Understanding of water and nitrogen cycle in an irrigated Mediterranean area in southern Turkey (part 1)

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ABSTRACT
In arid and semi-arid regions, freshwater resources are under the ever increasing pressure of many current issues such as population increase, economic development, climate change and pollution. Nitrogen leaching from agricultural land is a main pollutant in Turkey. Calculations of N budget in agricultural systems with use of different empirical of statistical methods are common practice in OECD and EU countries. However this methodologies do not include climate and water cycle as part of the process as it is established by Soil and Water Assessment Tool (SWAT) model which was developed especially for modelling agricultural catchments. The study was conducted in Lower Seyhan River Plain Irrigation District (Akarsu) of 9,495 ha in Cukurova region of southern Turkey. The aim of this study was to improve understanding of: a) the effects of by-pass flows due to irrigation on the calibration of SWAT model, b) irrigation return flow (IRF) and/or drainage generating processes, c) N leaching dynamics with simulation of agricultural land management (fertilisation, irrigation, plant species) under Mediterranean climate conditions. The performance indicators of the modelled flow (R2, NSE and PBIAS) during calibration period of 2009-2012 were 0.62, 0.57 and 6.3 and for the validation period were 0.67, 0.59 and -10.04, respectively. Objective function statistics, R2, NSE and PBIAS in specific, for nitrogen in drainage were defined as 0.47, -0.63 and 88.1% for the calibration and 0.50, -0.20 and 72.9% for validation, respectively. This basin is not natural instead it is a man-made hydrologically well-defined area in a semi-arid Mediterranean region where it is subjected to intensive irrigation and fertilizer applications by anthropogenic activities. Imported N loads by irrigation water, rainfall and mineral fertilizer inputs make the calibration and validation challenging and difficult with relatively weak results. The routine fertilizer applications are exceedingly higher than the recommended levels, i.e., 380 kg N ha-1 is applied to corn while only 240 kg N ha-1 is the expert recommendation for corn in the region. This results in high potential for nitrogen leaching. The SWAT model results helped us to highlight that almost 40% of diverted irrigation waters has been recklessly squandered in the irrigation scheme. It is almost impossible to quantify by-pass flow magnitudes in such irrigation system without using any modelling tools. Furthermore, modelling exercises showed that SWAT model run results were sensitive to crop rotations type due to the fact that runoff by precipitation is low and high due to irrigation applications exceeding 1000 mm per year with mostly flood irrigation type.

