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Contents

Aims and Scope

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Research Article

Natural Background Concentrations Determination for Metals in Surface Waters, Gediz River Basin

Yüzey Sularındaki Metaller için Doğal Arka Plan Konsantrasyonlarının Belirlenmesi, Gediz Havzası Örneği

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Abstract

In this study, an approach was developed for natural background concentration determination of metals and metalloids (Ag, Al, As, B, Co, Cr, Cu, Fe, Sb, Sn, V, Zn, Ti, Cd, Ni, Pb and Hg) listed in By-law on Surface Water Quality (OG: 30.11.2012/28483) as priority substances or specific pollutants. Gediz River Basin was selected as a pilot area and seasonal monitoring studies were conducted in the selected surface waters during 2015-2016. For determination of NBC, it is necessary to distinguish whether the presence of metals detected in the receiving environment is natural or anthropogenic. In this context, anthropogenic sources were monitored and evaluated according to the pollution contribution of each pressure; natural sources of investigated metals were considered according to mining activities and geothermal source distribution. A methodology was developed and applied by indicating the relative contribution of pollutant resources and whether critic value was exceeded or not. Pollution contribution was calculated representing the relative effect of anthropogenic sources. This approach was found suitable for determining NBC and could be helpful for decision makers by establishing critical factors (e.g. which facility should be established where; which plant can discharge its pollutant in which amount; what kind of precautions should be taken in agricultural activities; as well as how to reduce the pesticides used) while comparing the effect of pollution sources.

Keywords: *Metals, surface waters, water quality, natural background concentration, environmental quality standards*

Öz

Bu çalışmada, Yerüstü Su Kalitesi Yönetmeliği'nde (RG: 30.11.2012/28483) yer alan öncelikli maddeler ve Pb ve Hg için doğal arka plankonsantrasyonlarının belirlenmesine yönelik bir yaklaşım geliştirilmiştir. Bu amaçla Gediz Nehir Havzası pilot havza olarak seçilmiş ve belirlenen yüzey suları 2015-2016 yılları arasında mevsimsel olarak izlenmiştir. Doğal arka plan konsantrasyonlarının belirlenmesi için, alıcı ortamda tespit edilen metallerin varlığının, doğal kaynaklı mı yoksa antropojenik kaynaklı mı olduğunu ayırt etmek gerekmektedir. Bu kapsamda, antropojenik kaynaklar için olası her baskının kirlilik katkısı izleme çalışmaları yapılarak incelenmiş; doğal kaynaklar için madencilik faaliyetleri ve jeotermal kaynakların dağılımı değerlendirilmiştir. Antropojenik kaynakların kirletici etkisinin tespit edilmesi ve buna bağlı olarak Doğal arka plan konsantrasyonlarının belirlenmesi için kirlilik katkı yüzdesinin hesaplandığı bir metodoloji ortaya konmuştur. Geliştirilen bu yaklaşımla, yüzey sularında doğal arka plan konsantrasyonları belirlenebilmekte ve kirlilik kaynaklarının alıcı ortam üzerindeki etkisi ayırt edilebilmektedir. Buna bağlı olarak, geliştirilen yaklaşımın, karar vericilerin kritik kararları (hangi tesisin nerede kurulması gerektiği, hangi tesisin ne oranda kirletici deşarj edebileceği, tarımsal üretimde ne gibi önlemlerin alınması gerektiği, kullanılan zirai mücadele ilaçlarının ne oranda azaltılmasının uygun olacağı gibi) almasına yardımcı olacağı düşünülmektedir.

Anahtar kelimeler: *Metaller, yüzey suları, su kalitesi, doğal arka plan konsantrasyonu, çevre kalite standardı*

Introduction

Natural background concentration (NBC) is defined as the concentration of a chemical substance originating from natural and geological processes (EC, 2011). It is identified by the presence of chemical substances in the receiving water body as a result of natural processes joining the water either through point and diffuse sources. Determination of NBC of a pollutant in the water body has great importance while determining the Environmental Quality Standard (EQS) for that specific pollutant in order to define 'good ecological and chemical status' and to improve the water quality. NBC of pollutants in the water bodies varies according to typology, geology, geography of the watershed and to physical, chemical and biological features of the groundwater.

In the European Water Framework Directive (WFD; 2000/60/EC) (EC, 2000), the environmental objective is to achieve good surface water status in all Member States. For this purpose, environmental quality standards have been issued, either by the European Commission for priority substances, or by the Member States for river basin specific pollutants. In case of non-compliance with the standard, Member States are allowed to take account of NBCs or bioavailability. Thus, determination of NBC for relevant substances (e.g. trace metals) is required. WFD allows a correction for NBC only for metals though some organic contaminants also have a natural origin. WFD does not necessitate the derivation of NBC; therefore, each country can derive their own NBC.

In Turkey, Turkish By-law on Surface Water Quality (OG:30.11.2012/28483) covers metal and metalloid parameters of Ag, Al, As, B, Co, Cr, Cu, Fe, Sb, Sn, V, Zn, Ti, Cd, Ni, Pb and Hg either as priority substances listed in Table 5 or specific pollutants listed in Table 4 of Annex 5 for determination of NBC.

Several methods have been proposed to derive NBC of trace metals for surface waters such as i) the clean streams approach (based on measurements in relatively undisturbed aquatic systems); ii) the sediment approach (based on the composition of sediments and equilibrium partitioning); iii) the spring of surface water (based on natural background level based on groundwater background concentrations); iv) monitoring data approach, and v) stable summer levels as ambient background concentration (Oste et al., 2011). For instance, NBC for Dutch surface waters are derived according to the clean streams approach for As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, methyl-Hg, Mo, Ni, Se, Ti, Sn, V, and Zn and published in the Dutch 4th National Water Plan (1998). In UK, monitoring data approach was applied for derivation of ambient NBCs of metals (Peters et al., 2010).

In this study, 40 monitoring stations on surface waters were seasonally (4 periods) monitored during 2015-2016. Simultaneously, municipal discharges (29 points) and industrial discharges (54 points) sources were also monitored to determine the effect of point sources on the ambient water quality. For determination of NBC, a novel approach was developed since the inadaptability of existing data to present NBC determination methods used by other countries. Before developing a new approach, the suitability of present methods was investigated. Among the referred methods, “clean streams approach” and “monitoring data approach” seemed more appropriate for NBC determination. However it was recognized that these methodologies were not suitable when considering the available data. Clean streams approach, developed and described by Zuurdeeg et al. (1992) and used in the Netherlands, is based on the principle of water quality of the upstream waters in relatively unpolluted regions. However in this study, only one point among the receiving body monitoring points could be characterized as an upstream point although it was not a representative point for the entire basin. In monitoring data approach, based on a document of the Environment Agency and used in the UK, there should ideally be a minimum of 5 continuous monitoring data on at least 50 stations for derivation of NBC (Peters et al., 2010). But in this study, obtained monitoring data was not sufficient to apply the aforementioned methods. Therefore, instead of using pre-referred approaches, a new methodology was developed to calculate NBC values by taking into account the natural and anthropogenic sources affecting the surface water bodies. Relatively unpolluted monitoring points were selected and the pressures affecting the water quality at these points were investigated. Pollution caused by each pressure on the corresponding receiving water was evaluated by using its contribution ratio regarding pollution load. If the receiving body was identified as highly polluted due to a point source, the monitoring point at this receiving body was not taken into consideration for the assessment of NBC, and the rest of the monitoring stations were evaluated by considering their proximity to the existing geologic formation and mining sites.

Although several studies have been proposed for the determination of metal contamination in surface waters, sediments and biota samples in Gediz River Basin (Bizsel et al., 2017; Suzer et al., 2015; Aydin and Kucuksezgin, 2012; Kucuksezgin et al., 2008), these studies were subjecting the presence of metals and investigating the source metal pollution. However for NBC determination, there is still a lack of studies for both Gediz River Basin and Turkey. This study aims to develop a methodology for determining NBC for metals in surface waters. In that sense, it might be considered as a pioneer study for presenting an approach for NBC determination in Turkey. A method was set considering both natural and anthropogenic effects on water quality. For natural effects, mining areas and geothermal wells were taken into consideration while municipal and industrial wastewater discharges and solid waste dumping sites were evaluated for assessing the anthropogenic effect.

Method

Study Area

Gediz River Basin covers the region between Northern Aegean, Susurluk and Kucuk Menderes River Basins, located in the western part of Turkey discharging its waters via Gediz and its branches to Aegean Sea that is an elongated bay of Mediterranean Sea. The basin area is 1,703,394 ha and it covers 2.17% of Turkey. Gediz River has a length of 275 km, and its yearly average water potential is calculated as 2,270 hm^3 or 126 mm. Four sub-basins are determined by considering hydrologic and topographic conditions of the basin (MoFWA, 2015). The sub-basins are listed from upstream to downstream as i) Upper Gediz, ii) Alasehir Stream, iii) Gordes-Gurduk Stream and iv) Lower Gediz. The map demonstrating the sub-basins is provided in Figure 1.

Gediz River Basin has a great importance due to intensive industrial and agricultural activities. Textile, food, leather, food processing, construction materials, dairy, meat and poultry processing and manufacturing of agricultural vehicles are the predominant industries in the basin (MoFWA, 2017). Especially the sub-basins of Lower Gediz and Nif Stream are the main industrialized regions. In terms of agricultural activities, 50% of the basin area is used for the cultivation of different agricultural products mainly includes grape, cherry, olive, tomato, walnut and cotton (MoFWA, 2017, MoFAL, 2016).

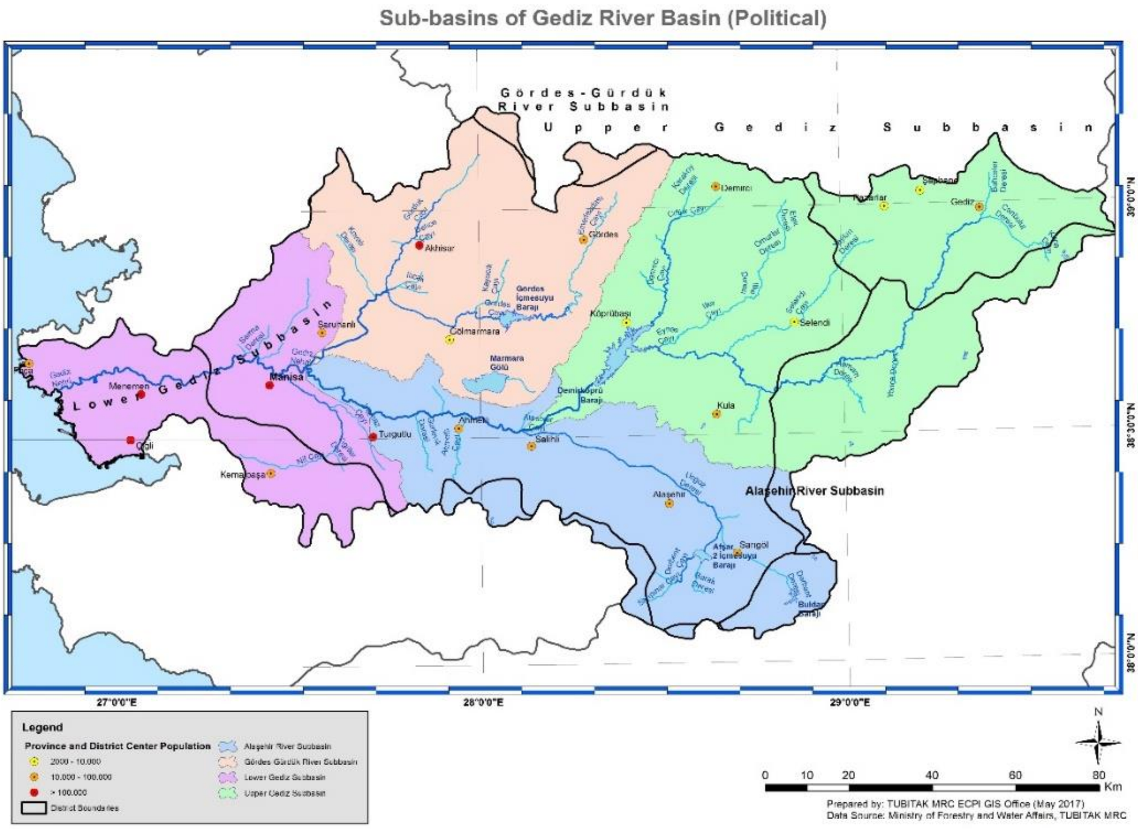

Figure 1. Sub-basins of Gediz River Basin.

Monitoring Program

Within the scope of this study, 40 stations in the mainstream and tributaries of Gediz River were seasonally monitored during the periods of 01-18 November 2015 (autumn), 01-17 February 2016 (winter), 02-17 May 2016 (spring) and 01-19 August 2016 (summer). Surface water monitoring programs were determined by taking into consideration i) the previous points of a discharges such as industrial facilities, urban discharges and urban wastewater treatment plants' (WWTPs), ii) if there was a new branch combining with main stream, both a point on this new branch and another point after their combination were chosen, iii) if there was a dam, points on branches both entering and leaving the dam were chosen, iv) if there was a possibility for reaching relatively clean conditions, points such as origins of streams were selected. Monitoring stations are presented in Figure 2. Metal parameters of Ag, Al, As, B, Co, Cr, Cu, Fe, Sb, Sn, V, Zn, Ti, Cd, Ni, Pb and Hg, which are among the priority substances in Table 5and point specific pollutants in Table 4 of Annex 5 in By-law on Surface Water Quality (OG:30.11.2012/28483), are studied for determining NBC.

