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ORIGINAL SCIENTIFIC PAPER

Using structural equation model to estimate nitrate pollution in the Melen Watershed of the Turkey

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Abstract
In this study, Bayesian technique was applied in order to estimate export coefficients for the Melen Watershed. Furthermore, instead of calculating the contributions of subwatersheds individually, the whole watershed was considered for the estimation of the total load at the outlet of the Melen Watershed using the calculated nitrate export coefficient. The Bayesian approach has the goal of combining prior knowledge with data to optimally use both sources of information. Success of the Bayesian approach is directly proportional to sufficiency of data for acquiring the prior information about estimands. Bayesian analysis was conducted through Structural Equation Model (SEM) using AMOS software and posterior information about land use based export coefficients was obtained through Markov Chain Monte Carlo (MCMC) method. Estimated land use based nitrate export coefficients are in kg/km^2/day unit. In addition, monthly river retention value of nitrogen in all subwatersheds of the Melen Watershed were estimated. This information was used in order to predict nitrate export coefficients appropriately. This study is aimed to be an important precedent for other basins that are determined as in priority in terms of pollution by The Ministry of Forest and Water Works of Turkey.

1. INTRODUCTION

The Melen Watershed is located in Western Black Sea region of Turkey (see Figure 1). It has the 2437 km^2 area (Ozturk et al., 2008). The Melen Watershed provides fresh drinking water to most of Istanbul. As foreseen by Erturk et al. (2008) since 2010 more than 50 percent of Istanbul's water demand has been supplied from the Buyuk Melen River. Istanbul Water and Sewerage Administration (ISKI) Master Plan foresee that 35 m^3/s water is going to be transferred from the Buyuk Melen River to Istanbul by 2039 (Erturk et al., 2008). For this purpose, a reservoir system is being constructed on the Buyuk Melen River. The Melen Watershed is regarded as a sensitive area, since the Buyuk Melen River is used as a potable water source for Istanbul (Mantas et al., 2007). The Buyuk Melen River is 30 km long. It is currently under the threat of land based pollution. In 2001 Sumer et al. revealed with their research that its water can be classified as water class number 2. Since 2001 settlements and the population in the watershed have been increased. As far as it is known there are no agricultural or urban best management practices applied in the region. Therefore, a significant decrease in the water quality of the river in the future is expected. Two main rivers are located in the Melen Watershed. These are the Buyuk Melen and the Kucuk Melen rivers. The government constructed a water regulator close to the outlet of the Buyuk Melen River. Fresh water is pumped to Istanbul with a 150 km long pipe. Protection of water quality in the Melen Watershed is also vital for

Istanbul's drinking water quality. Protection of water sources needs prior researches on determination of possible sources of pollution. Most importantly, transport of the nonpoint sources of pollution and land use management practices should be investigated. Because of this purpose, nitrate export coefficient modeling of the Melen Watershed is dealt with during this research.

Export coefficients are usually determined with the help of load measurements at an outlet of a subwatershed where there is a single dominant land use. In order to estimate the export coefficients it is assumed that the export coefficients for the same land use category are the same in all subwatersheds.

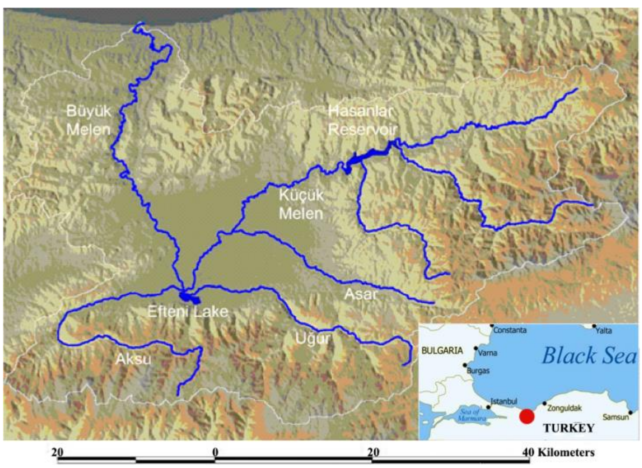

Figure 1. The Melen Watershed and its Rivers (Erturk et al., 2007).

2. MATERIAL AND METHODS

The structural equation model (SEM) simplifies the real-life relationships, explains them using the symbols.

The main purpose of the studying with SEM in scientific studies is to understand the complex events. The SEM approach is a multivariate statistical technique enabling simultaneous examination of direct and indirect real-life relationships using both quantitative and qualitative variables. It is a causal process that generates observations on multiple variables (Chenini and Khemiri, 2009). SEM has a theory-driven nature. It has been widely used in causal modeling for nonexperimental studies, especially in social sciences. However, this approach has also been applied in natural sciences, in recent years (Liu et al., 1997; Arhonditsis et al., 2006). In their study, Liu et al. (1997) used SEM as a tool to further understand the dynamics of nitrate, water quality, climate, and land management in the basin. Nowadays, Bayesian methods are gaining more popularity and moving into structural equation modeling. It may be considered as one of the most sophisticated approaches for modeling interactions. The values of observed variables can be predicted efficiently using combined structural equation modeling and Bayesian approach (Lee, 2007).

A successful ecological illustration of the use of Bayesian SEM is given in Arhonditsis et al. (2006). Furthermore, Muthen and Muthen (2002) mention a good example of Monte Carlo simulation with structural equation modeling for determining statistical power or sample size for a variety of different models.

2.1. Bayesian estimation using structural equation modeling software AMOS

AMOS (Analysis of moment structures) is a component of SPSS (Statistical package for Social sciences). AMOS is used to undertake regression analysis, confirmatory factor analysis, structural equation modelling (SEM), and latent variable growth curve modelling. In this study, prior distribution for the nitrate export coefficient parameters (Ei) were defined before applying Bayesian inference using Markov Chain Monte Carlo (MCMC) technique in AMOS. Value for each month was calculated according to the dominated land use, Ei (i=1…n; where n is the total number of land use). Ei parameter is an independent parameter for the analysis. All Ei parameters were linked to the dependent parameter, which is the total exported load from the whole watershed (L).

Through the Bayesian inference, using MCMC technique, AMOS produced the posterior distribution for pollution parameters (e.g. NO3-). The above steps were respectively repeated for every pollution parameter. During this process, nitrate retention in rivers was also taken into consideration. The constant of proportionality is calculated by normalization of the posterior density. In case of poor identifiability, the posterior distribution is not much different from the prior.

In case of high information content of data, it is typically much narrower. The disadvantage of this technique is that use of prior information introduces a subjective element into data evaluation procedure (see Figure 2). To get a numerical approximation to the posterior distribution, a sample was calculated by applying a MCMC technique using a structural equation modeling software AMOS. Although it is an efficient way of calculating export coefficients, the bad aspect of this methodology is the long burn-in periods.

Land use data was already prepared for whole watershed and for each subwatershed of the Melen Watershed, respectively through literature survey such as ESBN (2005), Oakes (1954) and Polat (2000) (see Figure 3). Figure 4 shows the flow path or the direction of the flow at the watershed.