Keywords: crop management, irrigation, nitrogen balance, SWAT, modelling

1. INTRODUCTION

The water quality is determined by a number of factors such as electrical conductivity, pH, amount of salts, dissolved oxygen, levels of microorganisms, nutrients, heavy metals, quantities of pesticides, and herbicides [3]. These factors can lead to the problems (salinity, infiltration, toxicity, and nutrients), which are extensively present in many watersheds with irrigated agriculture [4–7]. The European Union Water Framework Directive (WFD) has issued important regulations in order to reduce the environmental impact of nitrogen due to agriculture and to keep water bodies in good quality state; based on the EU Drinking Water Directive (80/778/EEC), the accepted maximum admissible concentration for the nitrate was set as 50 mg l−1 [10].
Understanding of nitrogen dynamics in the nature, nitrogen balance or nitrogen budget becomes more of an issue about prevention of environmental pollution and economic losses on a country basis. Nitrogen balance studies have been continued for over 170 years [17]. There are different ways of defining nitrogen budgets in empirical statistical methods, depending on the measurements and modeling. Calculation of N budget in agricultural systems by this way is a common practice in OECD and EU countries. This method does not include explaining the processes of nutrient cycle in the soil-plant-atmosphere system but follows statistical methodology at national and regional levels to determine nitrogen budget [18–20].
Measured nitrogen budgets in soil-plant-atmosphere level are based on the conservation of mass of nitrogen in the system. A previous study carried out [21, 22] aimed at evaluating nitrogen fluxes by measuring agronomic system in Akarsu Study Area in southern Turkey. As part of the findings, it was found that considerable amounts of nitrate are lost to drainage and shallow groundwater. During the study years, nitrogen budget calculations resulted in unaccounted values ranging from 40 to 60 kg N ha−1 [23].
As known, Mediterranean climate is characterized by mild rainy winters and hot dry summers [24]. Annual and interannual changes in dry and wet periods result in change of water balance and water level fluctuations especially in the areas where Mediterranean climate is dominating [25]. Based on the recent years' ongoing drought events and therefore water scarcity, irrigation scheduling and types need to be reevaluated. Recently, best management techniques such as drip irrigation [26] and rain water harvesting techniques [27] have been tried to put into practice in order to save both irrigation water and fertilizers. In the Mediterranean climate, irrigation is inevitable for maximizing the crop yield [28]. To increase crop yield and quality and at the same time to decrease the leaching below the rooting zone, managing nutrient concentrations in irrigation water is necessary, according to crop requirements [29].
Many tools are available to observe impacts of reduced irrigation and fertilization under agriculture best management practices (BMPs) scenario. Among those tools are different hydrological models capable of defining the nitrogen dynamics at the watershed level like AGNPS, AnnAGNPS, ANSWERS, ANSWERS-Continuous, CASC2D,DWSM, HSPF, KINEROS, MIKE SHE, APEX, and SWAT. And these are only a few of watershed modes, which are currently and commonly under the service of scientists and practitioners [30]. Soil and water assessment tool (SWAT) model is one of the tools developed to predict water and nutrient dynamics [31–34].

The aim of this study was to improve understanding of (a) the effects of bypass flows due to irrigation on the calibration of SWAT model, (b) irrigation return flow (IRF) and/or drainage generating processes, and (c) N leaching dynamics with simulation of agricultural land management (fertilization, irrigation, and plant species) under Mediterranean climate conditions.

2. MATERIALS AND METHODOLOGY

2.1. Study area

The Akarsu Irrigation District (AID) study area is located in the Mediterranean coastal region, between 36°51′45″ and 36°57′35″ N latitudes, and 35°24′10″ and 35°36′20″ E longitudes in Turkey. The district covers an area of 9,495 ha (irrigation area), and hydrological area is 11,308 ha in the Lower Seyhan Plain (LSP) and has been irrigated for over 60 years under conventional irrigation and drainage infrastructures. Until 1994, the national irrigation agency, i.e., State Hydraulic Works (DSI), was responsible for the management, operation, and maintenance of the district. Akarsu Water User Association has been responsible for the irrigation in the district since 1994. Irrigation water has been provided from Seyhan Dam (L6, L3, and L7 in Figure 1), in case of water shortage in the system during the peak irrigation season or if irrigation water is not diverted to the main irrigation canal through L6, then pumping station is activated and some water is diverted from Ceyhan River (Pumping Station, L9 in Figure 1). The drainage water flows through open ditches along the downstream areas and finally discharges into the Mediterranean Sea. In the area, 1st April–30th September is defined as irrigation season (IS), while 1st October–1st April is defined as non-irrigation season (NIS).
In the study area, the Mediterranean climate is dominant, summers are hot and dry winters are mild and rainy. Precipitation is mostly in the form of rain (average of 659 mm) that usually falls during winter and spring [35]. Temperature in June, July, and August is very high (average 33.3°C); winter months are cool with reasonable temperatures (average 10.5°C) [36]. While the long-term (1929–2014) mean temperature is 27.4°C, the long-term mean total evaporation is about 1559 mm annually (coefficient of variation <27%). According to the long-term data, soil moisture and soil temperature regimes are defined as xeric and thermic by Ref. [37]. The soils of Akarsu consist of 11 different soil series (Incirlik, Arikli, Yenice, Innapli, Arpaci, Canakci, Mursel, Ismailiye, Golyaka, Gemisure, and Misis) [37]. Arikli (29.5%), Incirlik (25.3%), and Yenice (12.2%) series cover 67% of the entire study area. Soils have on general clay or silty clay texture