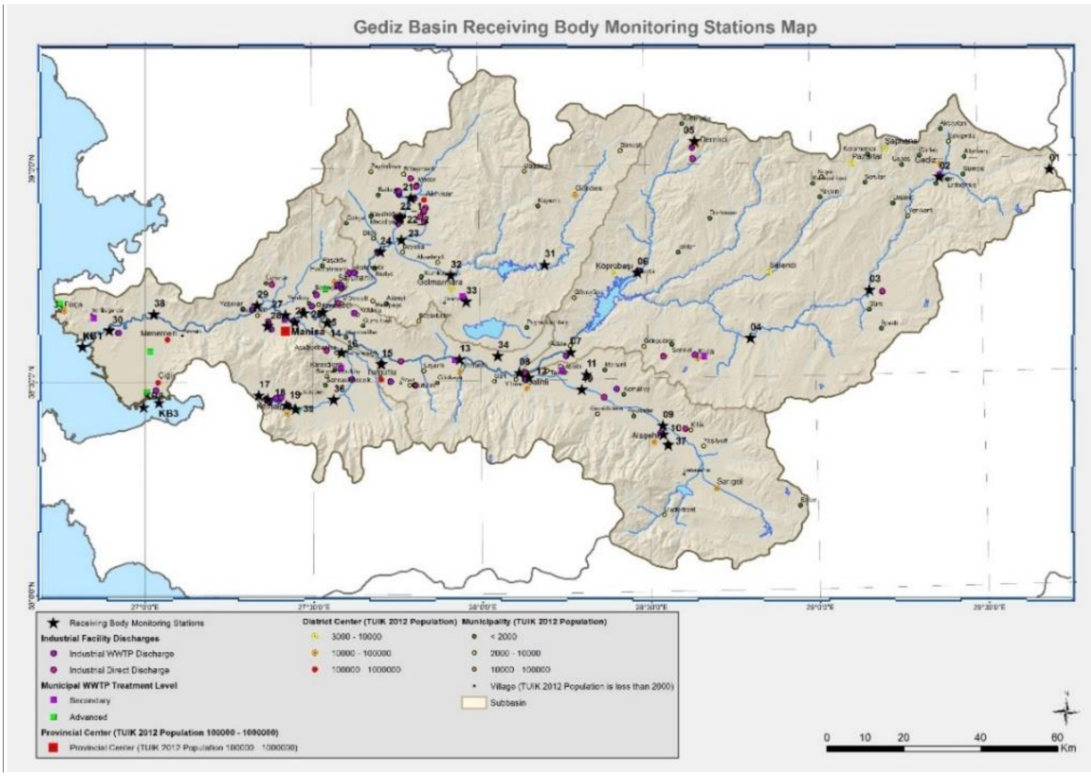

Figure 2. Surface water monitoring stations in Gediz River Basin.

Table 1
Instrumental Analyses Used in the Present Study

Parameter	CAS No	Analysis	Instrument	Detection Limit (LOD) (µg/L)	Quantification Limit (LOQ) (µg/L)
Hg	7439-97-6	TS 2537 EN 1483:1999-4	AAS Cold Steam	0.04	0.13
Pb	7439-92-1	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.022	0.066
Ni	7440-02-0	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.021	0.073
Cd	7440-43-9	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS , 81VN3092001	0.019	0.059
Al	7429-90-5	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.197	0.512
Sb	7440-36-0	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.042	0.12
As	7440-38-2	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.067	0.209
Cu	7440-50-8	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.091	0.263
B	7440-42-8	ISO 11885 ICP-OES	NEXION 300XX model ICP-MS, 81VN3092002	0.025	0.067
Zn	7440-66-6	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS , 81VN3092001	0.142	0.667
Fe	7439-89-6	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.839	2.172
Ag	7440-22-4	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.007	0.021
Sn	7440-31-5	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	3	10
Co	7440-48-4	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.008	0.026
Cr	7440-47-3	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 1VN3092001	0.065	0.2
Ti	7440-32-6	ISO 11885 ICP-OES/SM 4500-SiO2-:2005 F Colorimetric Method	PERKIN ELMER 8300 ICP-OES/Scalar autoanalyzer	2.3	7.67
V	7440-62-2	EPA 6020 A ICP-MS	NEXION 300XX model ICP-MS, 81VN3092001	0.008	0.021

Assessment of NBC

EQS values are limit values for protection of environment and human health from substances reached to the ambient by man-made activities. EQS are determined according to the ecotoxicology data of the related chemicals. While determining the EQS values for substances such as trace metals, defining of NBC that is the concentration originates from natural and geological processes is significant.

While determining the effect of anthropogenic pressure on the receiving water body, pollution contribution was calculated according to the equations (Equation 1 and

2) given below. If the calculated increase is higher than 2%, it is accepted that the related receiving body is under anthropogenic pressure (EC, 2008; EC, 2010).

$$\frac{PC}{EQS}x100 = \%increase$$

Equation 1

where;

PC = Process Contribution
EQS = Environmental Quality Standards

$$\frac{[CoC]_{eff}\,xQ_{eff}}{(Q_{river}+Q_{eff})} = PC$$

Equation 2

where;

CoC = Metal concentration in wastewater
Q_{eff} =Wastewater flow rate
Q_{river}= River flow rate

For the pressures with at least 2% pollution contribution, geological formations around the region were investigated. If there appears a geological formation around the water resource that has the potential of metal concentration, the monitoring station was included in NBC calculation; if not, the pressure was considered to be anthropogenic and the associated monitoring station was excluded. For each metal, NBC was calculated by taking the mean value of the seasonal monitoring data. NBCs were calculated for 17 metal parameters.

Following the derivation of the NBCs the final EQSs of the metals in Gediz River Basin were also determined by using the approach specified below.

- If NBC is lower than EQS, Environmental Objective (EO) is equal to EQS.

$$NBC < EQS \rightarrow EO=EQS \qquad (3)$$

- If NBC is equal to or higher than EQS, EO is equal to the sum of EQS and NBC.

$$NBC \geq EQS \rightarrow EO=EQS+NBC \qquad (4)$$

The aquatic environment can be affected by chemical pollution both in the short and long term, which is defined by acute and chronic effects, respectively. For providing protection against long-term exposure, EQS expressed as an annual average (AA-EQS) value, on the other hand, for providing protection against short-term exposure, maximum allowable concentrations (MAC-EQS) is used (EC,2011).

Considering the distribution of anthropogenic pressures, stations located in the Lower Gediz Sub-basin (downstream of Gediz River that reaches to Aegean Sea) and Nif Stream Sub-basin were eliminated because of under pressure of municipal and industrial discharges and being far away for determining the naturally presence of metals. For this reason 27 stations out of 40 stations were investigated for NBC assessment. For these 27 stations, the pressures were identified and their contribution to metal pollution in the surrounding receiving bodies was calculated.

Results & Discussion

Mean values of the seasonal monitoring data are presented in Table 2. Most of the metal concentrations were found to be higher than their AA-EQS with the exception of Ag, As, Ba, Be, Sb and Sn. The colored fields in the table were represented the exceeded AA-EQS values. Furthermore, it was found that the metal concentrations were higher in the downstream (Lower Gediz Sub-basin) compared to the upstream (Upper Gediz Sub-basin). Depending on higher values mostly being the result of anthropogenic pressures, stations taken place in in the Lower Gediz and Nif Stream Sub-basins were not evaluated for NBC determination.

In order to determine NBC values, it is significant to identify the presence of metals as a result of natural processes. Among the stations, there is only TMDL-01 station located in the source of the basin that is far away from anthropogenic pressures. According to the ecological monitoring results obtained by the project of Sensitive Areas and Determination of Water Quality Objectives, TMDL-01 station was defined as suitable for being a reference point for Gediz Basin (MoFWA, 2015). However, the typology of the water body in which TMDL-01 is located does not represent the entire basin. Therefore, the result of determining the NBC value on a single station is not found appropriate. Afterwards for aiming to evaluate the characteristic of entire basin, the monitoring results of 40 stations were considered for NBC by screening extreme values. However, at this stage it was a question mark that the effect of anthropogenic pressures could not be eliminated. At the final point, it was decided not to take stations on Lower Gediz Lower Sub-basin (downstream of Gediz River that reaches to Aegean Sea and Nif Stream), where anthropogenic pressures were intense, and the remaining 27 stations were examined for NBC determination.

Table 2

Monitoring Data of Metals in Surface Waters (Annul Values)

Sub-basin	Monitoring Station	Metals (µg/L) Ag	Al	As	B	Cd	Co	Cr	Cu	Fe	Ni	Pb	Sb	Sn	V	Zn	Hg	Ti
***AA-EQS Values** (µg/L)*		**1.5**	**2.2**	**53**	**707**	**0.08**	**0.3**	**1.6**	**1.6**	**36**	**4**	**1.2**	**7.8**	**13**	**1.6**	**5.9**	**0.07**	**26**
Upper Gediz	TMDL_01	0.05	110	1.3	55	0.10	0.51	9	17	276	12	1.63	0.70	< 10	0.44	40	< 0.13	< 7.67
	TMDL_02	0.16	342	9	211	0.09	1.33	11	13	809	27	1.83	1.45	< 10	1.54	27	< 0.13	< 7.67
	TMDL_03	0.14	576	42	562	0.11	1.57	9	18	1169	28	3	1.39	< 10	2.5	41	< 0.13	13
	TMDL_04	0.32	61	63	508	1.26	38	145	71	76888	249	27	3	< 10	114	187	2.8	2132
	TMDL_05	0.12	406	70	225	0.13	0.27	1.1	14	496	2.3	2	1.07	< 10	1.5	30	0.17	< 7.67
	TMDL_06	0.22	1.5	57	1223	0.15	1.31	4.4	13	2035	5.2	2.6	1,3		6	26	0.14	141
	TMDL_07	0.12	103	16	341	0.16	0.24	1.3	13	239	5.2	1.5	1.2	< 10	4.5	58	0.19	< 7.67
	TMDL_08	0.15	189	28	443	0.09	0.32	1.03	14	331	4.5	1.2	1.1	< 10	2.6	29	0.18	< 7.67
Alasehir Stream	TMDL_09*																	
	TMDL_10	0.29	14	82	1642	0.66	16	64	54	23180	54	19	6	< 10	49	188	0.73	597
	TMDL_11*																	
	TMDL_37	0.10	1.1	21	167	0.16	1.4	3	17	2025	6	2.5	2.7	< 10	4.7	49	0.30	186
	TMDL_40	0.16	380	36	10652	0.08	1.8	1.7	13	1372	3.9	1.6	12		3	38	0.49	18
	TMDL_12	0.16	1.2	37	4537	0.09	2.5	5	15	3217	6	2.2	1.4	< 10	6	161	0.17	76
	TMDL_13	0.14	5	80	1932	0.29	4	58	22	6667	14	5	4.5	< 10	14	89	< 0.13	356
	TMDL_14	0.08	1.1	48	1213	0.2	1.3	5	12	1975	6	3	1.4	< 10	5	35	< 0.13	26
	TMDL_15	0.05	323	38	384	1.62	0.54	2	16	794	4	3	0.72	< 10	2	60	0.30	< 7.67
Gördes-Gürdük Stream	TMDL_21	0.08	1.3	2.7	63	0.65	2.4	11	16	1807	26	3	0.18		6	185	0.31	31
	TMDL_22_1	0.32	27	27	141	1.13	30	137	71	33268	260	19	0.48		61	105	0.31	772
	TMDL_22_2	0.14	2.1	10	580	0.34	4.1	14	33	2488	25	9	1.08	< 10	12	165	0.41	80
	TMDL_23	0.12	74	5	186	0.10	0.5	4	12	194	4	2	0.28		1.23	34	0.23	< 7.67
	TMDL_24	0.18	9	24	255	0.17	7	27	28	8193	38	9	1.02	< 10	20	104	0.50	736
	TMDL_25	0.08	320	21	197	0.13	1.1	4	17	618	8	2	1.27	< 10	6	35	0.32	< 7,67
	TMDL_31	0.17	1.7	15	57	0.21	1.3	5	16	2239	6	3	0.50	< 10	8	48	0.37	251
	TMDL_32	0.22	7	23	109	1.85	5	23	28	9022	28	8	0.66		23	54	0.46	354
	TMDL_33	0.19	8	33	168	0.23	6	25	29	9381	33	8	0.92	< 10	23	65	0.76	1260
	TMDL_34	0.13	215	35	327	0.1	0.23	1.07	17	304	5	2.6	1.22	< 10	3	43	0.40	< 7.67
Nif Stream (Lower Gediz Sub-Basin)	TMDL_16	0.07	518	35	584	0.36	1	3.9	15	1068	6	3	0.77	< 10	3	66	0.27	< 7.67
	TMDL_17	0.05	252	9	67	0.27	0.3	1.2	10	330	2	2	0.24	< 10	2	70	0.07	< 7.67
	TMDL_18	1.07	1172	11	993	0.85	2.5	1046	380	2004	2969	97	1.98	< 10	5	1416	0.25	< 7.67
	TMDL_19	0.97	7505	10	691	3.5	19	50	56	3103	79	44	1.86	15	7	4145	0.47	44
	TMDL_39	0.43	2366	7	469	0.2	9	77	56	1034	228	17	2.7	< 10	4	15725	0.41	< 7.67
	TMDL_36	0.13	405	7	228	0.13	1.7	24	24	631	59	4	0.89	< 10	2	175	0.38	< 7.67
	TMDL_20	0.17	44965	104	272	0.32	16	80	46	50571	81	26	1.78	< 10	65	402	0.38	889
Lower Gediz Sub-Basin	TMDL_26	0.07	1303	47	1070	0.22	1.5	6	13	2280	8	3	1.58	< 10	6	40	0.32	68
	TMDL_27	0.11	2889	46	794	0.21	3.6	12	20	5107	21	6	1.34	< 10	10	81	0.39	54,25
	TMDL_28	0.08	633	4	376	0.81	0.8	11	712	2220	21	6	0.77	< 10	3	154	0.75	< 7.67
	TMDL_29	0.08	2870	45	785	0.7	3.6	21	27	6486	31	6	1.42	< 10	9	87	0.50	69
	TMDL_38	0.07	2653	45	679	0.24	3.7	26	25	4208	36	12	1.20	< 10	10	101	0.33	67
	TMDL_30	0.05	892	40	708	0.94	1.6	8	14	1470	20	3	1.36	< 10	7	174	0.50	12

Note. These stations were observed as dry during monitoring. As a consequence, no data is available.