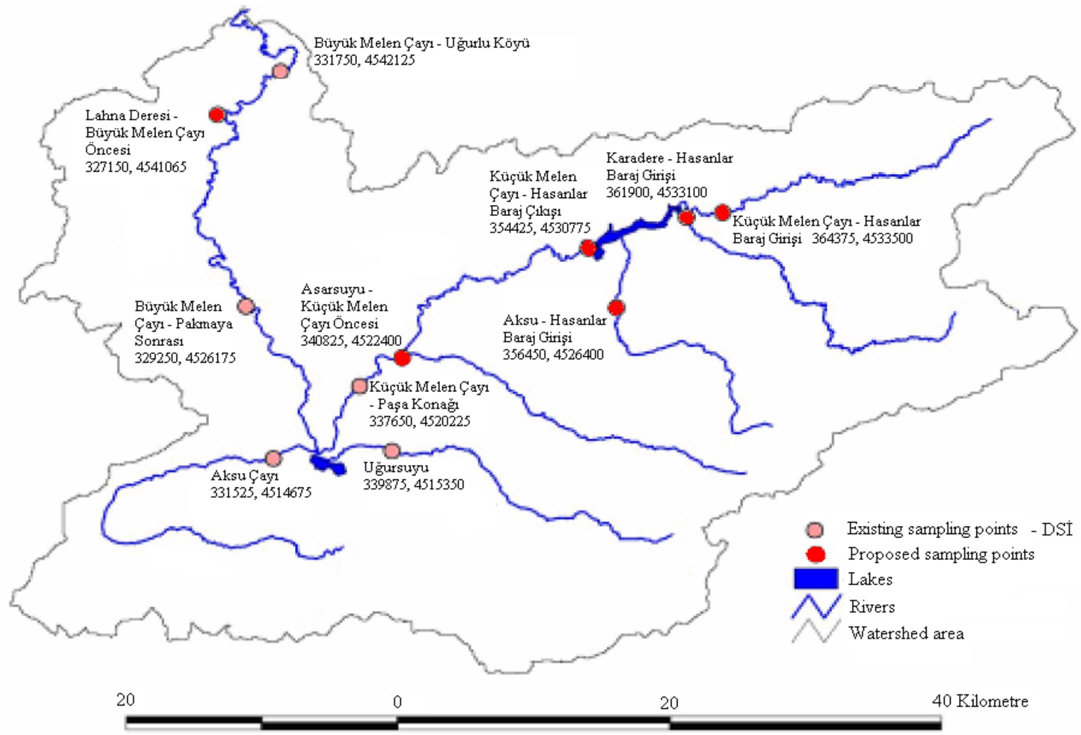

Figure 2. Sampling point coordinates in WGS84 Datum UTM coordinate system 36N.

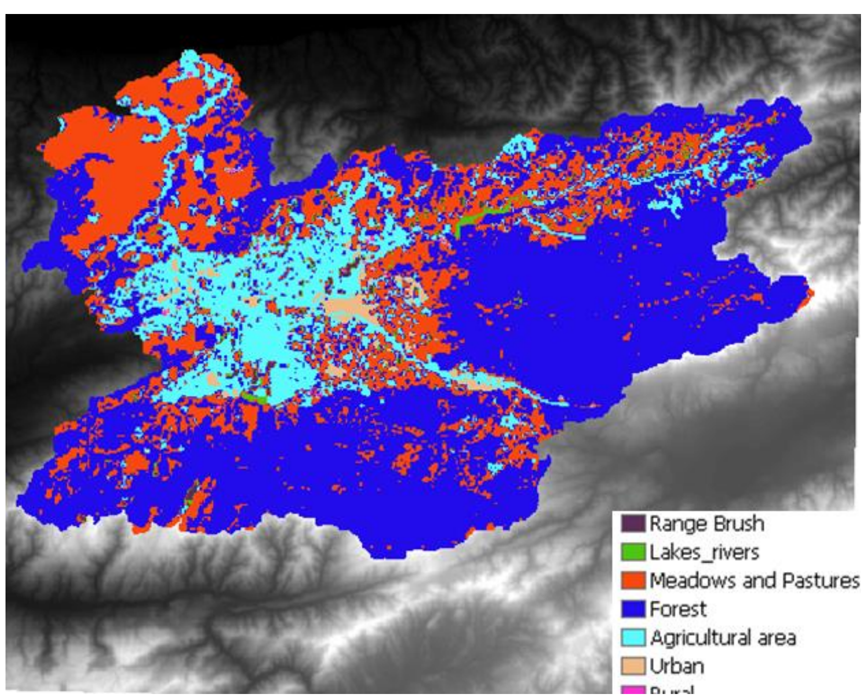

Figure 3. Digital land use grid map prepared for the Melen Watershed (DSI, 2010).

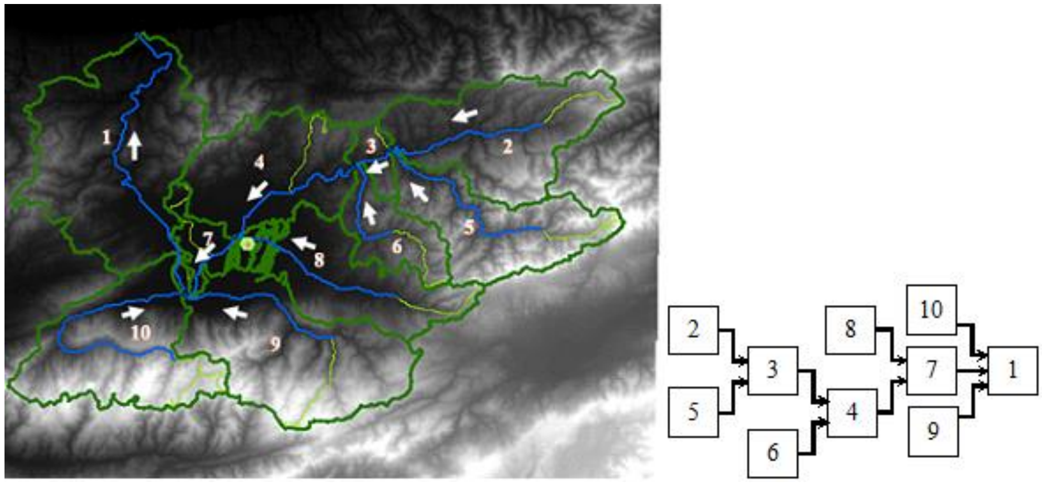

Figure 4. Subwatersheds, rivers, and flow path of the Melen Watershed.

Contribution of each subwatershed to the pollution load at the outlet of the Melen Watershed is calculated as shown in the following.

(i) Subwatershed 5:
$[[[[(E_{Mea}\times A_{Mea,5}+E_{Agr}\times A_{Agr,5+}E_{For}\times A_{For,5+}E_{Res}\times A_{Res,5})\times (1\text{-}R_5)]\times(1\text{-}R_3)]\times(1\text{-}R_4)]\times(1\text{-}R_7)]\times(1\text{-}R_1)$

(ii) Subwatershed 2:
$[[[[(E_{Mea}\times A_{Mea,2}+E_{Agr}\times A_{Agr,2+}E_{For}\times A_{For,2+}E_{Res}\times A_{Res,2})\times (1\text{-}R_2)]\times(1\text{-}R_3)]\times(1\text{-}R_4)]\times(1\text{-}R_7)]\times(1\text{-}R_1)$

(iii) Subwatershed 6:
$[[[(E_{Mea}\times A_{Mea,6}+E_{Agr}\times A_{Agr,6}+E_{For}\times A_{For,6}+E_{Res}\times A_{Res,6})\times (1\text{-}R_6)]\times(1\text{-}R_4)]\times(1\text{-}R_7)] \times (1\text{-}R_1)$

(iv) Subwatershed 3:
$[[[(E_{Mea}\times A_{Mea,3}+E_{Agr}\times A_{Agr,3}+E_{For}\times A_{For,3}+E_{Res}\times A_{Res,3})\times (1\text{-}R_3)]\times(1\text{-}R_4)]\times(1\text{-}R_7)] \times (1\text{-}R_1)$