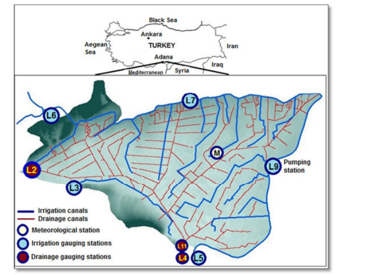

Figure 1. The Akarsu study area

2.2 Database

The SWAT model input data, which is used in the project, is listed in Table 1. The 25 m resolution digital elevation model was derived by Akgul [38]. The chemical and physical properties of soils were gathered from Ref. [37], and these data were checked and verified with various measurements and laboratory analysis. Soil albedos and values of USLE were calculated by using the equations given in Ref. [39]. Soil series characteristics were interpreted and soil hydrologic group codes were assigned to each soil series based on the run-off generating characteristics. Daily irrigation return flow rates were determined by the data observed at the Inlet (L2, L11) and Outlet (L4) drainage monitoring stations. Nitrate concentrations were determined in water samples collected via automatic sampler located in L4 gauging site.

Table 1. Model input data and the sources

Data type	Resolution	Source	Description/Properties
Topography (DEM)	25 m x 25 m	Akgul (2015)	Elevation, slope, channel slopes, overland
Land Cover/Land use	10 m x 10 m	Cetin et al. (2012)	Land cover, land use classification
Soils	10 m x 10 m	Dinc et al. (1995)	Spatial soil variability, soil types, soil physical properties; bulk density, texture, saturated hydraulic conductivity classes, etc.
Drainage Network		Cetin et al. (2012)	Drain spacing, length of cannels, drainage divides, etc.
Climate Data		Adana State Meteorological Station and meteorological monitoring gage (L8)	Daily precipitation, temperature (max., min.), solar radiation, wind speed, relative humidity
Agricultural Management Practices		Farmer questionnaires in Akarsu and field surveys (face to face)	Planting, fertilizer application rates and timing, tillage, harvesting dates, irrigation water management and amount, etc.
Daily Irrigation Return Flow Rate (Outlet)		1 monitoring and sampling station (L4 in Figure 1)	Daily flow (m^3 day^{-1})
Daily Irrigation Return Flow Rate (Inlet)		2 monitoring and sampling stations (L2, L11)	Daily flow (m^3 day^{-1})
Daily Irrigation Return Flow Nitrate Load (Outlet)		1 monitoring and sampling station	Daily NO_3-N load (kg day^{-1})
Daily Irrigation Return Flow Nitrate Load (Inlet)		2 monitoring and sampling stations (L2, L11)	Daily NO_3-N load (kg day^{-1})

2.3 Agricultural land management

The area is suitable for various agricultural productions with its favorable climatic and productive land conditions. Cropping pattern data have been assessed since 2006, and the likely crop rotation has been decided for the modeling practices. According to the data, land use and cropping pattern varied from year to year depending on the market and cultivation conditions. Based on the assessments, we have set five different crop rotations plus fruit orchards and citrus plantations (Table 2), which have been well adopted by the farmers in the region. Based on the recent years' evaluation, the main crops in the area were wheat, corn, citrus, cotton, and vegetables (Table 3). Agricultural management practices were determined based on the current surveys carried out at the local field and farmers' level.

The proportion of this land use type in the hydrological model area (11,308 ha) is: AGRL (Agricultural Area) (64.56%), ORAN (Citrus) (21.49%), ORCD (Orchards) (1.74%), WPAS (Winter Pastures) (9.20%), URMD (Settlement area (Medium Density)) (1.64%), and URLD (Settlement area (Low Density) (1.36%)). The agricultural areas in the study area contain various annual crops such as first crop corn, second crop corn, winter wheat, first crop soybean, second crop soybean, peanuts, and cotton.

Table 2. Agricultural land management crop rotations used in the model.