For comparing the obtained results (during 2015-2016), the monitoring studies conducted by the State Hydraulic Works (DSI) which were more representing for long term (during 2000-2015) were analyzed (DSI, 2016). However, it was determined that all metals listed in By-law on Surface Water Quality (OG: 30.11.2012/28483) were not being monitored. Besides the monitored parameters were not frequent for giving an idea. In addition to DSI, the Ministry of Environment and Urbanization also had monitoring studies for surface waters, but these observations were less comprehensive and less detailed when compared with the current study. Nevertheless similar results were obtained for the common parameters monitored.

The locations of the point source pressures are shown in Figure 3. The mining areas (mines in operation, mines not currently in operation, and mine potential) and geothermal wells are presented in Figure 4 to provide insight about geological formation of the basin.

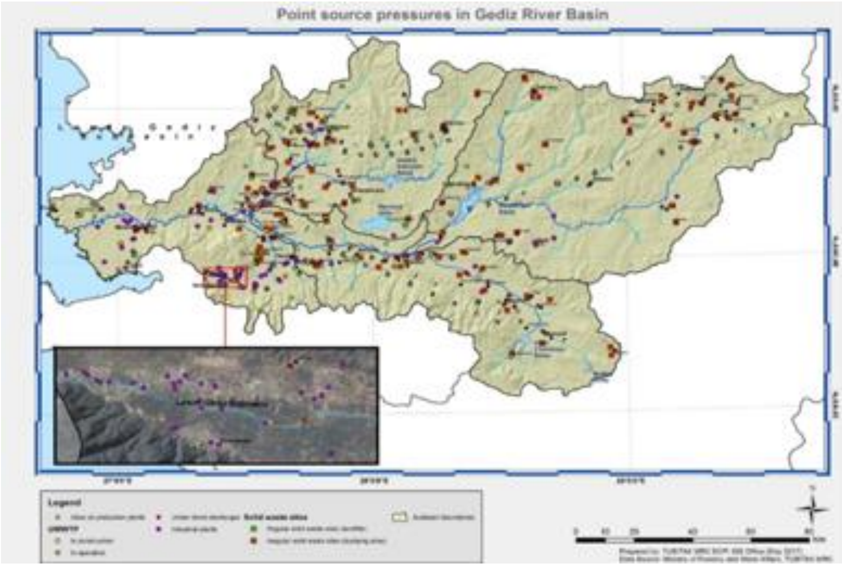

Figure 3. Point source pressures in Gediz River Basin.

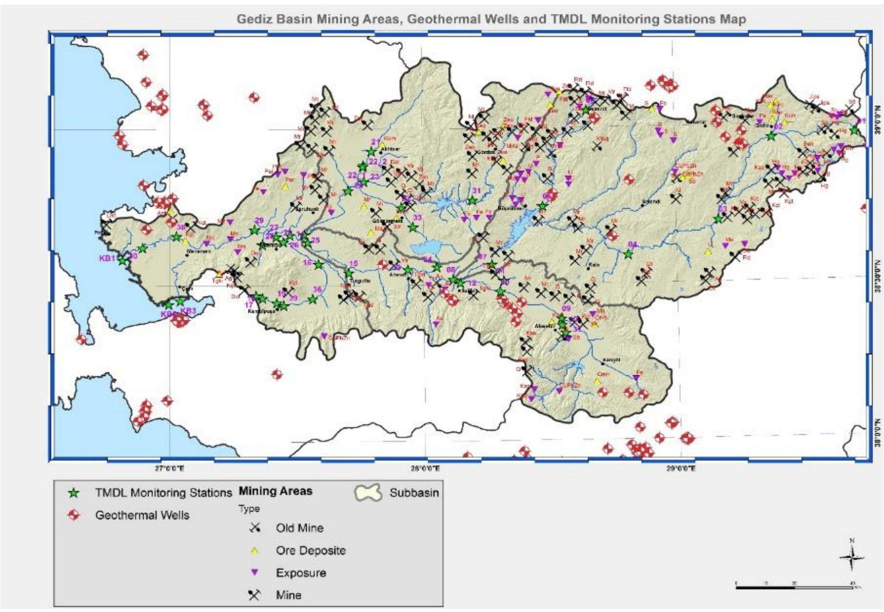

Figure 4. Mining areas and geothermal wells in Gediz River Basin.

The pressures affecting the water quality on each station were assessed considering their pollution contribution. Discussion on the NBC value was made for each metal in following sections.

Ag

It was observed that AA-EQS value of 1.5 μg/L for Ag was not exceeded in any stations. Relatively high Ag concentrations were obtained only in the stations of TMDL-18, TMDL-19 and TMDL-39 located around Nif Stream. None of the pressures detected in the basin exceeded a pollution contribution of 2% in the receiving water bodies. Accordingly, NBC value calculated for Ag was found as lower than the EQS value.

Al

Al concentrations have been observed as higher than the AA-EQS value of 2.2 μg/L for all the stations. The obtained values have ranged from 74 μg/L (TMDL-23) to 61147 μg/L (TMDL-04). There are kaolin deposits in the Upper Gediz Sub-Basin (around TMDL-01, TMDL-02, TMDL-03), kaolin potentials around the upstream of Alasehir Stream Sub-Basin and kaolin operations around the stations of TMDL-09, TMDL-10 and TMDL-37. In addition, zeolite and feldspar operations are present around TMDL-06 in the vicinity of Demirci and near the TMDL-31 station located in Gordes-Gurduk Stream Sub-Basin. Apart from these regions, receiving water bodies affected by anthropogenic pressures by at least 2% were excluded from NBC evaluation. On the other hand, in rainy period, relatively high Al concentrations were observed at some stations, which are associated with existing geological formations.

As

As was detected over 50 μg/L in the stations located around Demirci (TMDL-05, 70 μg/L), Koprubasi (TMDL-06, 57 μg/L), Kula (TMDL-04, 63 μg/L), Ahmetli (TMDL-13, 80 μg/L), Alasehir (TMDL-10, 82 μg/L) and Nif Stream mouth (TMDL-20, 104 μg/L). Similar results were obtained also in groundwater monitoring studies conducted by the State Hydraulic Works (DSI). In groundwater monitoring, it was observed that As value increased depending on the geological structures in various regions of the basin. As concentrations were observed over 100 μg/L in groundwater around Demirci, near Gure, around Borlu and Salihli, in the east of Manisa provincial center and in Menemen and its surroundings (DSI, 2016). As concentration measured in groundwater during dry period was identified as higher compared to the concentration in rainy periods. The high arsenic concentration in the study has been largely associated with the geological structure.

B

Boron concentrations detected in the stations of TMDL-40 (10652 μg/L), TMDL-10 (1642 μg/L), TMDL-12 (4532 μg/L), TMDL-13 (1932 μg/L) and TMDL-14 (1213 μg/L) located in Alasehir Stream Sub-basin were relatively higher compared to other stations. It has been observed that geothermal wells were located in this region. Therefore, it is possible to state that the B detected is of natural origin.

Co

The concentrations of Co measured in the majority of the receiving water stations were found to be higher than 0.3 µg/L, which is the AA-EQS value. The higher concentrations were observed at TMDL-04 (38 µg/L), TMDL-10 (16 µg/L), and TMDL-22-1 (30 µg/L). When the concentration values were converted to load unit, it has been observed that higher Co loads were introduced around Akhisar and Manisa-Center. Co is not found as a mineral naturally occurring in the basin. In receiving water bodies where Co was determined to be relatively high, the pressures at least with a 2% pollution contribution were identified. The contamination in these waters was assumed to be of anthropogenic origin and the stations were not taken into consideration for NBC evaluation.

Cr

AA-EQS value of Cr parameter, which is equal to 1.6 µg/L, was mostly exceeded in the monitoring stations. The higher values were obtained in TMDL-04 with a value of 145 µg/L and in TMDL-22-1 with 137 µg/L. There are no chromium deposits in the basin. It was observed that there were pressures with at least 2% contribution in the receiving bodies in which Cr concentrations were determined as relatively higher. It was accepted that the pollution in aforementioned receiving bodies was of anthropogenic origin, thus these receiving bodies were not taken into consideration for NBC evaluation.

Cu

Cu concentration measured in majority of the stations was found higher than 1.6 µg/L, which is AA-EQS value. Higher values were observed in the stations of TMDL-04 (71 µg/L), TMDL-10 (54 µg/L) and TMDL-22-1 (71 µg/L). There are Cu-Pb-Zn potentials in the upstream of Upper Gediz (TMDL-02 and TMDL-03) and Alasehir Stream Sub-Basins. The relatively higher values detected in the related stations were of natural origin and they were included in NBC evaluation. The rest of the monitoring results for Cu were assumed to be a result of anthropogenic effects.

Fe

Fe concentrations measured in nearly all of the stations were found as significantly higher than AA-EQS value of 36 µg/L. The values changed between 200 and 76888 µg/L. The higher values were observed in TMDL-04 (76888 µg/L), TMDL-10 (23180 µg/L), TMDL-22-1 (33268 µg/L). There are kaolin and feldspar operations around Alasehir Stream; Fe potential in the inlet of Gordes Dam (TMDL-31); feldspar operation in the upstream of Demirci Stream; Fe potential near Gediz (TMDL-02). It was accepted that relatively high Fe concentrations determined in these regions are of natural origin. In rainy periods, Fe concentrations were increased indicating the effect of geological formation.

Sb

It was observed that Sb value only exceeded AA-EQS value of 7.8 µg/L in TMDL-40 station. Sb values, which was determined as relatively high in TMDL-40 station was accepted to be of anthropogenic origin, and thus not taken into consideration in NBC calculation. On the other hand, there was antimony potential in the upstream of Alasehir Stream Sub-Basin and antimony operation in the upstream of Upper Gediz Sub-Basin. Therefore, it was accepted that

Sb values were determined as relatively high in TMDL-10, TMDL-13 and TMDL-37 stations of natural origin and these stations were included in NBC evaluation.

Sn

Sn concentrations did not exceed AA-EQS value (13 µg/L) in the basin apart from TMDL-19 station (15 µg/L) located around Nif Stream. There are no tin deposits in the basin. It was determined that there were pressures with at least 2% pollution contribution in the receiving bodies, where Sn concentrations were determined to be relatively higher (TMDL-09, TMDL-37). Thus, they were accepted to be of anthropogenic origin and not assessed for NBC determination.

V

V concentration measured in nearly all of the stations was found higher than 1.6 µg/L, which is AA-EQS value. There are no vanadium deposits in the basin. It was identified that there were pressures with at least 2% contribution in the receiving bodies, in which V concentrations were determined to be relatively higher. Thus, it was accepted that the pollution in the aforementioned stations is of anthropogenic origin and were not taken into consideration for NBC evaluation.

Zn

Zn concentration measured in all of the stations was obtained higher than 5.9 µg/L, which is AA-EQS value. The higher concentrations were observed in TMDL-04 (187 µg/L), TMDL-10 (188 µg/L), TMDL-12 (161 µg/L) and TMDL-21 (185 µg/L) stations. There has been Cu-Pb-Zn potential in the upstream of Alasehir Stream. Hence, it was accepted that TMDL-10 and TMDL-12 stations bearing relatively high Zn concentrations were under the influence of natural origins. The rest of the stations were assumed to be under the influence of anthropogenic sources and were not taken into consideration for NBC calculation.

Ti

Ti concentration was found higher than AA-EQS value of 26 µg/L in most of the stations. The higher values were detected in TMDL-04 with 2132 µg/L and in TMDL-33 with 1260 µg/L. There is titanium potential near Ahmetli-Salihli and Gordes. The other stations were accepted to be under the influence of anthropogenic sources and were not taken into consideration for NBC calculation.

Cd

Cd concentrations were determined over 0.08 µg/L which is AA-EQS value in all stations. The higher values were observed in Turgutlu (TMDL-15, 1.62 µg/L), Kula (TMDL-04, 1.26 µg/L) and Akhisar (TMDL-22-1, 1.13 µg/L). There are no cadmium deposits in the basin. Within the stations, it was observed that there were pressures causing pollution contribution of at least 2%, those stations were accepted to be under anthropogenic pressure and not used in NBC calculation.

Ni

Ni concentration was found higher than 4.5 µg/L which is AA-EQS value in most of the stations. The higher values were detected in TMDL-04 with 249 µg/L and in TMDL-22-1 with 260 µg/L. There are nickel operations between Turgutlu and Golmarmara (around TMDL-13 and TMDL-14) and near Gordes (head of TMDL-31). Additionally, according to the groundwater monitoring studies performed by the State Hydraulic Works, Ni was determined in the upstream of Gediz Basin that referred to be naturally present. The rest of the receiving bodies (other than those mentioned above) were subjected to the pollution contribution and stations under pollution contribution of at least 2%, were accepted to be of anthropogenic origin and were not taken into consideration for NBC calculation.

Pb

Pb concentration monitored in the all receiving body stations exceeded 1.2 µg/L which is AA-EQS value. TMDL-04 (27 µg/L), TMDL-10 (20 µg/L) and TMDL-22-1 (19 µg/L) stations were observed as the most polluted sites with Pb. There are Cu-Pb-Zn potential and operation around the upstream of Alasehir Stream and Gediz. Except the related stations (TMDL-9, TMDL-10, TMDL-37, TMDL-40 and TMDL-2) located in these regions, stations which were affected by pressures with at least 2% pollution contribution were accepted to be under the influence of anthropogenic pressures.

Hg

Although there is no AA-EQS value for Hg designated with the legislation, MAC-EQS value for Hg is provided as 0.07 µg/L. According to the monitoring results, Hg concentration (excluding Nif Stream and Lower Gediz Sub-Basins) measured in the stations ranged between 0.065 µg/L and 2.82 µg/L in TMDL-01 and TMDL-04, respectively. The stations, which the higher Hg values are measured, are TMDL-04 (2.82 µg/L), TMDL-33 (0.76 µg/L) and TMDL-10 (0.73 µg/L). There is mercury operation and potential in the upstream of Gediz River and an old mercury establishment in the upstream of Alasehir Stream. Apart from the stations located in these regions, stations affected by the pressures with at least 2% pollution contribution were assumed to be under the influence of anthropogenic sources.