(v) Subwatershed 4:
$[[(E_{Mea}\times A_{Mea,4}+E_{Agr}\times A_{Agr,4}+E_{For}\times A_{For,4}+E_{Res}\times A_{Res,4})\times (1\text{-}R_4)]\times(1\text{-}R_7)]\times(1\text{-}R_1)$

(vi) Subwatershed 8:
$[[(E_{Mea}\times A_{Mea,8}+E_{Agr}\times A_{Agr,8}+E_{For}\times A_{For,8}+E_{Res}\times A_{Res,8})\times (1\text{-}R_8)]\times(1\text{-}R_7)]\times(1\text{-}R_1)$

(vii) Subwatershed 9:
$[(E_{Mea}\times A_{Mea,9}+E_{Agr}\times A_{Agr,9}+E_{For}\times A_{For,9}+E_{Res}\times A_{Res,9})\times (1\text{-}R_9)]\times(1\text{-}R_1)$

(viii) Subwatershed 7:
$[(E_{Mea}\times A_{Mea,7}+E_{Agr}\times A_{Agr,7}+E_{For}\times A_{For,7}+E_{Res}\times A_{Res,7})\times (1\text{-}R_7)]\times(1\text{-}R_1)$

(ix) Subwatershed 10:
$[(E_{Mea}\times A_{Mea,10}+E_{Agr}\times A_{Agr,10}+E_{For}\times A_{For,10}+E_{Res}\times A_{Res,10}) \times(1\text{-}R_{10})]\times(1\text{-}R_1)$

(x) Subwatershed 1:
$(E_{Mea}\times A_{Mea,1}+E_{Agr}\times A_{Agr,1}+E_{For}\times A_{For,1}+E_{Res}\times A_{Res,1})\times(1 \text{-}R_1)$

where E stands for the nitrate export coefficient; Mea, Agr, For and Res stand for Meadows pastures and brush, Agricultural, Forest and Residential; A stands for the area; and R stands for the percent river nitrate retention coefficient.

The retention and loss of nitrates in river systems were specified using the approach of de Klein and Koelmans (2011). Monthly retention of nitrogen can be estimated from surface water area specific runoff as seen in Equation 1. Annual average monthly percent nitrogen retention for all subwatersheds is summarized in Table 1. See Table 2 for the precipitation - discharge relationship.

$$R_i = 0.0246\left(\frac{Q_i}{SW}\right)^{-0.57} \quad (1)$$

where Q_i is the average (monthly) discharge (m^3s^{-1}); *SW* is the total area of surface water in the catchment (ha); R_i is the retention fraction (-); and *i* the index for month (-).

B. Melen Çayı Uğurlu Köyü is the sampling point where the sufficient data for discharge (Q) is existed compared to other sampling points. Figures 5 to 9 show the discharge prediction phases for each sampling points based on the B. Melen Çayı Uğurlu Köyü. Discharge (Q) relations between B. Melen Çayı Uğurlu Köyü and all other sampling points are summarized in Table 3.

Table 1. Annual average monthly percent nitrogen retention for all subwatersheds.

	Subwatershed									
Year	1	2	3	4	5	6	7	8	9	10
1995	5.34	28.75	21.15	17.24	23.04	45.44	4.75	23.70	32.07	18.20
1996	8.03	33.59	26.33	21.45	29.64	59.81	8.47	30.56	47.99	27.26
1997	4.56	23.03	16.15	13.16	20.56	40.22	3.59	19.21	26.56	15.47
1998	5.20	29.24	17.24	14.04	22.26	43.89	4.87	21.20	33.83	19.71
1999	6.44	36.44	29.03	23.65	26.50	52.73	5.77	33.16	45.40	22.21
2000	4.62	23.23	17.62	14.38	20.75	40.65	3.81	16.93	33.72	16.38
2001	7.21	44.62	28.25	23.06	28.14	56.47	6.58	43.95	53.83	25.21
2002	5.30	27.39	25.37	20.67	23.06	45.47	4.48	20.77	38.31	18.91
2003	6.72	41.58	25.48	20.51	26.67	53.31	6.01	38.65	50.35	24.17
2004	5.19	27.90	21.96	18.02	22.26	43.94	4.30	21.35	41.64	18.75
2005	7.18	34.72	25.30	20.62	26.29	50.94	5.72	20.84	40.57	23.37
2006	8.04	46.58	30.72	25.03	30.76	61.10	8.17	42.36	47.38	29.66
2007	5.41	27.50	24.08	19.62	23.11	44.83	4.41	19.60	38.08	19.30
2008	4.49	21.71	14.61	11.90	20.72	40.40	3.53	14.29	27.90	16.04
2009	4.12	19.52	11.88	9.68	19.49	37.83	3.18	12.40	24.29	14.81
2010	4.47	21.73	15.46	12.59	20.59	40.15	3.53	14.54	28.33	15.96

Table 2. AMOS Bayesian analysis output for precipitation - discharge relationship.

	Mean	**S.E.**	**S.D.**	**C.S. (convergence)**	**Median**	**95% Lower bound**	**95% Upper bound**
Regression weights							
DISCHARGE<--PRE	32.763630	0.024903	4.790619	1.000014	32.760338	23.353979	42.217579
Intercepts							
PRE	1.165055	0.000225	0.048745	1.000011	1.165029	1.069376	1.260383
DISCHARGE	14.552746	0.024027	5.865717	1.000008	14.557041	3.018368	26.010193
Variances							
error_(e1)	0.741119	0.000283	0.059921	1.000011	0.737922	0.631984	0.867234
error_(e2)	1504.948404	1.146202	192.517305	1.000018	1489.320374	1172.983398	1925.5335

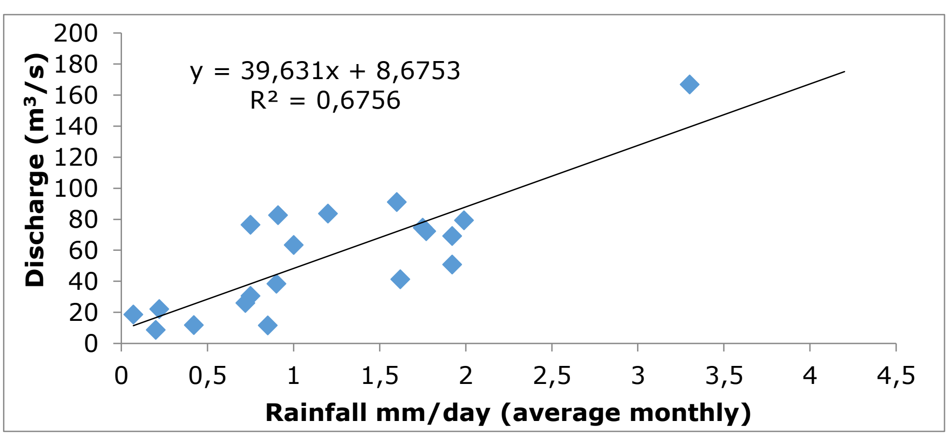

Figure 5. Precipitation vs. Discharge at B. Melen Çayı Uğurlu Köyü (DSİ AGİ) between 1998-2000 (best fitted period).