Year	Soil Tillage and Crop Growing Period	Crops	Inorganic Nitrogen Fertilizer (kg elemental N ha^{-1})	Irrigation Water (mm)
Rotation 1				
1	16th Mar. - 16th Sep.	C1[1]	385	1168
1/2	20th Nov. - 07th June	WW[2]	230	383
2/3	15th June - 10th Oct.	S2[3]	120	870
3	16th Mar. - 16th Sep.	C1[1]	385	1168
3/4	20th Nov. - 1 June	WW[2]	230	383
4	15th June - 10th Oct.	S2[3]	120	870
Rotation 2				
1	15th June - 10th Oct.	S2[3]	120	870
2	16th Mar. - 16th Sep.	C1[1]	385	1168
2/3	20th Nov. - 07th June	WW[2]	230	383
3	15th June - 10th Oct.	S2[3]	120	870
4	16th Mar. - 16th Sep.	C1[1]	385	1168
Rotation 3				
1	15th Mar. - 15th Oct.	Co[4]	290	1535
2	15th Apr. - 10th Sep.	P1[5]	210	1068
3	15th Mar. - 15th Oct.	Co[4]	290	1535
4	16th Mar. - 16th Sep.	C1[1]	385	1168
Rotation 4				
1	15th June - 25th Oct.	P2[6]	210	800
2	16th Mar. - 16th Sep.	C1[1]	385	1168
2/3	20th Nov. - 07th June	WW[2]	230	383
3	15th June - 25th Oct.	P2[6]	210	800
4	15th Mar.- 15th Oct.	Co[4]	290	1535
4/1	20th Nov. - 07th June	WW[2]	230	383
Rotation 5				
1	20th June - 30th Oct.	C2[7]	330	858
2	16th Mar. -16th Sep.	C1[1]	385	1168
2/3	20th Nov. - 07th June	WW[2]	230	383
3	20th June - 30th Oct	C2[7]	330	858
4	15th Mar. - 15th Oct.	Co[4]	290	1535
4/1	20th Nov. - 07th June	WW[2]	230	383
				Orchards and Citrus[*]
Perennial	15th Mar. - 8th Oct.	Orchards	250	1238
Perennial	1st Oct. - 27th Sept	Citrus	335	1040

[1]C1 First crop corn, [2]WW Winter wheat, [3]S2 Second crop soybean, [4]Co Cotton, [5]P1 First crop peanut, [6]P2 Second crop peanut, [7]C2 Second crop corn and [*]All kinds of operations done to orchards and citrus between these dates

3. RESULTS AND DISCUSSION

3.1 Calibration of drainage flows

Calibration process of the model used in this specific research was first completed with hydrologic calibration and followed by the drainage nitrogen. In general, calibration and validation of water quality models are typically performed with data collected at the outlet of a watershed to be able to assess possible pollution risks. In Akarsu, daily measured data were used during the model processes. The most sensitive parameters for hydrologic calibration process were SURLAG, GW_Delay, Revapmn, GW_Revap, and Esco, while Nperco, Cmn, Hlife, and Ngw are the sensitive ones for nitrogen calibration (Table 4).

Three recommended quantitative statistics, determination (R2), Nash-Sutcliffe efficiency (NSE), and PBIAS, in addition to the graphical techniques for visual examination have been used to assess the hydrologic model performance [59], i.e., model calibration and validation (Table 3, Figure 2)

Table 3. Objective function statistics for drainage flow and nitrogen in drainage

Variable	R^2	NSE	PBIAS
Calibration (2009-2012)			
Daily drainage flow	0.62	0.57	6.3
Daily nitrogen loss	0.47	-0.63	88.1
Validation (2013-2014)			
Daily drainage flow	0.67	0.59	-10.04
Daily nitrogen loss	0.50	-0.20	72.9

Because the study area is under irrigation in dry periods of the year, it was necessary to consider irrigation amounts of field and horticultural crops grown in the region. Therefore, during the calibration period, irrigation requirements of the crops were estimated by using universal reference evapotranspiration method of Penman-Monteith. Then, using the crop coefficients of FAO [60], net irrigation requirements of irrigated crops were obtained and used in management files as a model input. For the calibration, the created base model with net irrigation amounts and routine fertilizer rates were saved in crop rotations. The actual irrigation bypass flows were determined through running different simulations by adapting calibrated SWAT parameters. Finally, it was determined that 40% of the total diverted irrigation water to the district at any time was directly draining into the drainage system as bypass flow.