According to the obtained results, both anthropogenic pressures and geological formation have an effect on metal concentrations. Until now there are limited studies subjecting the source of metals where coming from anthropogenic activities or geological formation for Gediz Basin. The study done by Kindler and Sevim (1990) has importance for providing information about the previous source distribution of the metals in the basin. Kindler and Sevim (1990) investigated natural and anthropogenic effects of metals in sediments during the months of July-October 1988, for the Basins of Gediz, Menderes, Sakarya, Kizilirmak, Yesilirmak, Seyhan and Ceyhan. The study was undertaken with subjecting the metals of Cd. Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. For Gediz Basin 19 samples were collected at 10-20 km intervals during 320 km of Gediz River. In order to classify local anthropogenic heavy metal pollution, "index of geoaccumulation (I_{geo})" was used for trace metals in sediments and their classification. Geoaccumulation index calculation was dependent on the measured concentration of the element in the fraction < 2 µm in the sediment. The classes were ranged between 0-6, that 6 means "very strong anthropogenic effect" while 0 means "practically none anthropogenic effect". According to the I_{geo} classification Cd, Cr, Cu, Pb and Zn was classified as 0, 2, 3, 2 and 2 respectively. In other words presence of Cr, Pb and Zn were correlated with "moderate effect", while the presence of Cu was correlated with "moderate to strong effect" of anthropogenic pressures. The obtained values by Kindler and Sevim (1990) were 0.236 μg/L, 232 μg/L, 110 μg/L, 35 μg/L and 147 μg/L for Cd, Cr, Cu, Pb and Zn, respectively. When the highest values of our results were compared with the previous study, it is seen that the degrees of the numbers are similar within the exception of Cd (Table 2). For Cd almost 6 times higher values were obtained in our study that could be the reason of anthropogenic sources that raised after 1990's.

Another study done by Kucuksezgin et al. (2008) investigated the distribution of Hg, Pb, Cu, Zn, Mn, Ni and Fe in the sediment, water and particulate matter and their possible sources of derivation. In this context, metals measured in surficial sediment, water and particulate matter of the Gediz River collected from 5 different points in August, October 1998, February, June 1999. According to the results, the highest values were obtained at Muradiye (corresponding to station of TMDL-29 in our study) in summer periods as a result of industrial and agricultural activities. Relatively high concentrations of Ni and Mn values measured through the origin of the basin was correlated with to geochemical composition of the sediments. In our study, similarly TMDL-29 was one of the stations that metal values were observed highly.

For comparing different methods for NBC determination, there is a study done by Oste et al. (2011) evaluating the approaches of i) clean streams, ii) erosion model, iii) sediment approach, iv) stable summer levels, v) monitoring data and vi) origin of surface water. Some criteria were used for comparison of these methods such as i) well defining natural dissolved background concentrations, ii) data necessity, iii) uncertainty, iv) elements and v) regional differentiation. According to the obtained results, all methods were evaluated as uncertain since one or more assumptions used in methods and resulted with serious limitation in deriving NBC. Among these criteria, natural dissolved background concentrations has the most significance as being the WFD focusing on. For this criteria, acceptable results were obtained for the approaches of clean stream, the sediment and the origin of surface water. The monitoring data method based on actual measurements, had the maximum score on criteria of daily data, number of elements that NBC defined and regional differentiation and this method was regarded as an acceptable fall-back alternative. The approaches of erosion model and the stable summer levels were rejected. The method of stable summer levels was found as lack of producing real NBC and also further development was required. The erosion model concentrated on natural concentrations especially on metals associated with the rock composition of the catchment area. The values obtained needed to be convert to dissolved concentrations. This conversion was not found so reliable (Oste et al., 2011).

According to the evaluation presented above, recommended NBC and Final EQS values of the metals in the inland waters are presented in Table 3. The grey colored field in the table represented the results that EQS values equivalented to EO values.

Table 3

NBC Values and Final EQS Values Recommended for Inland Waters of Gediz River Basin

	EQS Value- Inland Waters			**Final EQS**	
µg/L	**AA-EQS (µg/L)**	**MAC- EQS (µg/L)**	**NBC**	**AA-EQS (µg/L)**	**MAC-EQS (µg/L)**
Ag	*1.5+NBC*	*1.5+ NBC*	0.12	1.50	1.50
Al	*2.2+ NBC*	*27+ NBC*	2162.41	2165	2189
As	*53+ NBC*	*53+ NBC*	33.22	53	53
B	*707+ NBC*	*1472+ NBC*	1084.98	1792	1792
Co	*0.3+ NBC*	*2.6+ NBC*	1.66	2.0	2.6
Cr	*1.6+ NBC*	*142+ NBC*	12.62	14	142
Cu	*1.6+ NBC*	*3.1+ NBC*	19.52	21	23
Fe	*36+ NBC*	*101+ NBC*	3795.80	3832	3897
Sb	*7.8+ NBC*	*103+ NBC*	1.68	7.8	103
Sn	*13+ NBC*	*13+ NBC*	<10	13	13
V	*1.6+ NBC*	*97+ NBC*	9.29	11	97
Zn	*5.9+ NBC*	*231+ NBC*	73.54	79	231
Ti	*26+ NBC*	*42+ NBC*	220.22	246	262
Cd	*0.25+ NBC*	*1.5+ NBC*	0.45	0.70	1.50
Ni	*4.00+ NBC*	*34 + NBC*	29.33	33	34
Pb	*1.20+ NBC*	*14 + NBC*	4.11	5.3	14
Hg		*0.07+ NBC*	0.45		0.52

Conclusion

This study aims to develop an approach for determination of NBC for metals in surface waters. Within this scope, 17 metals indicated in the By-law on Surface Water Quality were subjected to NBC evaluation by taking into account the effect of anthropogenic and natural sources. The pollution impact on receiving water bodies was revealed by using the seasonal monitoring data for 40 stations during 2015-2016. Both point source pressures and geologic formation were examined to understand the origin of pollution. For anthropogenic sources, monitoring was performed on industrial and urban wastewater discharges both with and without treatment plants simultaneously with the receiving body monitoring and pollution contribution of each point source on surface water was calculated. For natural sources, mining activities and geothermal source distribution were investigated.

According to the monitoring results in surface waters, nearly all metals were detected at concentrations higher than their AA-EQS within the exception of Ag, Sb and Sn. Among 17 parameters, Ag, Al, Fe, As, B and Sb were observed in surface waters as the result of natural sources. The rest of the parameters were subjected to the question of which source has an effect on their existence.

The approach for determining anthropogenic effect was a suitable way to distinguish the relative effects of the pressures on receiving bodies. . This method could be beneficial to identify and compare the effect of sources, and thus help to establish critical factors for decision makers such as deciding a location of a new facility, the amount of pollution discharge of the plants and precautions for agricultural activities, especially when long-term monitoring data is not available.

By the suggested methodology, it was possible to determine NBC values for metals in surface waters. The presented method may be suitable for making general inferences with less data, but future work is recommended that includes long-term observation. Monitoring data is required not only in receiving water body; but also, in sediment while calculating NBC. On the other hand, in future, NBC values could be determined on water body basis by taking into consideration the typology of water bodies.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Yüzey Sularındaki Metaller için Doğal Arka Plan Konsantrasyonlarının Belirlenmesi, Gediz Havzası Örneği

Arka plan konsantrasyonu, bir kimyasal maddenin doğal ve jeolojik proseslerden kaynaklanan miktarı olarak tanımlanmaktadır (EC, 2011). Diğer bir ifadeyle, bir alıcı ortamın, insan faaliyetleri sonucu noktasal ve yayılı kaynaklı kirleticilerin etkisi altında kalmadan, kimyasal maddenin doğal prosesler sonucu ortamda bulunmasıdır. Alıcı su ortamlarında ekolojik ve kimyasal iyi durum statüsünün sağlanabilmesi ve su kalitesinin iyileştirilebilmesi için esas oluşturan Çevre Kalite Standardı (ÇKS) belirlenirken su ortamındaki kirleticilere ait Doğal Arka Plan (DAP) konsantrasyonları büyük önem taşımaktadır. Kirleticilerin su ortamlarındaki DAP konsantrasyonları, bölgenin tipolojisi, jeolojisi, coğrafyası ve toprağının ve yeraltı suyunun fiziksel, kimyasal ve biyolojik özelliklerine göre farklılık göstermektedir.

AB Su Çerçeve Direktifindeki temel amaç tüm üye devletlerde iyi yüzey suyu statüsünü elde etmektir (WFD, 2000/60/EC). Bu amaca yönelik olarak, "öncelikli maddeler" için Komisyontarafından, "belirli kirleticiler" için üye ülkelerin kendileri tarafından su kalitesi standartları oluşturulmuştur. Üye devletler standartlara uyulamadığı durumlarda, DAP konsantrasyonlarını dikkate alabilmektedirler. Su Çerçeve Direktifi, bazı organik kirleticilerin doğal bir menşeine sahip olmasına karşın, yalnızca metaller ve yarı-metaller için DAP konsantrasyonu belirlenmesine izin vermektedir. Her ülke, DAP konsantrasyonu belirleyip belirlemeyeceğine kendi karar vermektedir.

Yüzey sularındaki metaller için DAP konsantrasyonlarının belirlenmesinde AB ülkelerinde farklı yöntemler uygulandığı görülmektedir. Bu yöntemlerde, i) temiz sulardaki metal içeriği, ii) sedimentteki metal içeriği, iii) yeraltı suyundaki arka plan konsantrasyonları, iv) uzun dönem izlenen yüzey sularındaki metal içeriği ve v) yaz döneminde (değişken olmayan) yüzey sularındaki metal içeriği dikkate alınmaktadır (Oste, et al., 2011).

Bu çalışma kapsamında Yerüstü Su Kalitesi Yönetmeliği'nde (RG: 30.11.2012/28483) yer alan metaller (Ag, Al, As, B, Co, Cr, Cu, Fe, Sb, Sn, V, Zn, Ti, Cd, Ni, Pb ve Hg) için DAP konsantrasyonlarının belirlenmesi hedeflenmiştir. Bu amaçla Gediz Havzası pilot havza olarak seçilmiştir. Havzada belirlenen yüzey suları için 2015-2016 yılları arasında, 4 dönem boyunca, 40 adet alıcı ortam istasyonu ile 29 adet kentsel atıksu ve 54 adet endüstriyel atıksu deşarj noktasında izleme yapılmıştır. Zuurdeeg ve diğ. (1992) tarafından açıklanan ve Hollanda'da uygulanan "temiz sular" yaklaşımında, DAP değeri olarak, akışın başlangıç noktasına doğru nispeten kirlenmemiş bölgedeki (memba) su kalitesi referans alınmaktadır. Çalışmada izleme yapılan noktalardan yalnızca birisinin bu tanıma uyduğu, bu noktanın da tüm havzayı karakterize etmediği sonucuna varılmıştır. İngiltere'de kullanılan "uzun dönem izlenen yüzey suları" yaklaşımında, prensip olarak en az 5 veri seti ile en az 50 istasyonun izlenmesi kabul edilmektedir (Peters ve diğ., 2010)..Çalışmadaki izleme verilerinin bu anlamda yetersiz kaldığı görülmüştür. Bu sebeple, doğal ve antropojenik kaynaklar dikkate alınarak, DAP konsantrasyonun belirlendiği yeni bir yaklaşım geliştirilmesine gidilmiştir. Eldeki veriler ışığında, "temiz sular" ile "uzun dönem izlenen yüzey suları" yaklaşımları da dikkate alınarak DAP değerinin belirlendiği yöntemleri takip etmek uygun bulunmuştur. Çalışmada izleme noktalarının nispeten az kirlenmiş olanları ele alınmışve bu alıcı ortamlara etki eden baskılar incelenmiştir. Bu kapsamda, izleme çalışmaları dikkate alınarak antropojenik kaynaklar için olası her baskının kirlilik katkısı incelenmiş; ve doğal kaynaklar için madencilik faaliyetleri ile jeotermal kaynakların dağılımı değerlendirilmiştir.

Türkiye'de DAP konsantrasyonlarının belirlenmesi ile ilgili henüz bir çalışma yapılmadığı, mevcut çalışmaların daha çok yüzey sularında, sedimentte ve biyotada metallerin izlenmesi üzerine olduğu görülmektedir (Bizsel ve diğ., 2017; Suzer ve diğ., 2015; Aydin ve Kucuksezgin, 2012; Kucuksezgin ve diğ., 2008). Yüzey sularında metaller için DAP konsantrasyonunun belirlenmesini konu alan bu çalışma, Türkiye için öncü bir çalışmadır.

DAP konsantrasyonun belirlenmesinin ilk adımını, alıcı ortamda tespit edilen yüksek metal içeriğinin doğal kaynaklı mı yoksa antropojenik kaynaklı mı olduğunu belirlemek oluşturmuştur. Kirliliğin antropojenik kaynaklı olup olmadığını tespit etmek için alıcı ortamdaki izleme çalışmaları ile eş zamanlı olarak, olası noktasal kirletici kaynaklar (kentsel ve endüstriyel atıksular deşarjları) izlenmiştir. Her bir baskının, alıcı ortam üzerinde kirliliğe en az %2 oranda katkısı olanları belirlenmiş ve ardından ilgili alıcı ortamlardaki jeolojik etkisi incelenmiştir. Eğer jeolojik durum söz konusu ise DAP hesabına, incelenen alıcı ortam dahil edilmiş; değilse baskının antropojenik olduğu kabul edilip alıcı ortam dahil edilmemiştir. Bu tespit sonrasında antropojenik baskının yoğun olduğu Aşağı Gediz Alt Havzası (Gediz Nehri mansabı ve Nif Çayı) üzerindeki istasyonlar dikkate alınmayarak kalan 27 istasyonun verilerinin incelenmesine karar verilmiştir. Noktasal baskıların alıcı ortam üzerindeki kirletici katkısının belirlenmesinde kullanılan formüller aşağıda yer almaktadır.

$$\frac{PK}{ÇKS} x\%100 = \%_{Artış}$$

PK = Proses Katkısı
ÇKS = Çevre Kalite Standardı

$$\frac{[CoC]_{deş}\, xQ_{deş}}{\left(Q_{nehir} + Q_{deş}\right)} = PK$$

$CoC_{deş}$ = Atıksudaki metal konsantrasyonu
$Q_{deş}$ =Atıksu debisi
$Q_{deş}$= Nehir debisi

DAP değerlerinin belirlenmesinin ardından, Gediz Havzası'ndaki metallerin nihai Çevresel Kalite Standardı (ÇKS) değerlerinin belirlenmesi için aşağıdaki yaklaşım uygulanmıştır.