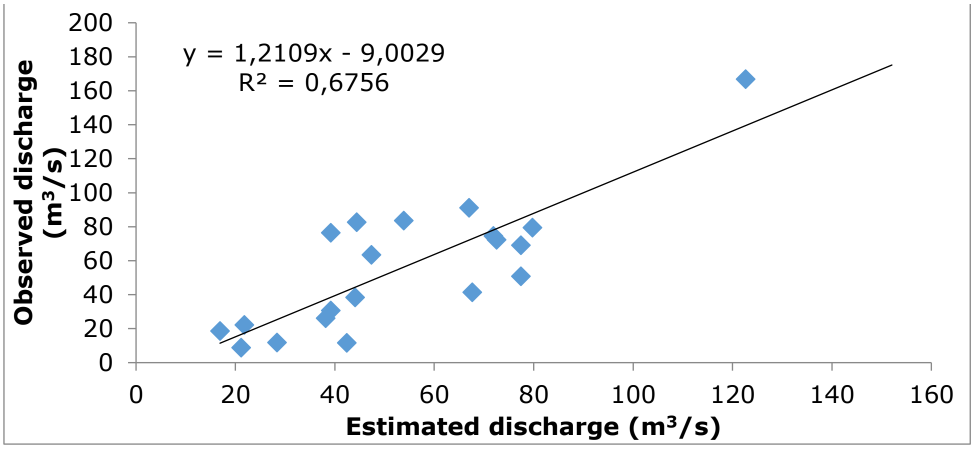

Figure 6. Bayesian estimation vs. observed discharge at B. Melen Çayı Uğurlu Köyü (DSİ AGİ) between 1998-2000 (best fitted period).

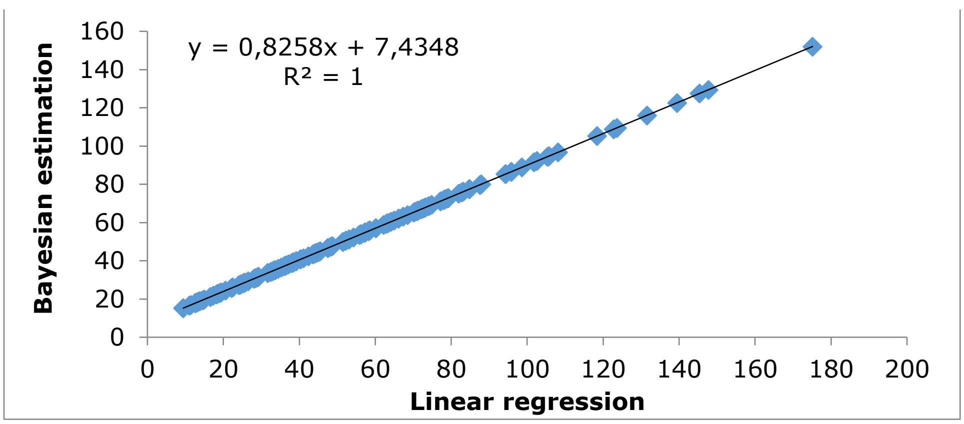

Figure 7. Estimation of Q values (m^3/s) of B. Melen Çayı Uğurlu Köyü (Bayesian vs. linear regression).

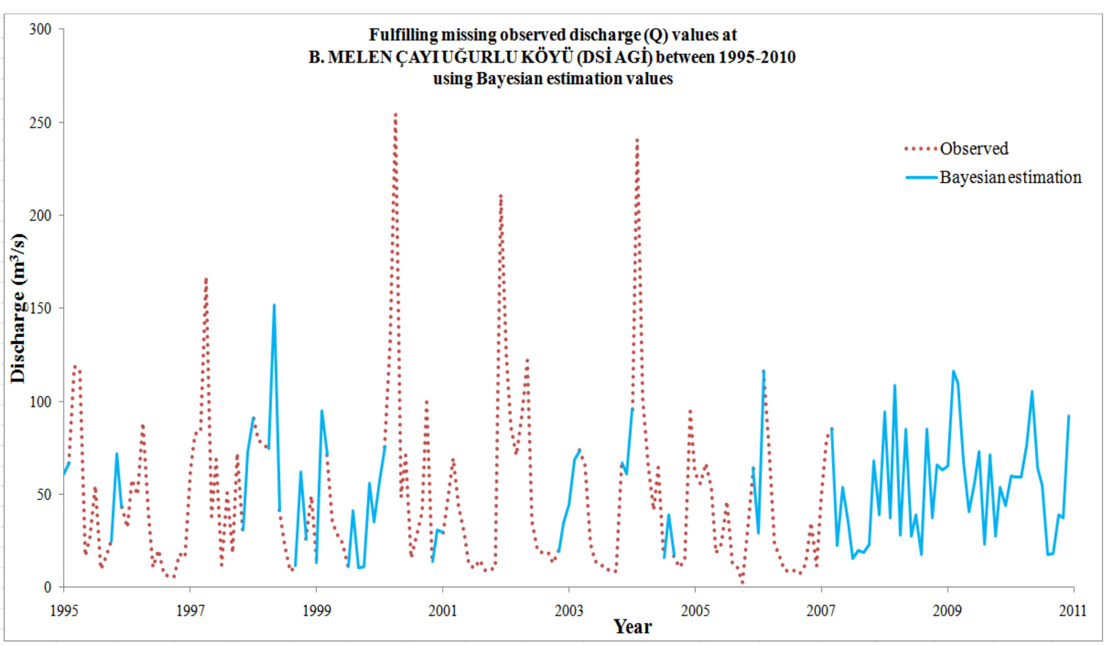

Figure 8. Fulfilling missing observed discharge (Q) values at B. Melen Çayı Uğurlu Köyü between 1995-2010 using Bayesian estimation values (DSI, 2011).

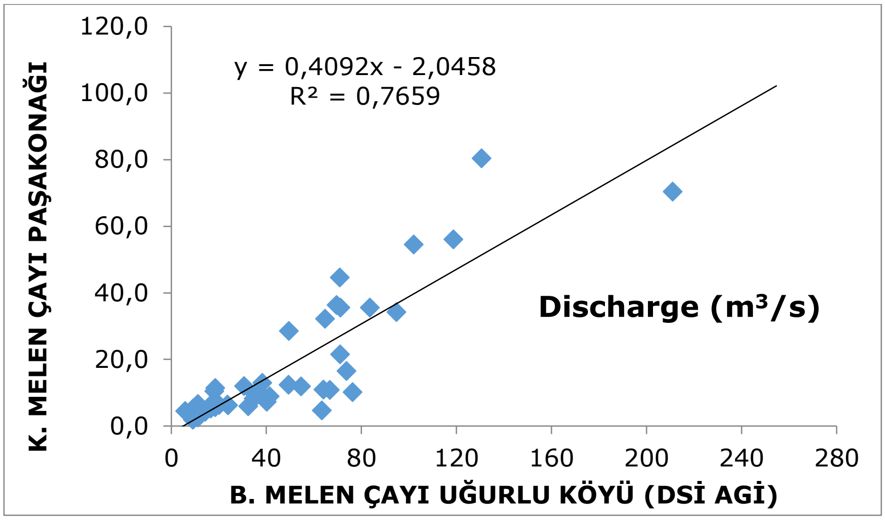

Figure 9. Discharge (Q) relation between measuring points K. Melen Çayı Paşakonağı and B. Melen Çayı Uğurlu Köyü.

