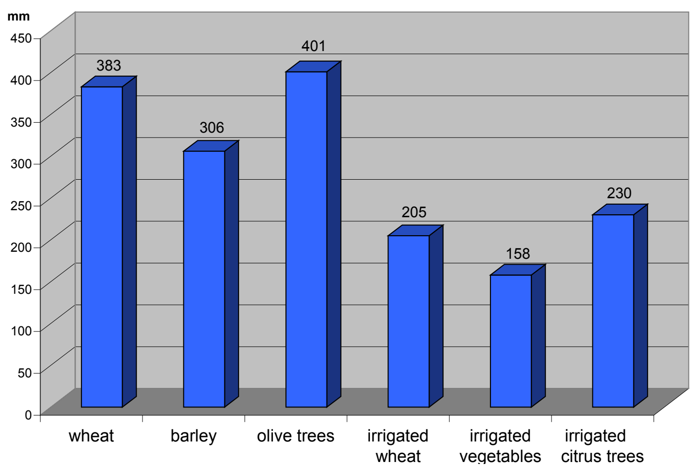

Figure 2. Minimum annual precipitation necessary for groundwater recharge for six agricultural crops in case of moderate soil available water capacity.

Another influencing factor is the crop itself: transpiration losses by crops with shallow rooting depths and short vegetation periods such as small vegetables are low in comparison to perennial crops with deep root zones such as olives. Against this background the following order of mean annual groundwater recharge under standardized conditions along land use types can be derived from model simulations: olive trees < wheat < barley < irrigated citrus trees < irrigated wheat < irrigated vegetables. (Hydro-) pedotransfer functions that require only easily available soil, crop and climate information as presented here can serve as a useful tool to provide reliable estimates of the groundwater recharge rate for most of typical land use types in Syria.

OUTLOOK/NEED FOR ACTION

Simulation results of the soil water balance following the dual crop coefficient concept were validated on the basis of measurement results from single test sites in southern Syria and Tunisia (Jabloun et al., 2008). By interpreting results from (hydro-) pedotransfer functions up to now some limitations have to be noted:

- The amount of surface runoff has to be known and was neither simulated by models nor empirically estimated.
- Results are not valid for groundwater affected soils with shallow water tables and capillary rise towards the root zone.
- Results are based only on long-term monthly mean values of agroclimatic data.
- All (hydro-) pedotransfer functions have to be furthermore validated on the basis of available measurements from test sites.

REFERENCES

Allen R.G., Pereira L.S., Raes D., Smith M., 1998: *Crop evapotranspiration – Guidelines for computing crop water requirements.* FAO Irrigation and Drainage Paper, 56; Rome.

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (Ed.), 1998, 2001, 2003: *Hydrologischer Atlas von Deutschland (Hydrological Atlas of Germany).* 1st Delivery 1998, 2nd Delivery 2001, 3rd Delivery 2003; Bonn.

Clarke D., Smith M., El-Askari Kh., 1998: *CropWat for Windows: User Guide.* Land and Water Development Division of FAO, Institute of Irrigation and Development Studies (IIDS) of Southampton University & National Water Research Center (NWRC) of Egypt.
http://www.fao.org/waicent/faoinfo/agricult/agl/aglw/cropwat.htm.

Droubi A.M., Al-Sibai M., Abdallah A., Zahra S., Obeissi M., Wolfer J., Huber M., Hennings V., Schelkes K., 2008: *A Decision Support System (DSS) for Water Resources Management - Design and Results from a Pilot Study in Syria.* In: Zereini, F. & Hötzl, H. (Eds.): Climatic Changes and Water Resources in the Middle East and North Africa. Environmental Science and Engineering, 20, Springer-Verlag, Berlin, pp. 199–225.

Harbaugh A.W., Banta E.R., Hill M.C., McDonald M.G., 2000: *MODFLOW-2000. The U.S. Geological Survey Modular Groundwater Model.* User Guide to Modularization Concepts and the Groundwater Flow Process. – Open-File Report 00-92, 121 p.

Jabloun M., Rezig M., Ben Abdallah H., Sahli A., Mougou H., 2008: *Développement et possibilités d'utilisation d'un logiciel "MABIA-Exploitation" pour la maîtrise et l'optimisation des irrigations a l'échelle de l'exploitation.* Annales de l'INRGREF, X, X-X, 1-12. Tunisie.

Kroes J.G., van Dam J.C., (Eds.), 2003: *Reference Manual SWAP Version 3.0.3.* Alterra-report 773. Alterra, Wageningen/The Netherlands.

Stockholm Environment Institute, 2005: *WEAP - Water Evaluation and Planning System.* User Guide for WEAP21. – Stockholm.

Wessolek G., Duijnisveld W.H.M., Trinks S., 2008: *Hydro-pedotransfer functions (HPTFs) for predicting annual percolation rate on a regional scale.* Journal of Hydrology, 356, pp. 17–27.

International Association of Hydrogeologists

AGH University of Science and Technology

2-vol. set + CD
ISSN 0208-6336
ISBN 978-83-226-1979-0