- DAP konsantrasyonu, ÇKS'den düşükse Çevresel Hedef (ÇH), ÇKS'ye eşittir.
  DAP<ÇKS → ÇH=ÇKS,

- DAP, ÇKS'den yüksek veya eşitse ÇH, ÇKS ile DAP'nın toplamına eşittir.
  DAP≥ÇKS → ÇH=ÇKS+DAP

Alıcı ortam istasyonlarındaki izleme sonuçları incelendiğinde, Ag, Sb ve Sn dışında neredeyse tüm metallerin yıllık ortalama değerlerinin ÇKS değerlerinin üzerinde olduğu tespit edilmiştir. DAP konsantrasyonu bulunması hedeflenen 17 metalden, Ag, Al, Fe, As, B ve Sb'nın yüzey sularında doğal kaynaklı olarak bulunduğu görülmüştür. Kalan diğer metallerin ise doğal kaynaklı veya antropojenik kaynaklı olarak yüzey sularında bulunma durumu, önerilen yaklaşıma göre incelenmiştir. Bu çalışmayla önerilen DAP konsantrasyonları belirlenmesi yaklaşımının, izleme çalışmalarında ve yalnızca Gediz Havzası özelinde değil, tüm havzalarda kolaylıkla uygulanabileceği sonucuna varılmıştır. Ayrıca bu yaklaşımla, kirliliğin kaynağının tespit edilmesi veya kirlilik katkısının belirlenmesi konularının yanı sıra, karar vericilerin hangi tesisin nerede kurulması gerektiği, hangi tesisin ne oranda kirletici deşarj edebileceği, tarımsal üretimde ne gibi önlemlerin alınması gerektiği, kullanılan zirai mücadele ilaçlarının ne oranda azaltılmasının uygun olacağı gibi kritik kararları almasında yardımcı olacağı düşünülmektedir.

Belirlenen yöntemde nispeten az veri ile genel çıkarımlar yapmak mümkündür. Ancak DAP değerinin belirlenmesi için yürütülecek yeni çalışmalarda uzun dönem ve yalnızca su ortamında değil, aynı zamanda sedimentte de izleme yapılması, ayrıca DAP değerlerinin havza geneli için tek değer olarak değil, tipolojiler dikkate alınarak su kütleleri bazında da belirlenmesi önerilmektedir.

Research Article

Domestic Wastewater Discharges into Rural Alabama Streams and Impact on Water Quality

Evsel Atıksuların Alabama Kırsalındaki Akarsulara Deşarjı ve Su Kalitesine Etkisi

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Abstract

In rural areas, direct discharge of untreated domestic wastewaters can cause harmful effects on the region's rivers and streams, so determining and addressing the water quality of these aquatic ecosystems requires identification of the sources of contamination, such as runoff sources from straight pipes, or septic systems. Surface water quality in Hale County in Alabama, USA was evaluated at least once a month at twenty sites in wet and dry seasons. Samples were analyzed for physical (turbidity), chemical (pH, conductivity, chloride, sulfate, calcium, iron, magnesium, potassium, sodium, ammonium, ortho-phosphorus, nitrite, nitrate, dissolved organic carbon, optical indices), and microbiological (*E. coli*) water quality parameters. Excitation-emission matrixes Parallel Factor Analysis was used to identify and classify fluorescence emitting organic substances based on fluorescence peak location. Principal Component Analysis was used to identify analytic signatures associated with sewage contamination. To detect direct discharge wastewater impacts on water quality, three main sites were sampled upstream, midstream and downstream of the town of Newbern, Alabama over the three months of the drought period (i.e., from September to November, 2016). Over 20 water quality parameters were analyzed and compared with the World Health Organization, Environmental Protection Agency and Alabama Department of Environmental Management standards. The results showed that *E. coli* values highly exceeded the water quality standards, particularly after the drought when peak *E. coli* concentrations in the downstream site exceeded 100,000 MPN per 100 mL. Our study is one of the first documents concerning the adverse impacts of direct discharges on water quality in the United States.
Keywords: *water quality, water management, wastewater, watershed, rural Alabama streams*

Öz

Kırsal alanlarda, evlerden doğrudan deşarj edilen arıtılmamış atık sular bölgenin nehirleri ve akarsuları üzerinde zararlı etkilere yol açabildiği için bu sucul ekosistemlerin su kalitesini belirlemek düz borulardan ya da fosseptiklerden gelen atık sular gibi kirlilik kaynaklarının tanımlanmasını gerektirmektedir. Amerika Birleşik Devletlerinin Alabama Eyaletinde bulunan Hale County'deki yüzey suyu kalitesi, en az ayda bir kez olmak üzere, yağışlı ve kuru mevsimlerde yirmi noktada değerlendirilmiştir. Numuneler fiziksel (bulanıklık), kimyasal (pH, iletkenlik, klorür, sülfat, kalsiyum, demir, magnezyum, potasyum, sodyum, amonyum, ortofosfat, nitrit, nitrat, çözünmüş organik karbon, optik indeksler) ve mikrobiyolojik (E. coli) su kalitesi parametreleri olarak analiz edilmiştir. Uyarma-emisyon matrisleri Paralel Faktör Analizi floresan tepe noktasını temel alan floresan yayıcı organik maddeleri tanımlamak ve sınıflandırmak için kullanılmıştır. Ana Bileşen Analizi (PCA), atıksu kirliliği ile ilişkili analitik imzalarını tanımlamak için kullanılmıştır. Doğrudan deşarjların su kalitesi üzerindeki etkilerini tespit etmek için yağışsız dönemde (Eylül-Kasım 2016) üç ay boyunca Newbern, Alabama kasabasının üç ana bölgesinden (nehrin memba, orta ve mansabı) numune alınmıştır. Yirmiden fazla su kalitesi parametresi analiz edilmiş ve Dünya Sağlık Örgütü, Çevre Koruma Ajansı ve Alabama Çevre Yönetimi Bölümü standartları ile karşılaştırılmıştır. Sonuçlar, E. coli değerlerinin su kalite standartlarını oldukça aştığını, özellikle yağışsız dönem sonrası mansapta pik değerlerin 100.000 EMS/100 mLdeğerini aştığını göstermiştir. Bu çalışma, doğrudan deşarjların ABD'deki su kalitesi üzerindeki olumsuz etkilerini belgeleyen ilk çalışmalardan biridir.
Anahtar kelimeler: *su kalitesi, su yönetimi, atıksu, havza, kırsal Alabama akarsuları*

Introduction

About 75% of US population is served with different types of sewer systems which end-up with a domestic wastewater treatment plants. The remaining 25%, 80 million people, should treat their wastewater on site, mostly using conventional septic systems (U.S. EPA, 2013). It is recognized that these systems can fail and, when they do, inadequately treated effluent can have serious environmental effects. Since failing systems pose public health and environmental risks, strategies need to be adopted to control these risks. Additionally, some soil conditions are unsuitable for septic systems. In rural areas with these soil conditions and no access to sewers, many poor residents are left with no affordable, safe and legal options for onsite waste water management.

In the Black Belt region of Alabama USA (Figure 1), many communities struggle with wastewater management. Soil and geology type of Black Belt region is mostly unsuitable for the conventional septic system (He et al., 2011). In addition to failing septic systems, household raw sewage is often discharged directly into wooded areas by using a pipe, so called "straight pipe" (Figure 2) in the rural Black Belt. The prevalence of straight pipes and septic tanks failures in rural areas can cause environmental and human health problems when associated pollutants are discharged to nearby waterways.

White and Jones (2006) reports that in Bibb County, Alabama, 15% of homes not connected with any sewer systems were directly discharging raw sewage. While the impacts of raw sewage discharges to waterways and ecosystems are expected to be substantial, the greatest concern is their threats to human health. Based on these results and Bibb County water use report by Littlepage et al. (2005), we estimate that homes with straight pipes account for over 567 m^3 of raw sewage discharged into the land surface and streams each day in Bibb County alone. Based on average pathogen concentrations in wastewater (Payment and Locas, 2011; Robertson et al., 2006), we estimate that straight pipes in Bibb County potentially discharge billions of infectious pathogens per day. Representative pathogen loads from these straight pipes per day in Bibb County are >3 billion enteric viruses, >5 billion Giardia cysts, and >1 billion Cryptosporidium oocysts. These pathogens have very low infectious doses and survive much longer in the environment than indicator bacteria like E. coli—the absence of E. coli may indicate the absence of viable pathogenic bacteria while these more robust pathogens are still present.

Figure 1. Alabama Black Belt Counties. (URL 1)

Figure 2. A typical straight pipe discharge (EPA Region 4, 2002).

Dissolved organic matter (DOM) is an assemblage of heterogeneous compounds present in all natural waters and is a massive carbon pool in aquatic ecosystems (Purves et al., 2001). DOM is becoming highly recognized for the role it plays in moderating the environmental and ecological processes, such as transforming carbon into the microbial food web, protecting aquatic biota through buffering pH, complexing metals, transporting organic pollutants and absorbing ultraviolet radiation (Martell et al. 1988; Williamson et al. 1994; Findlay 2003; Clements et al., 2008). Although a complex mixture, DOM composition can be characterized by optical properties including using UV-VIS (visible) and fluorescence spectroscopy methods. Relative to molecular methods (e.g., Lu et al., 2015), optical measurements provide a more rapid and economic means for characterizing DOM compositions and distinguishing biological sources. Using UV spectroscopy, a large number of useful proxies can be obtained, such as $SUVA_{254}$ (specific UV absorbance at 254 nm) that indicate aromaticity, E2/E3 ratios (absorbance at 254 nm divided by absorbance at 365 nm) and spectral slopes ratio (S_R) (S_R=S275– 295 nm/S350–400 nm) that measure molecular weight (Helms et al. 2008; Shang et al. 2017). Using fluorescence spectroscopy, fulvic-like, humic-like and protein-like fluorescence components can be detected by gathering emission spectra over a range of excitation wavelengths, generating three-dimensional spectra referred to as excitation-emission matrices (EEM) (Coble, 1996). PARAFAC analysis of EEM creates a model to determine primary components in DOM. This method has been widely applied to DOM studies including evaluating photochemical and microbial modifications (Stedmon and Markager 2005; Lu et al., 2013) and discerning primary sources (Lu et al., 2014; Hu et al., 2016). Using DOM to identify pollution from wastewater in rural streams was one of the focuses of this investigation. The organic matter detected in the stream has a distinct fluorescence signature and distinct characteristics that are different from in stream samples. The sample compositions show small $SUVA_{254}$ value with high DOC concentrations indicating more labile and less aromatic carbon structures. The fluorescence index (FI), calculated as the ratio of intensity at 470 nm/520 nm emission and 370 nm excitation, has been commonly used to indicate the relative contributions of algal versus terrestrial derived DOM. While lower FI is related to more highly processed, terrestrial derived material that has greater aromatic content and higher molecular weight, higher FI is with algal derived material which has lower aromatic content and lower molecular weight (McKnight et al., 2001, Jaffe et al., 2008).

The detection of optical brighteners (OBs), also known as fluorescent whitening agents, is a chemically based microbial source tracking method. OBs comprise of several classes of compounds including water soluble dyes that act as brightening agents by absorbing light in the ultraviolet range and fluorescing in the visible region. They are added not only to the manufacture of paper but also to laundry detergents solid in the United States and other countries (Waye, 2003). OBs may appear in surface waters adjacent to a failing on-site sewage treatment system, since laundry effluents are estimated to be a significant part of total on-site wastewater treatment system (US. Environmental Protection Agency, 1990). The main advantage of OBs as an effluent tracing technique is that sources of OBs are exclusively anthropogenic, which provides indisputable evidence of human impacts on surface waters (Dates, 1999). Besides, OBs are relatively persistent under environmental conditions and resistant to microbial degradation as a tracer (Poiger et al., 1998). Many investigators have reached the same conclusion that these compounds have a high potential as a monitoring wastewater contamination in natural waters (Hagedorn and Weisberg, 2011; Cao et al., 2009; Tavares et al., 2008). These compounds demonstrate a real promise in our data to act as an indicator of human fecal contamination from onsite wastewater discharges into the streams.

This study aims to identify a water quality signature that can be used to identify the presence of wastewater contamination in rural streams in Alabama. It also serves as a baseline study for our ongoing investigation of stream water quality conditions of the Hale County in Alabama. The specific objective of the paper is, we focus on Big Prairie Creek water samples taken from upstream, midstream and downstream before (drought condition) and after precipitation (Post-drought condition), to determine if these samples contain wastewater signals from septic effluent or straight pipes.

Methods

Site Descriptions and Experimental Design

This study was conducted in and around Hale County in the west-central part of Alabama, USA. Samples were collected each month for nine months (March 2016 to November 2016) from twenty sampling points selected along the course of the Hale County (Figure 3) and also three main sites: Upstream, midstream and downstream of the Big Prairie Creek in the town of Newbern were sampled over the three months of the drought period (i.e., from September to November, 2016) to detect straight pipe wastewater impacts on water quality. The stream samples were taken as grab samples, and all were stored in 500 ml polypropylene bottles. These bottles were cleaned by soaking in HCl and then rinsed with tap water and deionized water. The bottles were kept in an ice-packed cooler while they were transported and then kept in the refrigerator for analysis. Some samples were analyzed within five days of their collection and in the case of frozen samples, analyses were made in a month for their date frozen. A portable dissolved oxygen meter and a HACH model portable pH meter were used to make in-situ measurements.