Table 3. Discharge (Q) relation between B. Melen Çayı Uğurlu Köyü and all other sampling points.

x	Y	Equation	R^2
B. MELEN ÇAYI UĞURLU KÖYÜ (DSİ AGİ)	**K. MELEN ÇAYI PAŞAKONAĞI**	y = 0.4092x - 2.0458	0.7659
	K. MELEN ÇAYI HASANLAR BARAJ GİRİŞİ (DSİ AGİ)	y = 0.1142x - 0.6536	0.8954
	K. MELEN ÇAYI HASANLAR BARAJI DİPSAVAK ÇIKIŞI	y = 0.4158x - 5.9215	0.8907
	ASAR SUYU K. MELEN ÇAYI ÖNCESİ	y = 0.0945x - 1.0058	0.9231
	KARADERE HASANLAR BARAJ GİRİŞİ (TAŞ OCAĞI)	y = 0.0469x + 0.5217	0.9459
	AKSU HASANLAR BARAJ GİRİŞİ	y = 0.0206x + 0.1712	0.9573
	B. MELEN ÇAYI PAKMAYA SONRASI	y = 0.5333x - 1.4643	0.9872
	UĞUR SUYU	y = 0.1175x - 1.2078	0.7008
	AKSU ÇAYI	y = 0.2006x - 3.7061	0.7183
	LAHNA DERESİ B. MELEN ÇAYI ÖNCESİ	y = 0.0229x - 0.1194	0.538

3. RESULTS AND DISCUSSION

3.1. Results of the Bayesian Approach (BA)

Using AMOS software (see Figure 10), Bayesian analysis was conducted. Bayesian inference is based on a formulation that leads to make an optimal prediction using the available parameters in our hand. Independent subbasins are not affected by other subbasins. Independent subbasins of the Melen Watershed are subbasins 2, 5, 6, 8, 9 and 10. It is necessary to use observed data from independent subbasins in order to define prior distributions of the land use based export coefficients. Single value for each land use based nitrate export coefficients was calculated using observed whole monthly data from January 1995 to December 2006 (Table 4). This prior information helps us to see what is the distribution of export coefficient frequencies, what is their mean, standard deviation, etc. Sometimes use of high level prior information is crucial. For this purpose, the usual method of getting this prior information is to have sampling stations in such an area where a single land use is dominated. More precisely, if it is required to observe a prior distribution for agricultural area nitrate export coefficient (Agr or EAgr), we need to sample in an area that is agriculturally dominated. Data gathered from the State Hydraulic Works (DSİ) covers crucial information about the historical trend of the pollution in the Melen Watershed. Refer to the current DSİ sampling points; it is clear that single land use locations were out of their consideration. Fortunately, we could be able to have small amounts of data measured by İstanbul Technical University (Ozturk et al., 2008) from different locations in the Melen Watershed, including independent basins (see proposed sampling points in Figure 1). First of all, observed data from independent subbasin 6 were analyzed since forest area is dominated (91.15%) in this subbasin. After getting information for forest area nitrate export coefficient (EFor), data from independent subbasins 10, 2 and 8 were consecutively analyzed in order to specify agricultural (EAgr), meadows (EMea) and residual area (ERes) nitrate export coefficients, respectively. Please notice t hat observed data available from these subbasins were in a sufficient amount only for nitrate parameter. Thus prior distributions were created for the nitrate export coefficients of each type of land use (Mea, Agr, For, Res) (see Figures 11-14). Then Bayesian estimation was able to start. Bayesian analysis was conducted and posterior information about land use based nitrate export coefficients was obtained using MCMC method (see Figures 15-16). Using the Bayesian approach nitrate export coefficient were predicted as; Mea=1.611, Agr=3.832, For=1.288, Res=2.462 (see Figure 17).

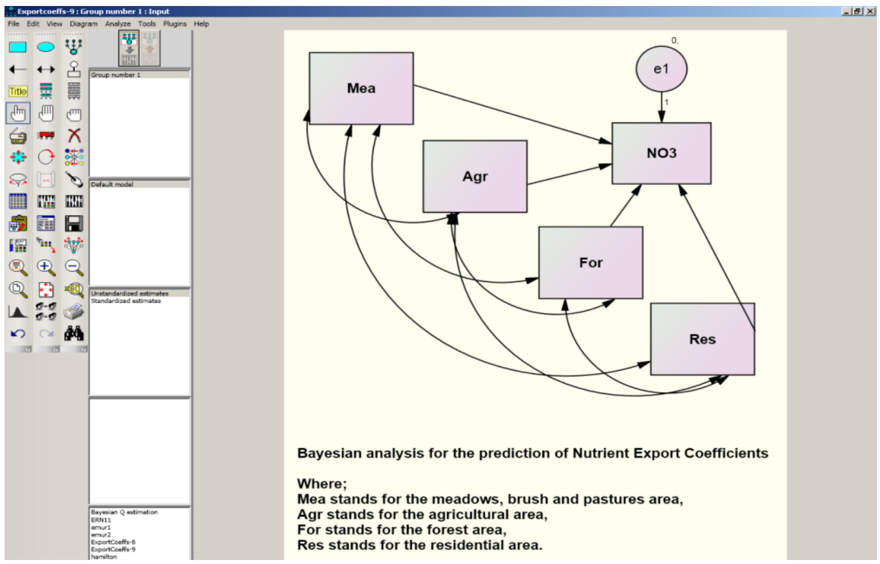

Figure 10. Bayesian analysis for the prediction of NO_3^- export coefficients (kg/km^2/day) using AMOS.

Table 4. Calculated NO_3^- export coefficients (kg/km^2/day) using observed monthly data.

	Whole watershed - NO_3^- - Export coefficient (kg/km^2/day) monthly average value			
Year	Meadows Brush and Pasture	Agricultural	Forest	Residential
1995	0.595	2.687	0.505	1.901
1996	0.508	2.084	0.405	1.206
1997	0.708	3.544	0.612	1.995
1998	0.710	3.140	0.554	1.926
1999	0.608	2.033	0.400	1.257
2000	1.220	3.331	0.950	1.968
2001	0.705	2.117	0.605	1.106
2002	0.826	3.077	0.700	1.966
2003	0.804	3.000	0.615	1.903
2004	1.101	3.125	0.815	1.844
2005	0.603	2.182	0.505	1.410
2006	0.726	2.673	0.600	1.653
Mean	0.759	2.749	0.606	1.678
SD	0.209	0.533	0.159	0.338

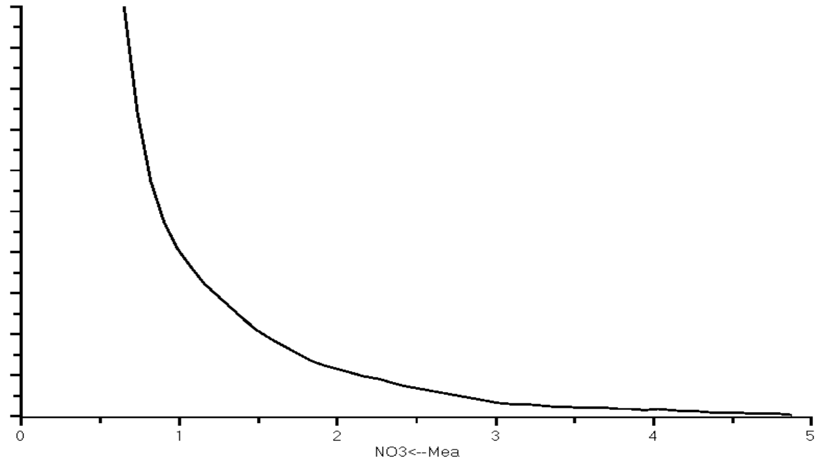

Figure 11. Prior distribution for NO_3^- export coefficient (kg/km^2/day) of Meadows Brush and Pasture (Mea) type land use in the Melen Watershed.