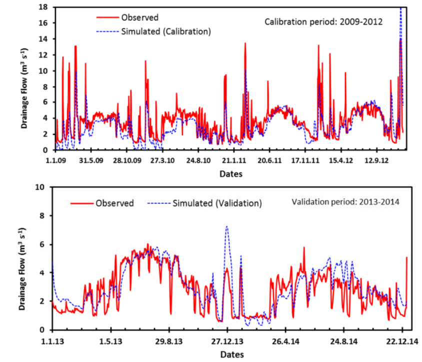

Figure 2: Daily drainage discharge (m^3 s^{-1}) for calibration and validation period for the Akarsu catchment outlet L4

Table 4. Sensitive hydrologic model parameters for SWAT

Parameter	Default	Range	Calibrated Values
CN2	83	35-98	73.9
Alpha_BF	0.048	0-1	0.55
GW_Delay	31	0-500	36.08
Gwqmn	1000	0-5000	4187.5
Surlag	4	1-24	0.42
Esco	0.95	0-1	0.837
Revapmn	750	0-1000	488.75
Ch_K2	0	-0.01-500	378.75
Gw_Revap	0.02	0.02-0,2	0.089
Ch_n2	0.014	-0.01-0,3	0.266

3.2 Nitrogen Balance

Nitrogen calibration was carried out on daily basis. Average daily NO3-N loads (kg day−1) of selected water quality parameter were calculated based on daily discharge data (m3 day−1) at L4 gauging station (Table 5 and Figure 3). Nitrogen did not show a strong relationship between measured and simulated values. One of the main reasons is that for hydrologic reasons inclusion of the two hilly pasture areas (Figure 1) into the 9495 ha hydrologically well-defined Akarsu irrigation district by extending the area to 11,308 ha. Therefore, when the actual N inputs were distributed in a larger area the prediction became lower. Also, since the soils are climatically suitable to nitrification, greater amount of nitrogen especially from the inorganic fertilizers may be quickly transformed to nitrate in a very short time period and leached to the drainage [62]. As also discussed by Abbaspour et al. [56], amount of nitrogen fertilizer leached below the root zone, which is 0–90 cm in the study, is under-estimated. In addition, fertilizer application level may be higher than that of the recorded from our three consecutive survey data. Therefore, it may cause higher measured NO3 concentrations in drainage. Overall, since the irrigated area is under very intensive agricultural management practices including irrigation and very dynamic fertilization, it is quite possible to underestimate the N leaching to the drainage. For example, SWAT model prediction was very successful for calibration (and validation) of rivers accounting the dynamics of nitrate transport [56].

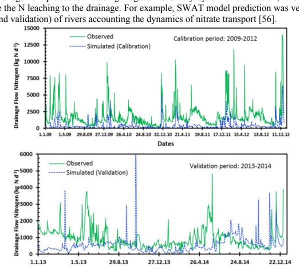

Figure 3. Nitrogen load (kg/day) at L4 (outlet) calibration and validation period on monthly level