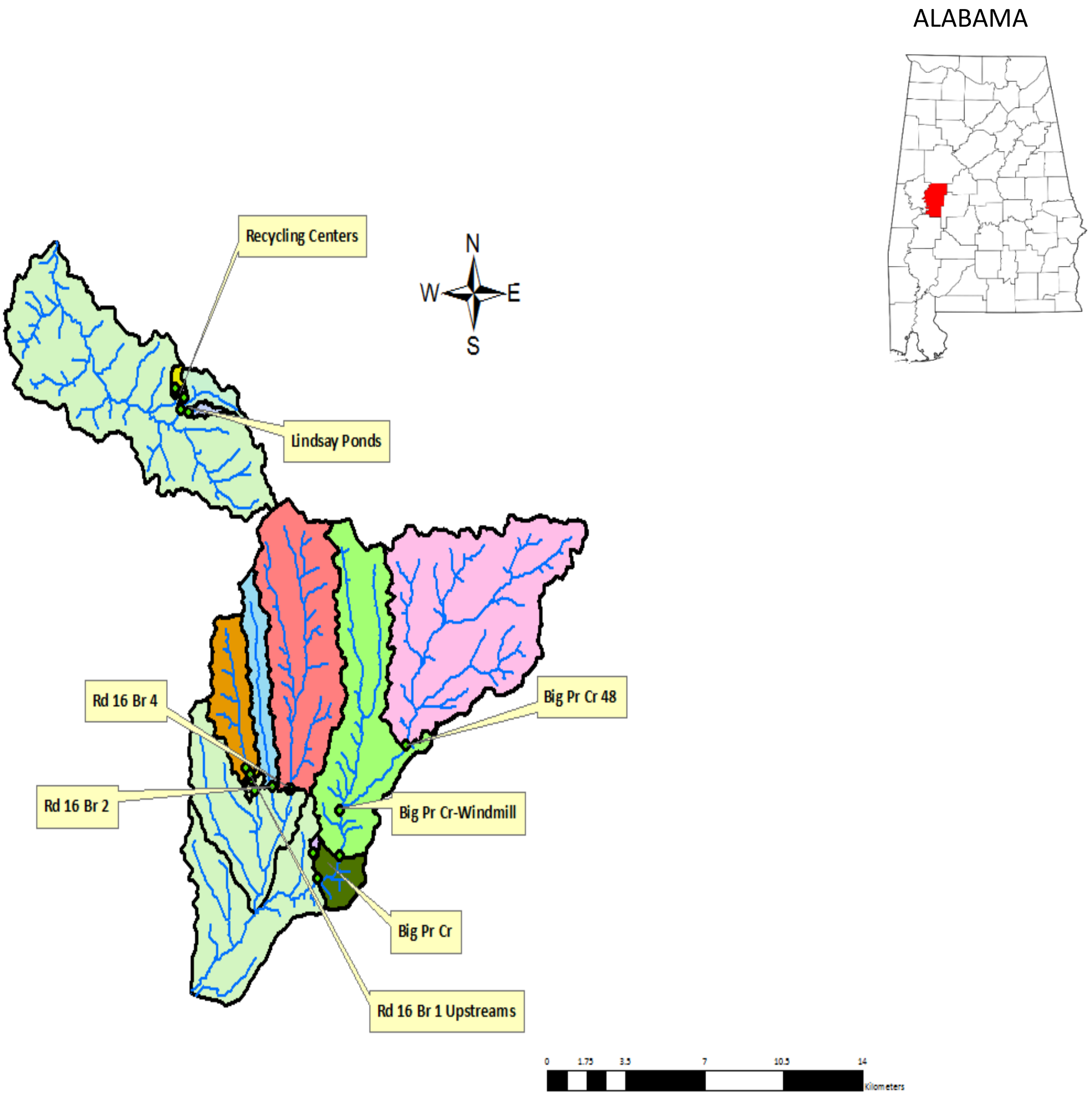

Figure 3. Locations of study sites in Hale County Watershed, Alabama, USA, streams are indicated by blue lines, watershed boundaries are indicated by black lines, and sampling sites are denoted by black dots.

Water Quality Measurements

Water samples were tested for chemical, physical and microbiological parameters. Chemical parameters included anions, cations, DOM, Dissolved Organic Carbon (DOC), nutrients, pH and conductivity. Turbidity was analyzed as a physical measure of particles in the water. E. coli and coliform bacteria were analyzed as microbial indicators.

For microbiological parameters, the IDEXX Quanti-Tray 2000 system with Colilert media (IDEXX Laboratories, Inc., Westbrook, ME) was used for detection of E. coli and coliform bacteria. Dilutions were carried out in sterile phosphate buffered saline (PBS) when high bacterial concentrations were anticipated to ensure a readable quantitative result. The standard analysis procedure was used, as follows: the Colilert media snap pack was opened, and the reagent was added to 100 ml of water sample in a sterile 120 ml vessel and allowed to dissolve. The Quanti-Tray was held upright, the foil tab was pulled without touching the inside of the foil, and the sample was poured into the tray. The Quanti-Tray was sealed with the sealer and incubated 24 and 48 hours at 35 °C. After incubation, wells positive for total coliform turned yellow, and a negative sample looked the same visually as when the sample was collected. Each tray was placed under long-wave, 365 nm ultraviolet (UV) light and wells positive for E. coli fluoresced blue. The most probable number (MPN) of coliforms and E. coli in each 100 mL sample was obtained by counting the positive wells and using appropriate Quanti-Tray table to find the MPN (USEPA 2007).

Turbidity measurements were obtained by the nephelometric method using a HACH 2100Q Portable Turbidimeter with turbidity units (NTUs). The method is based on a comparison of the intensity of light scattered by the sample under defined conditions as compared to the intensity of light scattered by standard reference suspensions under the same circumstances. The standards were used to reference and calibrate the turbidity meter. The higher the intensity of scattered light, the higher the turbidity. Results were reported as nephelometer turbidity units (NTUs).

For chemical analysis, all samples were filtered to 30 mL bottles as anions, cations, nutrients, DOM, DOC separately through a glass-fiber filtration unit in the lab. For the DOC and nutrient concentration analyses were stored at −20℃ in the dark. We preserved samples for anion, cation and DOM quality analysis at 4℃ in the dark to avoid any potential interferences. Duplicate samples (A & B) were analyzed for 20 locations.

Fluorescence excitation-emission matrix (EEM) measurements were conducted by using a Horiba Jobin Yvon Flouromax-3 spectrofluorometer. To attain fluorescence EEMs, excitation wavelengths increased from 240 to 500 nm at step intervals of 5 nm, yielding 53 excitation wavelength data points (240 nm, 245 nm…. 500 nm). Emission and fluorescence were measured at emission wavelengths of 280 to 538 nm at step intervals of 3 nm resulted in 87 emission wavelength data points. The excitation and emission slits were set to a 5 nm bandpass. A flowthrough water bath was used to keep a constant temperature of 20°C. UV-visible absorbance measurements were conducted with a UV-VIS Spectrophotometer. DOC concentrations were measured as non-purgeable organic carbon and total dissolved N (TDN) using Shimadzu TOC-VCSH analyzer with lower detection limits of 0.4 mg C/L for DOC and 0.1 mg N/L for TDN using high-temperature catalytic oxidation. Glucose was used to construct standard curves, and a consensus seawater reference standard (URL: 2) was used to confirm analytical accuracy. Specific ultraviolet absorbance at 254 nm ($SUVA_{254}$) was determined by dividing the UV absorbance measured at 254 nm by the DOC concentration and are reported in units of liter per milligram of carbon (Weishaar et al., 2003). E2/E3 ratios were calculated (Dahlen, 1996) and specific UV absorbance at 280 nm (SUVA280) was obtained by normalizing the absorbance at 280 nm to dissolved organic carbon concentration (Chin et al., 1994; Chin et al., 1998). We also conducted S_R for molecular weight, biological indices, humification indices, and percentage contributions of different fluorescence component, etc. (Yang et al., 2015, Lu et al., 2013); we also looked for the optical brighteners used in detergent.

Several post-acquisition steps were used to adjust the EEM data. First, the excitation and emission data were corrected for the instrument-specific response. Second, the EEM response of Milli-Q water was subtracted from sample EEMs. Third, the UV-visible absorption spectra were used to correct the EEM data for inner filter effects (McKnight et al., 2001). And finally, the fluorescence intensities of the EEMs were normalized to the area under the Raman peak, thereby converting the arbitrary units (AU) into Raman units (RU). Following the creation of EEMs, they were then exported into Excel files and MATLAB files for further interpretation and modeling, including removing portions of the EEMs at which there was interference from Raleigh scattering, converting the data into vectors, and selecting characteristic peak signals based on documented key excitation/emission pairings (McKnight et al., 2001, Coble, 1996) and also plotting the data into contour and surface maps. The fluorescence index (FI), which is the ratio of emissions at 470 nm to 520 nm at an excitation of 370 nm, was calculated for all samples.

Analysis of the cations for this research (most notably Ca^{++}, Mg^{++}, K^{+}, Na^{+}) in the stream water samples was made by spectrometer PerkinElmer Inc. Optima 4300 DV ICP-OES with PerkinElmer AS-93 Plus Autosampler. This setup uses inductively coupled plasma mass spectrometry for detecting metals and several non-metals. Calibration and Quality Control Standards: 0.25, 0.5, 1.0, 5.0, 10.0 and 20.0 mg/L (prepared from multielement standards (100 mg/L) from CPI International and High Purity Inc.). Concentrations were measured in mg/L. Each cation were measured in three replicates and averaged. Before running analysis, if required, samples were diluted by 2% HNO_3 Blank Solution.

Analysis of the anions for this research (most notably chloride and sulfate) in the stream water samples were made by Ion Chromatography (IC). Ion Chromatograph is used to measure concentrations of inorganic anions in aqueous samples. In ion chromatography, separation of a mixture of compounds into its components was achieved based on their relative interactions with an inert matrix. The detection of ions separated through the ion chromatographic column was done with a conductivity detector.

Concentrations of chloride and sulfate (Cl^{-}, SO_4^{2-}) in aqueous samples were measured using a Dionex (now acquired by Thermo Scientific) DX 600 Ion Chromatograph (IC) instrument. Aqueous samples collected for the analysis of inorganic anions were filtered through 0.45 micron or lower syringe filter and collected in clean HDPE bottles. At least 20 mL of sample was required for analysis with the IC. Samples were kept frozen and thawed on the day of analysis. When analyses were done, concentrations were calculated by using the Dionex PeakNet software.

Nutrient samples were analyzed for nitrate, nitrite, ammonium (NH_4^{+}), and ortho-phosphorus with Lachat Quikchem 8500 series 2 Flow Injection Analyzer. The method used was for Ammonia (Phenolate) in Waters, Lachat method # 10-107-06-1-F.

Parallel Factor Analysis (PARAFAC)

PARAFAC can statistically decompose EEMs into fluorescent groups or components (Stedmon et al., 2003). PARAFAC modeling can be obtained by either creating or validating the model using the complete data set of EEMs or by fitting the EEMs to an already established PARAFAC model. The data consisted of 98 samples, each analyzed for 87 emissions and 53 excitation wavelengths. Resulting excitation and emission matrices were processed for PARAFAC in MATLAB using the DOMFluor toolbox according to (Stedmon and Bro, 2008; URL: 3). The data were evaluated by split-half analysis where it was split randomly into two halves, a calibration and validation array, each consisting of 49 samples. The PARAFAC algorithm was then applied stepwise to both arrays for 2-10 components. The three component model was determined to be the best fit for those datasets after validation using four approaches: residual analysis, examination of spectral properties, split-half analysis and random initialization (Stedmon and Bro 2008). We described fluorescence components in this study as "humic-like" or "protein-like" since these components were likely a mixture of similar fluorophores rather than pure fluorophores.

Wastewater Dilution

Wastewater samples that were too concentrated for analysis were diluted with deionized (DI) water. Dilutions were carried out at the following ratios to enable analysis: 1:2, 1:5, 1:10, and 1:20.

Principal Component Analysis (PCA)

Principal components analyses (PCA) were made with varimax factor rotation on the drought/post-drought, wet/dry and wastewater data sets, individually. PCA helped us to identify promising parameters for inexpensive and robust detection of wastewater contamination. Variables incorporated in the two PCAs were: Ca, Fe, Mg, K, Na, Chloride, Sulfate, DOC, $SUVA_{254}$, S_R, E2/E3, NH4, ortho-phosphorus, Nitrate, Nitrite, E. coli, FI, Optical Brighteners and the percent contribution of each of the three PARAFAC components.

Results and Discussion

Surface water quality results were presented in this section, organized based on precipitation conditions. In figure 4 daily precipitation for the sampling period with precipitation on sampling dates indicated by blue dots and the corresponding precipitation categories (e.g., Wet, Post-Drought) specified for each sampling date were shown. Household wastewater is the pollution source of interest; therefore, wastewater samples were also analyzed. Data from the extended drought in fall 2016 were grouped with other dry weather points; water sample data collected in late-November 2016 were categorized as post-drought and grouped separately from other wet weather sampling data.