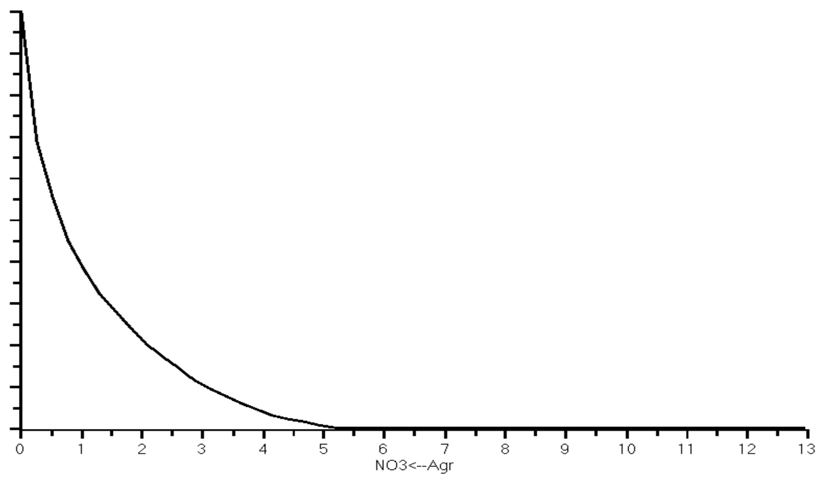

Figure 12. Prior distribution for NO_3^- export coefficient (kg/km^2/day) of Agricultural (Agr) type land use in the Melen Watershed.

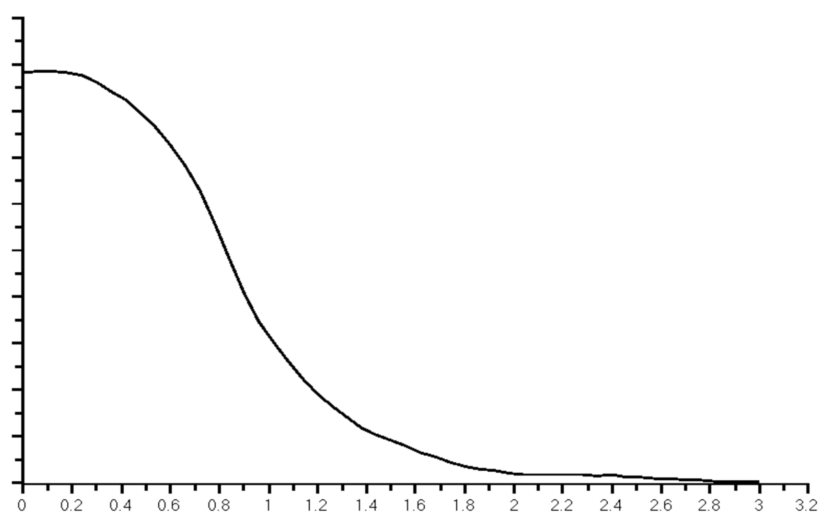

Figure 13. Prior distribution for NO_3^- export coefficient (kg/km^2/day) of Forest (For) type land use in the Melen Watershed.

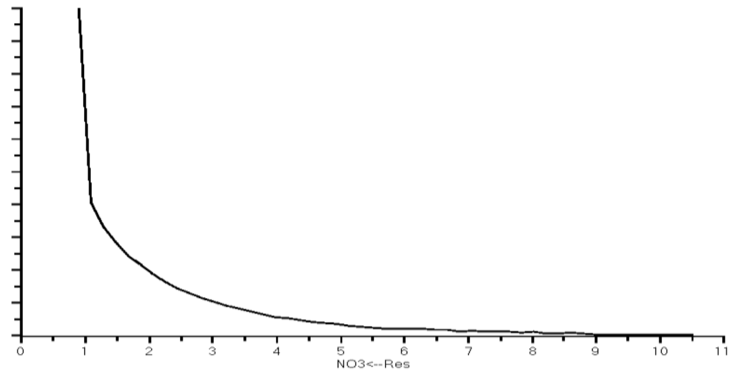

Figure 14. Prior distribution for NO_3^- export coefficient (kg/km^2/day) of Residential (Res) type land use in the Melen Watershed.

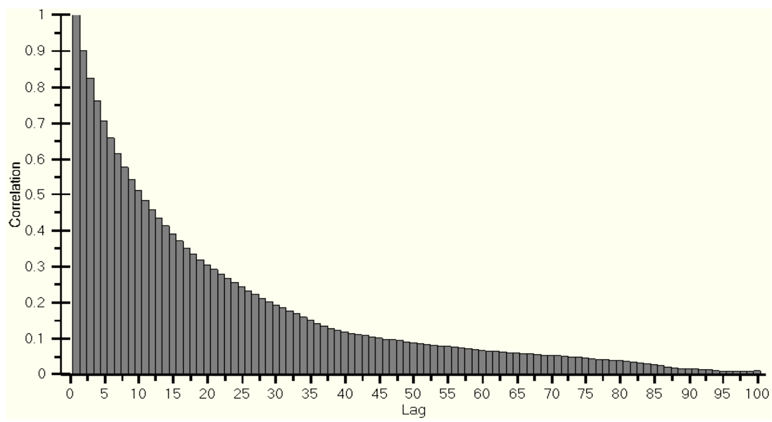

Figure 15. Correlations between the consecutive iterations for the NO_3^- export coefficient (kg/km^2/day) value of Agricultural (Agr) type land use in the Melen Watershed.

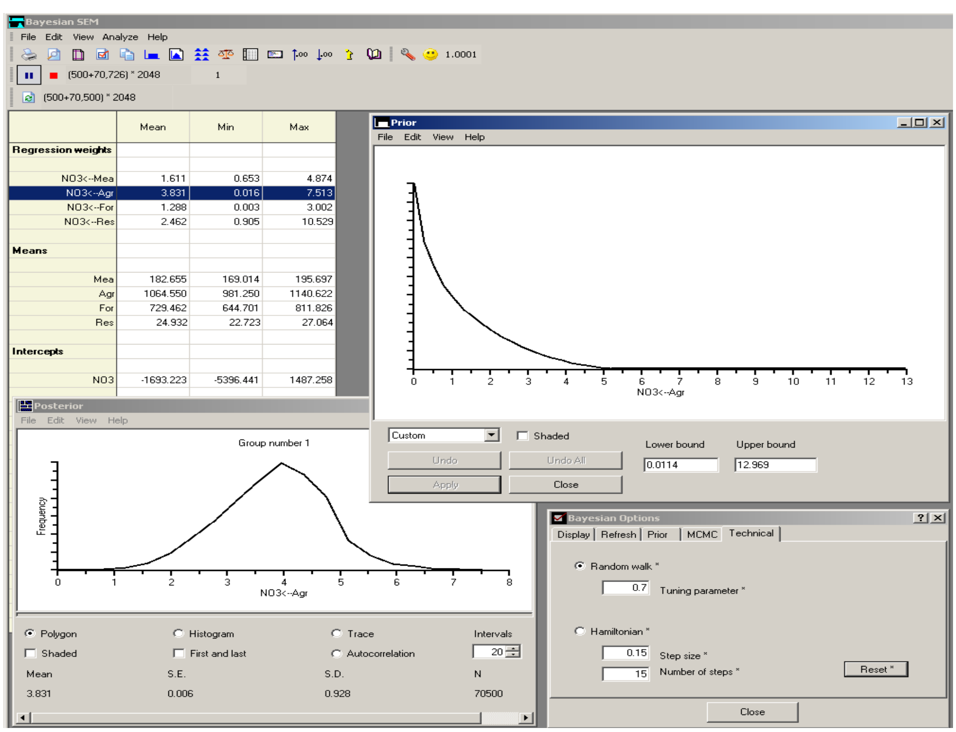

Figure 16. Bayesian analysis window in AMOS shows best convergence (1.001 ≈ 1), prior distribution (upper right) and posterior distribution (lower left) of the NO_3^- export coefficient (kg/km^2/day) value of Agricultural (Agr) type land use in the Melen Watershed.