Nitrogen balance variables are given in Table 5. The sums of nitrate nitrogen leached from the soil profile in kg NO3–N (NO3L) and N uptake by plants (NUP) from 2009 to 2014 are reasonably in agreement with the amount of applied nitrogen (N APP). The remaining inputs in the so-called man-made research area are coming from the N content of irrigation water, rainfall, mineralization of soil organic matter, and transforms of N forms into readily available NH4+ and NO3. Based on the climatic conditions, amount of rainfall, thus leaching to drainage, and groundwater, varies year to year. For example, in 2013, total rainfall was 349 mm, which was the lowest figure among the other years of the study (ranged 349–951 mm). The reflection of this unusual rainfall was clearly performed in Figure 5, which is for the simulation period.
Figure 3 clearly indicates that impacts of rainfall in winter and irrigation applications in summer are the most important drivers of the N leaching. Conflicting performance ratings of N calibration seen in Figures 3 might be attributed to above mentioned two drivers. In addition, routine fertilizer applications are exceedingly high than the recommended levels, i.e., 380 kg N ha−1 is applied to corn while only 240 kg N ha−1 is the expert recommendation for corn in the region [63]. This results in high potential for nitrogen leaching (Figure 4).

Table 5. Temporal variability of nitrogen balance by SWAT modeling for the Akarsu region (2009–2014).

Year	Nitrogen balance variables (kg N ha^{-1} $year^{-1}$)		
	N_APP[*]	NO3L	NUP
2009	329.2	196.8	270.0
2010	368.1	212.8	228.3
2011	310.9	234.7	181.3
2012	368.1	256.3	175.1
2013	329.2	159.2	277.7
2014	368.1	249.3	254.6

[*] N_APP, NO3L and NUP stand for applied, leached and taken-up nitrogen at the catchment level

4. CONCLUSIONS

Model calibration and validation were carried out to determine the most sensitive and appropriate parameter values for the drainage flows generated by the agricultural catchment. In the irrigated catchment, irrigation water losses directly from irrigation channels to drainage ditches, i.e., bypass flows, has direct influence on calibrating hydrologic part of the SWAT model. In this case, the SWAT model findings helped us to highlight that almost 40% of diverted irrigation water has been recklessly squandered in the irrigation scheme. It is almost impossible to quantify bypass flow magnitudes in such irrigation system without using any modeling tools.

Furthermore, modeling exercises showed that the SWAT model run results were sensitive on crop rotations due to the fact that runoff by precipitation and irrigation applications are affected by the land use and land cover types. Contrary to the expectations, daily nitrate modeling results were not able to yield rather satisfactory model performance statistics, indicating that simulated daily nitrogen loads data in drainage were not sufficiently matched with the measured ones. Visual evaluation of measured and simulated nitrogen graphs showed implicit signals that measured nitrogen data might involve some inherent uncertainties and irregularities at the catchment level. Based on the findings, as highlighted in the literature [59], we concluded that model performance can be improved to some extent by increasing the time step from daily to monthly or yearly level for the nitrogen data with involves inherent uncertainties. These uncertainties should be considered when calibrating, validating, and evaluating watershed models because of differences in inherent uncertainty between measured flow, sediment, and nutrient data.

Improved fertilization practices are not only necessary for farmer's economy but also crucial for preserving soil and water resources. In recent years, especial soil analysis in the study area became a very useful tool for fertilizer subsidizes and expert recommendations. However, recommendations can not only be related to and designed by the soil analysis, it should be comprehensively evaluated in a broader environment. At this stage, a suitable model performance enables modeling more sensitive management practices like the fertilizer rates.

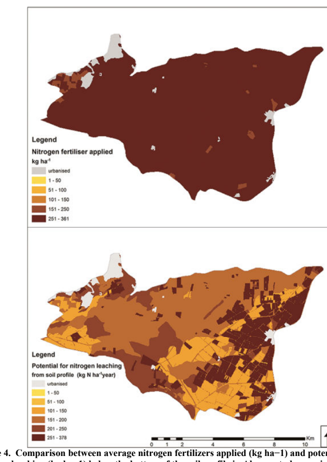

Figure 4. Comparison between average nitrogen fertilizers applied (kg ha−1) and potential for nitrogen leaching (kg ha−1) below the bottom of the soil profile in Akarsu study area in the period between 2009 and 2014.

5. ACKNOWLEDGMENTS

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