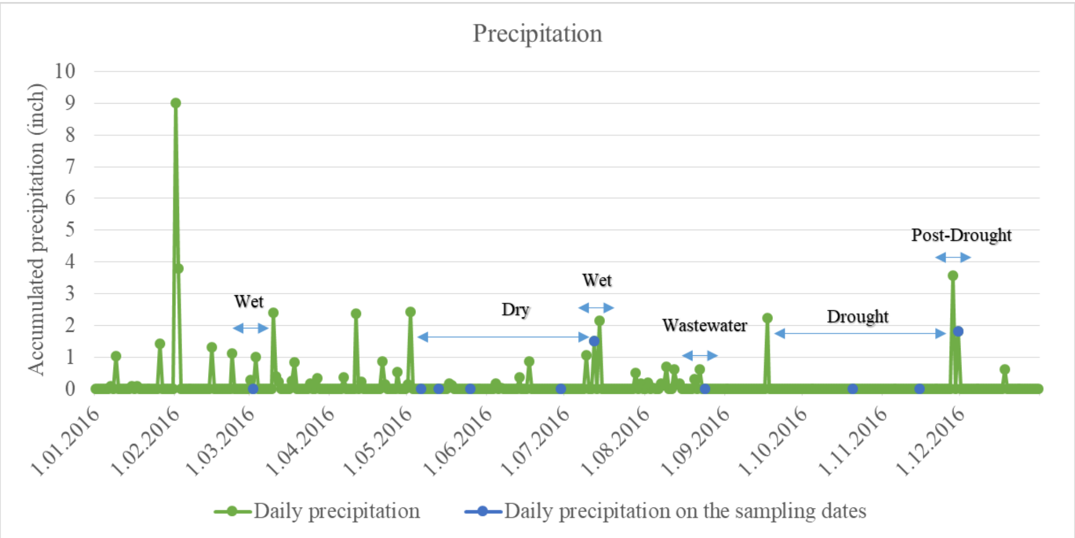

Figure 4. The precipitation data of the sampling areas. Sampling dates are 2 March, 6 May,13 May, 25 May, 29 June, 12 July, 24 August, 20 October, 15 November and 30 November.

The specific objective of the paper was, to focus on stream water samples taken from upstream, midstream and downstream, before (drought condition) and after (Post-drought condition) precipitation to determine whether or not these samples had significant wastewater signals from septic effluent or straight pipes.

We found that there was a positive correlation between E. coli, DOC, and Optical Brightener in the basin. The source of contamination within the surface water in Hale County could be runoff sources from roads, straight pipes, or septic systems as the water is brought to the surface through flushing of the soil.

Clustered column graphs were displayed for the parameters of E. coli, DOC, S_R, $SUVA_{254}$, E2/E3, FI, and Optical Brighteners. These parameters were shown to be above the criteria and recommendations for Alabama streams. The results were intended to be used as an essential mean for differentiating water quality between the three sampling sites. During the drought under baseflow conditions, the sampling sites showed no notable changes in pollutant concentrations from its upstream to downstream. In contrast, during the post-drought condition, we observed large increases in key water quality parameters from its upstream to downstream. In addition, both PCA and EEM-PARAFAC model were used to verify these observations.

DOC and Optical Indices

The minimum DOC measurements were 4.79, 5.54, 2.99 mg/L, the maximum DOC were measured as 4.90, 9.98, 7.13 mg/L and the concentrations were averaged as 4.85 ± 0.05; 2, 7.30 ± 0.83; 6, 5.75 ± 1.38; 3 mg/L (mean ± SE; n) through its upstream, midstream, downstream respectively tunder the site's drought condition. And also, the minimum DOC measurements were 5.96, 16.21, 7.90 mg/L, the maximum DOC measurements were 6.02, 24.95, 49.42 mg/L and the concentrations were averaged as 5.99 ± 0.03; 2, 20.53 ± 2.42; 4, 35.55 ± 13.83; 3 mg/L (mean ± SE; n) through its upstream, midstream, downstream respectively under the site's post-drought condition (Figure 5a).

The minimum $SUVA_{254}$ measurements were 3.88, 2.95, 2.96 L/(mg m), the maximum $SUVA_{254}$ measurements were 3.98, 3.35, 5.42 L/(mg m) and the concentrations were averaged as 3.93 ± 0.05; 2, 3.12 ± 0.07; 6, 3.78 ± 0.82; 3 L/(mg m) (mean ± SE; n) through its upstream, midstream, downstream respectively under the site's drought condition. And also, the minimum $SUVA_{254}$ measurements were 4.17, 2.73, 1.90 L/(mg m), the maximum $SUVA_{254}$ measurements were 4.19, 3.22, 4.59 L/(mg m) and the concentrations were averaged as 4.18 ± 0.01; 2, 2.97 ± 0.13; 4, 2.80 ± 0.89; 3 L/(mg m) (mean ± SE; n) through its upstream, midstream and downstream respectively under the site's post-drought condition (Figure 5b).

The minimum S_R measurements were 0.90, 0.90, 0.92 L/(mg m), the maximum S_R measurements were 0.91, 0.99, 0.95 L/(mg m) and the concentrations were averaged as 0.91 ± 0.01; 2, 0.95 ± 0.02; 6, 0.94 ± 0.01; 3 L/(mg m) (mean ± SE; n) through its upstream, midstream, and downstream respectively under the site's drought condition. And also, the minimum S_R measurements were 0.82, 0.83, 0.77 L/(mg m), the maximum S_R measurements were 0.83, 0.85, 1.03 L/(mg m) and the concentrations were averaged as 0.83 ± 0.00; 2, 0.83 ± 0.00; 4, 0.94 ± 0.09; 3 L/(mg m) (mean ± SE; n) through its upstream, midstream, and downstream respectively under the site's post-drought condition (Figure 5c).

The minimum E2/E3 measurements were 3.96, 4.99, 5.06, the maximum E2/E3 measurements were 4.02, 5.90, 5.48 and the concentrations were averaged as 3.99 ± 0.03; 2, 5.38 ± 0.15; 6, 5.34 ± 0.14; 3 (mean ± SE; n) through its upstream, midstream, and downstream respectively under the site's drought condition. And also, the minimum E2/E3 measurements were 3.71, 4.46, 3.97, the maximum E2/E3 measurements were 3.75, 5.08, 4.01 and the concentrations were averaged 3.73 ± 0.02; 2, 4.76 ± 0.16; 4, 3.98 ± 0.01; 3 (mean ± SE; n) through its upstream, midstream, and downstream respectively under the site's post-drought condition (Figure 5d).

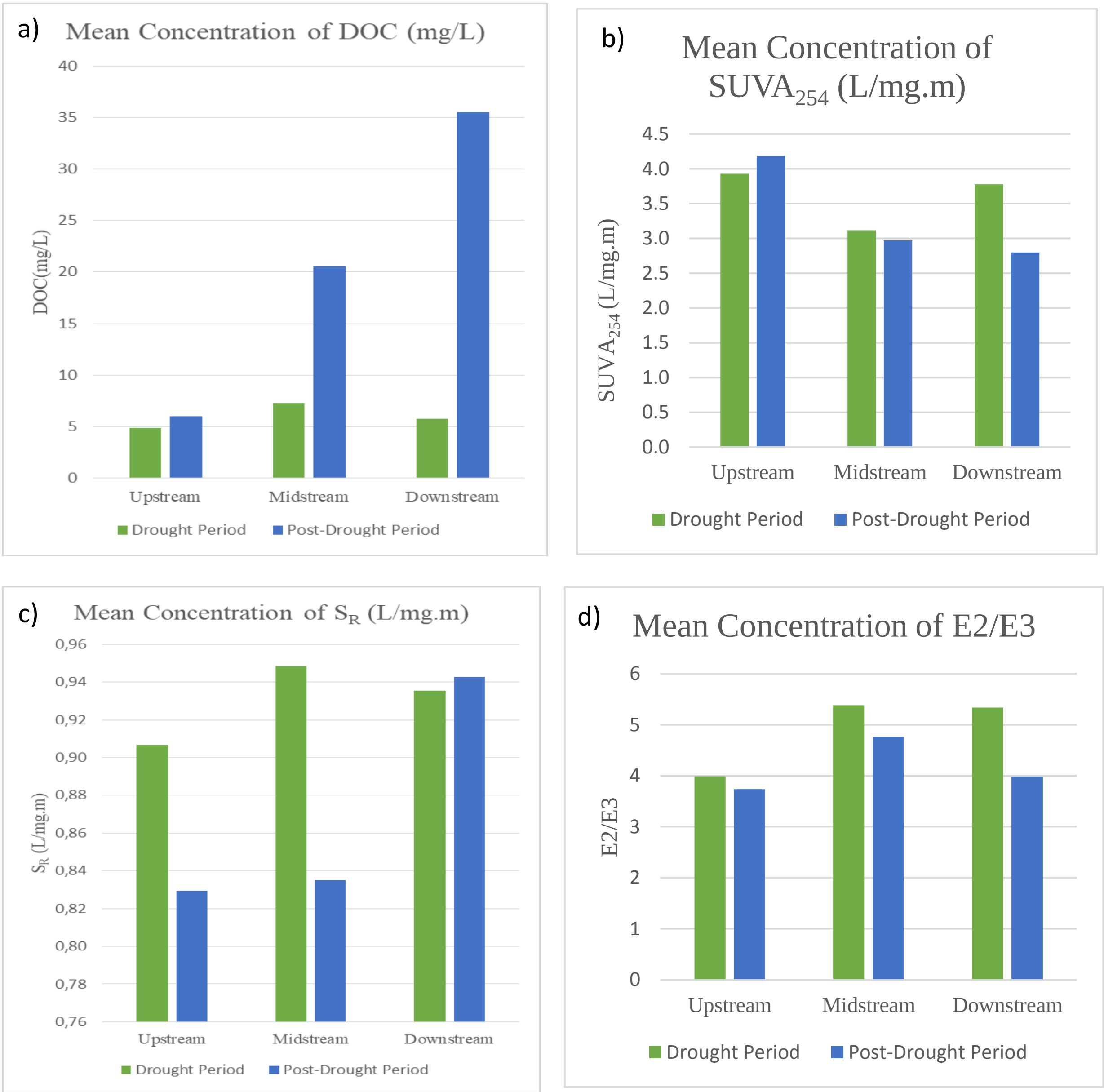

Figure 5. Mean values of DOC, $SUVA_{254}$, S_R and E2/E3 for water quality of the Big Prairie Creek's upstream, midstream and downstream both under the drought and post-drought conditions.

Bacteria

Figure 6 shows that sampling during drought revealed average concentrations of E. coli bacteria around 50-100 CFU per 100 mL; during the storm, at the end of November, the drought E. coli levels increased by about 10-times upstream of the creek in Newbern (this is expected because E. coli is in animal and bird feces and washes into stream. Downstream of Newbern, average E. coli concentrations increased to nearly 100,000 E. coli per 100 mL. This indicates a primary source of E. coli in and around Newbern.

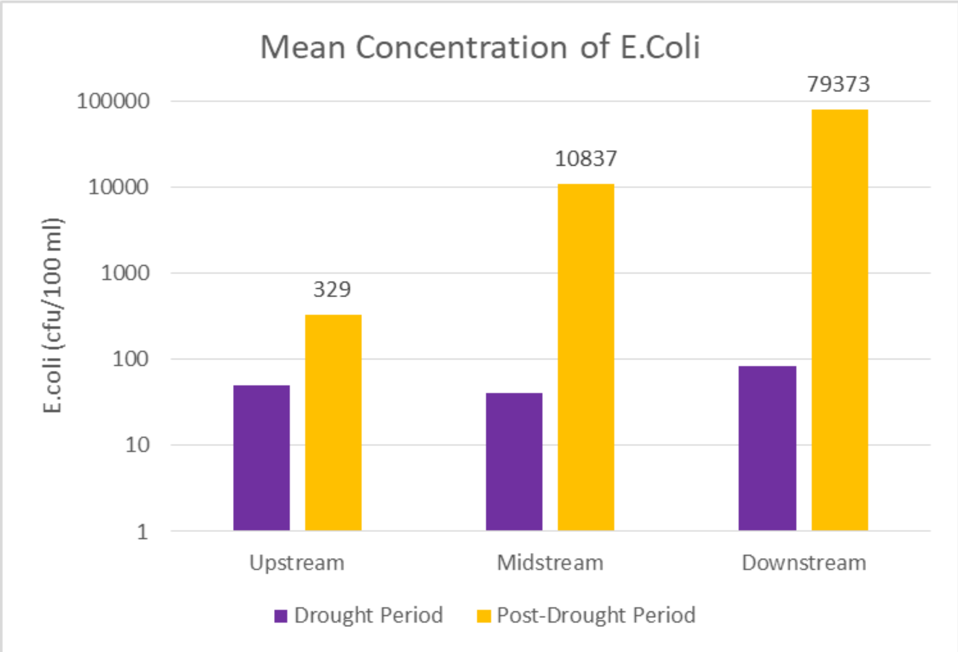

Figure 6. Mean values of *E. coli* for water quality of the Big Prairie Creek's upstream, midstream and downstream.

The minimum values for E. coli were measured as 50.20, 32.60, 51.80 cfu/100 mL, the maximum values for E. coli measurements were 50.20, 46.13, 143.90 cfu/100 mL and the concentrations were averaged as 50.20 ± 0.00; 2, 40.98 ± 2.67; 6, 82.50 ± 30.70; 3 cfu/100 mL (mean ± SE; n) through its upstream, midstream, and downstream respectively under the site's drought condition. And also, the minimum value for E. coli were measured as 329.25, 1139.95, 5800.00 cfu/100 mL, the maximum value of E. coli measurements were 329.35, 20535.00, 116160.00 cfu/100 mL and the concentrations were averaged as 329.30 ± 0.05; 2, 10837.48 ± 5598.87; 4, 79373.33 ± 36786.67; 3 cfu/100 mL (mean ± SE; n) through its upstream, midstream, and downstream respectively under the site's post-drought condition (Figure 6).

Around Newbern, *E. coli* concentrations were getting high and high following the period of precipitation (Figure 6). Additionally, the rate of increase in the downstream of Newbern was greater than the upstream. *E. coli* value increased about 5 times in its upstream, 250 times in its midstream and almost 1000 times in its downstream from its drought period through its post-drought period. The reason of this increase in *E. coli* was likely abundan in the large number of straight pipes in Newbern. Wastewater directly discharge onto the ground surface by straight pipes led to stream contamination as the accumulated wastewater in Newbern was flushed into the nearby creek during precipitation.