	Mean	S.E.	S.D.	C.S.	90% Lower bound	90% Upper bound	Skewness
Regression weights							
NO3<--Mea	1.611	0.006	0.943	1.000	0.688	3.707	1.294
NO3<--Agr	3.832	0.005	0.929	1.000	2.241	5.252	-0.111
NO3<--For	1.288	0.004	0.747	1.000	0.231	2.652	0.447
NO3<--Res	2.462	0.009	1.782	1.000	0.947	6.395	1.741

Figure 17. Bayesian estimations for NO_3^- export coefficients (kg/km^2/day) (AMOS output).

Dagum, Gamma, Kumaraswamy and Wakeby distributions were encountered during the Bayesian analysis phase of this study. Necessary explanations for these distributions were given in the Equations 2-7, see plotted Posterior distribution for NO_3^- export coefficient (kg/km^2/day) of each type of land use from Figures 18-21:

Probability Density Function for Four – Parameter Dagum Distribution:

$$f(x) = \frac{\alpha k \left(\frac{x-\gamma}{\beta} \right)^{\alpha k - 1}}{\beta \left(1 + \left(\frac{x-\gamma}{\beta} \right)^{\alpha} \right)^{k+1}} \quad (2)$$

Probability Density Function for Three – Parameter Dagum Distribution:

$$f(x) = \frac{\alpha k \left(\frac{x}{\beta} \right)^{\alpha k - 1}}{\beta \left(1 + \left(\frac{x}{\beta} \right)^{\alpha} \right)^{k+1}} \quad (3)$$

where k and α are continuous shape parameters $(k > 0)$, $(\alpha > 0)$; β is the continuous scale parameter $(\beta > 0)$; γ is the continuous location parameter ($\gamma \equiv 0$ yields the three-parameter Dagum distribution). Domain: $\gamma \leq x < +\infty$

Probability Density Function for Three – Parameter Gamma Distribution:

$$f(x) = \frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} \exp\left(-\frac{x-\gamma}{\beta} \right) \quad (4)$$

where α is the continuous shape parameter $(\alpha > 0)$, β is the continuous scale parameter $(\beta > 0)$, γ is the continuous location parameter ($\gamma \equiv 0$ yields the two-parameter Gamma distribution). Domain: $\gamma \leq x < +\infty$

Also, Γ is the Gamma Function:

$$\Gamma(\alpha) = \int_0^{\infty} t^{\alpha-1} e^{-t} dt \qquad (\alpha > 0) \quad (5)$$

Probability Density Function for Kumaraswamy Distribution:

$$f(x) = \frac{\alpha_1 \alpha_2 z^{\alpha_1 - 1} (1 - z^{\alpha_1})^{\alpha_2 - 1}}{(b-a)} \quad (6)$$

where α_1 is the continuous shape parameter $(\alpha_1 > 0)$, α_2 is the continuous shape parameter $(\alpha_2 > 0)$, a, b are the continuous boundary parameters $(a < b)$, $z \equiv (x-a)/(b-a)$. Domain: $a \leq x \leq b$

The five-parameter Wakeby distribution is defined only with the quantile function:

$$x(F) = \xi + \frac{\alpha}{\beta}\left(1 - (1-F)^{\beta}\right) - \frac{\gamma}{\delta}\left(1 - (1-F)^{-\delta}\right) \quad (7)$$

where ε is the location and a, β, γ and δ are other parameters. Both a-β and γ -δ prevalently relate to the scale of the variable, β and δ are exponential parameters defining the shape of the quantile function.

The following conditions are imposed:

$\alpha \neq 0$ or $\gamma \neq 0$; $\beta + \delta > 0$ or $\beta = \gamma = \delta = 0$; if $\alpha = 0$, then $\beta = 0$, if $\gamma = 0$, then $\delta = 0$, $\gamma \geq 0$ and $\alpha + \gamma \geq 0$.
Domain: $\xi \leq x < \infty$ if $\delta \geq 0$ and $\gamma > 0$
$\xi \leq x \leq \xi + \frac{\alpha}{\beta} - \gamma/\delta$ if $\delta < 0$ or $\gamma = 0$.

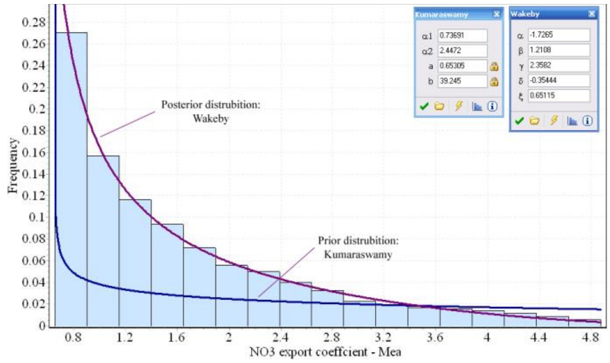

Figure 18. Posterior distribution for NO_3^- export coefficient (kg/km²/day) of Meadows Brush and Pasture (Mea) type land use in the Melen Watershed.

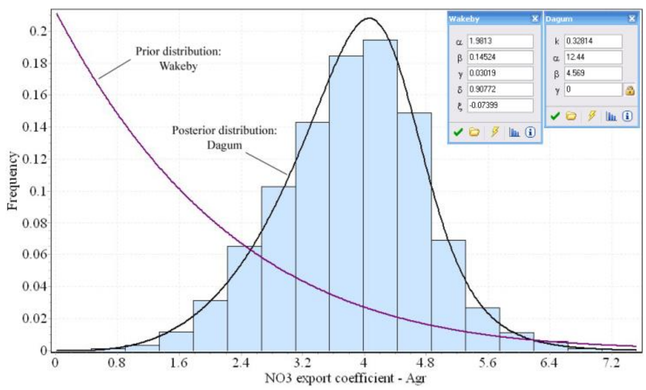

Figure 19. Posterior distribution for NO_3^- export coefficient (kg/km²/day) of Agricultural (Agr) type land use in the Melen Watershed.

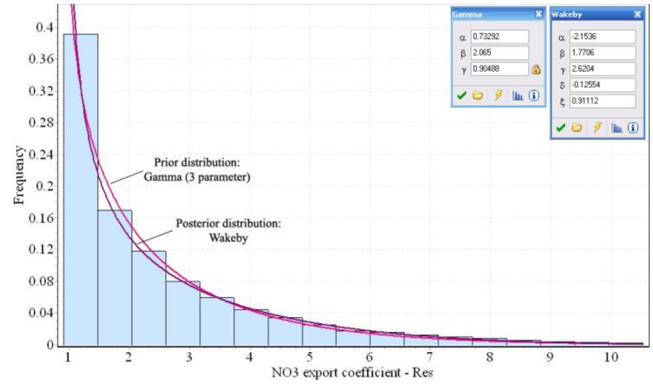

Figure 21. Posterior distribution for NO_3^- export coefficient (kg/km²/day) of Residential (Res) type land use in the Melen Watershed.

Prior information is not always very informative. Posterior distribution is significantly different from the prior and the likelihood. The Bayesian approach gives different estimates for land use based nitrate export coefficients. Predicted yearly average nitrate loads (kg/day) using the Bayesian approach has been plotted versus observed nitrate load values (see Figure 22). Figure 23 shows that the assigned priors are highly informative for the Bayesian estimation. Bayesian approach gives closer estimates to the observed values (see Figure 23).

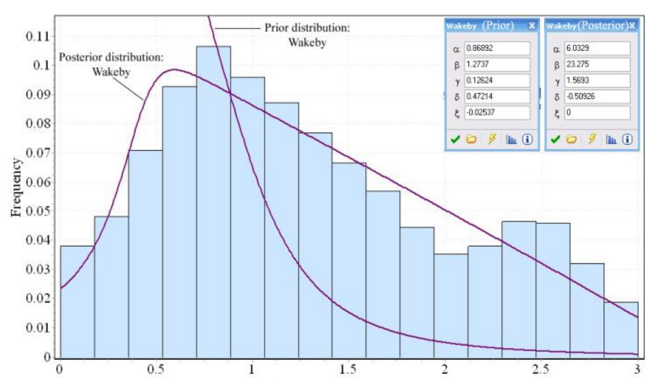

Figure 20. Posterior distribution for NO_3^- export coefficient (kg/km²/day) of Forest (For) type land use in the Melen Watershed.

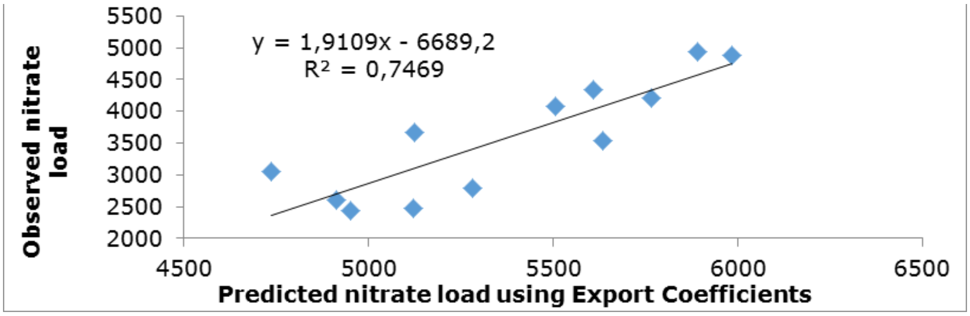

Figure 22. Bayesian estimation vs. Observed nitrate load (kg/day) average daily values at the outlet for each year between 1995 and 2006.

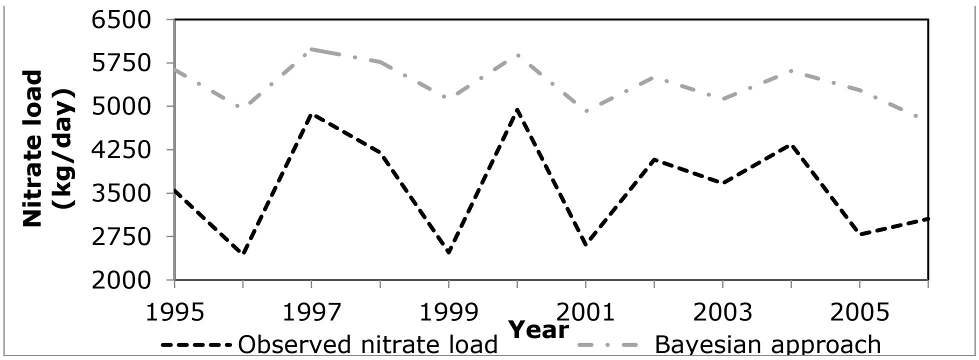

Figure 23. Observed nitrate loads (kg/day), Bayesian estimations for each year between 1995 and 2006.

3.2. Discussion of results

A sample application of the Bayesian approaches for land use based nitrate export coefficients was shown in detail. The Melen Watershed has distinct soil characteristics. Therefore, it's natural to have estimates different from those stated in the literature. However, our findings seem to be a bit high because, unlike cited papers, river nitrate retention is considered as a separate factor in our study (see Figure 24). Estimated export coefficient alone is not enough for calculating the nitrate loading in the Melen Watershed. All estimations were tabulated (see Table 5). Prior distributions were created only for the nitrate export coefficients of each type of land use (Mea, Agr, For, Res), because of the scarcity of the available data from independent subbasins (especially subbasin 6, 2 and 8). As a recommendation for future projects, field works especially sampling in dominated land use areas and laboratory tests help to specify more reliable prior distribution of each land use based nitrate export coefficient. This situation also helps to get more precise estimations, particularly through the Bayesian approach.

Figure 24. 16 years average % river retention of nitrate for each subwatershed (SW).

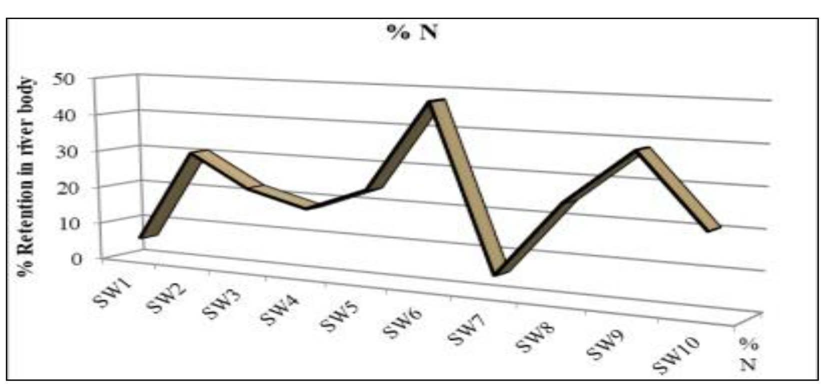

Table 5. Estimated nitrate export coefficients (kg/km^2/day) using Bayesian approach.

	Meadows Brush and Pasture	Agricultural	Forest	Residential
The Bayesian Approach (kg/km^2/day)				
NO_3^-	1.611	3.832	1.288	2.462

4. CONCLUSIONS

The primary objective of this research is to create a unique nitrate export coefficient model for the Melen River Basin. The Melen Watershed area has specific land use and soil characteristics. This situation affects hydrologic processes since land use and soil classification hasve a significant influence on that. Proposed model is aimed to be a fundamental knowledge for the further researches in order to ascertain Turkey's own nitrate export coefficients. Water quality, spatial and temporal data were prepared for nitrate export coefficient modeling phase of this study. Current status of the Melen Watershed was put forth, and comprehensive data analyses were carried out by compiling data obtained from the State Hydraulic Works (DSİ) and other institutes. Additional data requirements, tools (including water quality model and Geographical Information Systems (GIS) infrastructure) and methods for water quality management were specified as well. GIS were integrated to delineate watershed and sub watershed boundaries, and to define the topologies of the stream reaches among each other and with sub watersheds. Model accepts observed monthly average precipitation values as an input (NOAA, 2010). Daily precipitation data between 1995 and 2020 were generated using artificial neural networks (ANN) methodology. Furthermore, nitrate export coefficient model was developed for the Melen Watershed. Together with this retention coefficient, the effect of the draining upper subwatershed was also considered. Bayesian estimation using MCMC algorithm was used for the modeling of nitrate export coefficients. For the Bayesian estimation, AMOS software was used. Bayesian estimation is using the prior information about estimands. Result of the Bayesian approach has a good correlation with observed values ($R^2 \approx 0.75$). Reliability of the results depends on the quality of the data used. Field works especially sampling in dominated land use areas helps to specify more reliable prior distribution of each land use based nitrate export coefficients in order to get more precise estimations, particularly through the Bayesian approach.

In the current study, results from the Bayesian approach would have been better if we could have sufficiently large temporal data for independent subwatersheds. Further studies, which take this issue into account, will need to be undertaken. Results of this study do not verify findings of a great extent of earlier studies in the same research field. Hence accepting results of previous researches on export coefficient models as reliable is an incorrect decision. This study has important findings for developing export coefficient models for other regions in Turkey and abroad. In conclusion, this study is intended to guide researchers on the subject.

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