In the study, *E. coli* concentrations taking from different sampling sites and the results showed that the *E. coli* counts varied between 40.98 ± 2.67 cfu/100 ml and 79373.33 ± 36786.67 cfu/100 mL (Figure 6). In the study, RD 61 Bridge which had the highest *E. coli* concentration (116160 cfu/100mL), so single sampling location could be used as an example for the comparison of the Alabama Bacteria's Criteria, so E. coli values (colonies/100 ml) categorized respectively; single sample maximum should be equal or less than 235 according to Outstanding

Alabama Water (OAW), single sample maximum should be equal or less than 2507 October through May according to Public Water Supply (PWS), single sample maximum should be equal or less than 235 according to Swimming and Other Whole Body Water Contact Sports (S), single sample maximum should be equal or less than 235 according to Shellfish Harvesting (SH), single sample maximum should be equal or less than 2507 October through May according to Fish and Wildlife (F&W), single sample maximum should be equal or less than 2507 according to Limited Warmwater Fishery (LWF) and single sample maximum should be equal or less than 3200 according to Agricultural and Industrial Water Supply (A&I) for Non-Coastal Waters (ADEM, 2016). The range of variation of E. coli concentrations amongst sampling sites from upstream to downstream indicates a high level of fecal bacteria contamination during drought and post-drought. The maximum E. coli measurements were recorded 50.20, 46.13, 143.90 cfu/100 mL through upstream, midstream, downstream respectively at site Drought condition, while the maximum E. coli measurements were 329.35, 20535.00, 116160.00 cfu/100 mL through upstream, midstream, downstream respectively at site Post-Drought condition. The possible source of higher concentrations during the post-drought condition discharge of septic system and untreated wastewater discharge from the houses located at Newbern.

Indices

The minimum FI measurements were recorded in 1.83, 1.85, 1.85, the maximum FI measurements were recorded in 1.83, 2.24, 1.86 and its average concentrations were recorded in 1.83 ± 0.00; 2, 2.01 ± 0.07; 6, 1.86 ± 0.00; 3 (mean ± SE; n) through its upstream, midstream, and downstream respectively at drought conditions of the site. And also, the minimum FI measurements were recorded in 1.79, 1.64, 1.57, the maximum FI measurements were recorded in 1.79, 1.97, 2.22 and its average concentrations were recorded in 1.79 ± 0.00; 2, 1.80 ± 0.09; 4, 2.00 ± 0.22; 3 (mean ± SE; n) through its upstream, midstream, and downstream respectively at post-drought conditions of the site (Figure 7a).

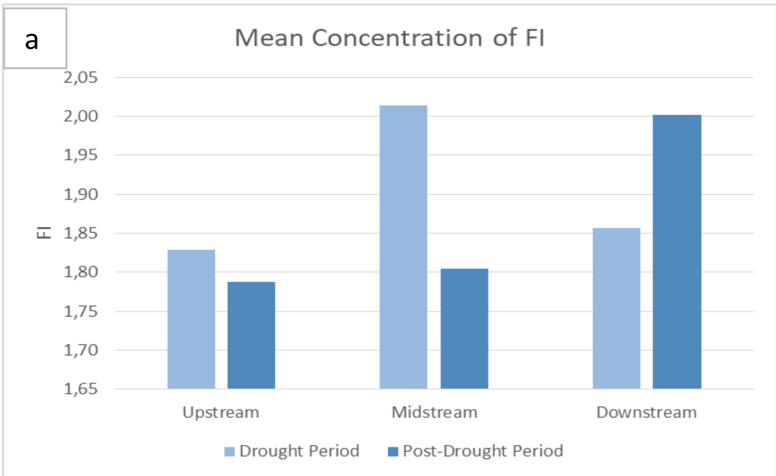

Figure 7a. Mean values of FI for water quality of Big Prairie Creek's upstream, midstream and downstream.

The minimum OPT (Optical Brighteners) measurements were 2.83, 3.20, 3.21, the maximum OPT measurements were 2.84, 6.34, 3.87 and the average concentrations were 2.84 ± 0.00; 2, 4.45 ± 0.60; 6, 3.63 ± 0.21; 3 (mean ± SE; n) through its upstream, midstream, and downstream respectively at the site's drought conditions. And also, the minimum OPT measurements were 3.04, 7.67, 3.87, the maximum OPT measurements were 3.03, 10.19, 11.72

and the average concentration were 3.03 ± 0.01; 2, 8.93 ± 0.72; 4, 9.08 ± 2.61; 3 (mean ± SE; n) through its upstream, midstream, and downstream respectively at the site's post-drought conditions (Figure 7c).

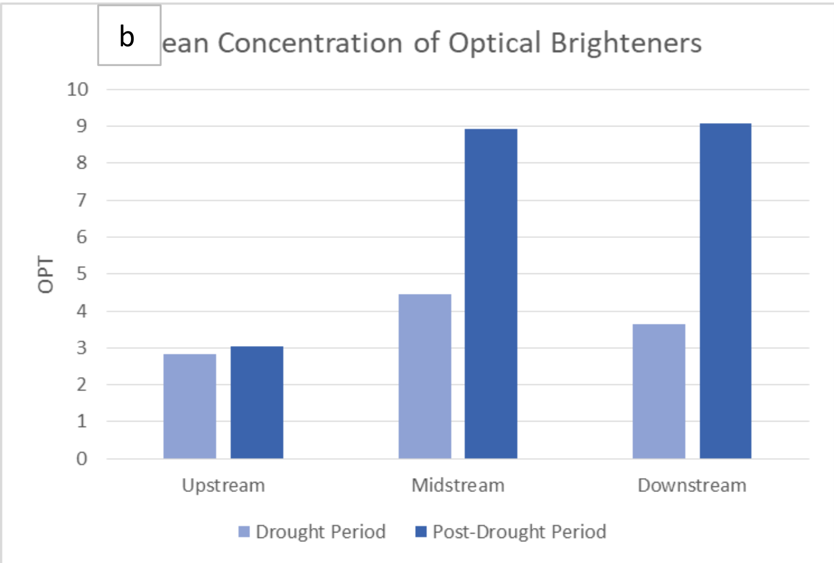

Figure 7b. Mean values of Optical Brightener for water quality of Big Prairie Creek's upstream, midstream and downstream.

In our study, the optical brightener concentrations, found at Newbern, indicated that the source of fecal bacterial contamination was human waste in the form of sewage leaks or spills or septic system leakage. As noted above, Newbern has suffered for many years from problems with onsite wastewater management. We observed that the maximum values of optical brightener ranged from 2.84, 6.34, 3.87 and the average concentrations in the samples were 2.84 ± 0.00; 2, 4.45 ± 0.60; 6, 3.63 ± 0.21; 3 (mean ± SE; n) through upstream, midstream, and downstream of Big Prairie Creek respectively at the site drought conditions. After precipitation, the maximum optical brightener values were ranged from 3.03, 10.19, 11.72 and the average concentrations in the samples were 3.03 ± 0.01; 2, 8.93 ± 0.72; 4, 9.08 ± 2.61; 3 (mean ± SE; n) through its upstream, midstream, and downstream respectively at the site post-drought conditions (Figure 7b). It is evident that the optical brightener values at its post-drought conditions were three times more than the values at its drought conditions. Data at our pristine (no human influence) control site at Mayfield Creek showed that an average optical brightener values ranged from 0.83 and 2.83 through its drought and post-drought conditions respectively. Therefore, we determined that there was a close relationship between the optical brightener values and precipitation at Newbern. This experiment showed that the value of using optical brighteners are promising as a supplement of fecal indicator bacteria, probably enabling differentiation of wastewater from animal fecal contamination in rural areas (Tavarese et al., 2008).

In our study, stream samples all included an FI value bigger than 1.66, classifying the organic matter in those samples as having a more microbial derived structure (Figure 7a). Furthermore, our samples also consisted of higher DOC concentrations with high FI values and $SUVA_{254}$, determinative of less changeable carbon and more aromatic structure (Figure 7b). The downstream samples demonstrated their characteristics in the mid-range for DOC, $SUVA_{254}$ and FI values. This supported the idea that the organic matters at these sites had a highly complex structure with their sources which might have been adequately characterized by the structures of the stream samples.

Principal Component Analysis (PCA)

The principal component analysis, and figures show the high information content inherent to peak C1, C2 and C3 in the excitation-emission matrix to delineate the different sources of the variable organic matter in this study sampling set. The skill to use a model for predictive abilities requires that characteristic properties can be traceable in aquatic samples.

The PCA (varimax rotation) identified three primary components (Eigenvalue >1), accounting for 40.4%, 19.0% and 8.7% of total variance respectively. The wastewater and members have well separated from stream water and post-drought (first flush) water samples by PC1, which are dominated by soluble reactive phosphorus (SRP), dissolved organic carbon concentration (DOC), *E. coli*, Ammonium-N, protein fluorescence, and optical brighteners. All these indicators show that wastewater has a characteristic nutrient & microberich signal that can be used to trace water sources in natural waterways, which are well synthesized by PC1. The post-drought samples had a higher PC1 score than stream water samples, indicating precipitation mobilizes sewage associated chemicals to nearby streams. Using base-flow stream water and wastewater as end members, we estimated that post-drought stream water contains 6.7% of wastewater. PC2 and PC3 are associated more with hydrological flow paths and hence not discussed in detail in this study. The drought period ensured a critical opportunity for multiple sampling trips before and then immediately following the first rain after two months. Newbern, Alabama, a small town with a conservative estimate of 50% straight pipes and very impermeable clay soil, provided an ideal setting to sample runoff containing untreated wastewater. Figure 6 displays how during the drought period under baseflow conditions, sampling sites upstream, adjacent (midstream) and downstream of the creek in Newbern show no change in *E. coli* concentration. In contrast, during the first rainstorm following the drought period, median *E. coli* increased by less than one log unit upstream but by nearly 3 log10 (1000x) downstream. The PCA results verified these observations by showing increasing PC1 scores from upstream to the downstream sites (Figure 8).

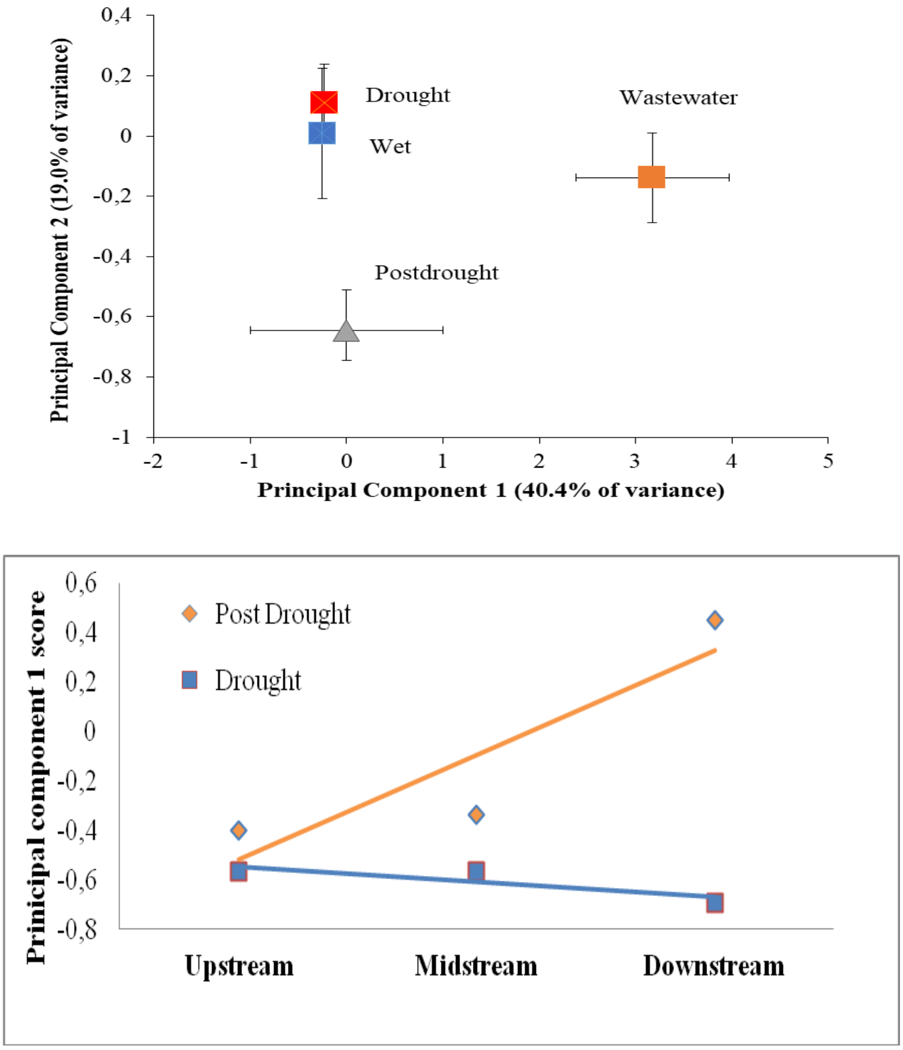

Figure 8. Median loading scores of PC1 (wastewater indicator) increase dramatically from the upstream to downstream sites of the creek in Newbern after a precipitation event, relative to a decrease or little change during drought period.

EEM-PARAFAC Model

Wastewater was lastly detected in our study area in Newbern by using EEM-PARAFAC model. The model identified three fluorescence components: 1) Terrestrial humic-like compounds derived from soils, 2) microbial humic-like compounds and 3) protein-like humic compounds respectively. The fluorescence spectra obviously demonstrated that wastewater samples (Figure 9a) had higher amounts of microbially produced, protein-like compounds than a regular stream water without an input of wastewater (Figure 9b). As it is known that the upstream site of Newbern no input of wastewater to the downstream site collecting data from wide range of straight pipe discharges that lead to shifting what the dominant fluorescence region from indicating humic, soil-derived compounds to indicating microbially-derived compounds.

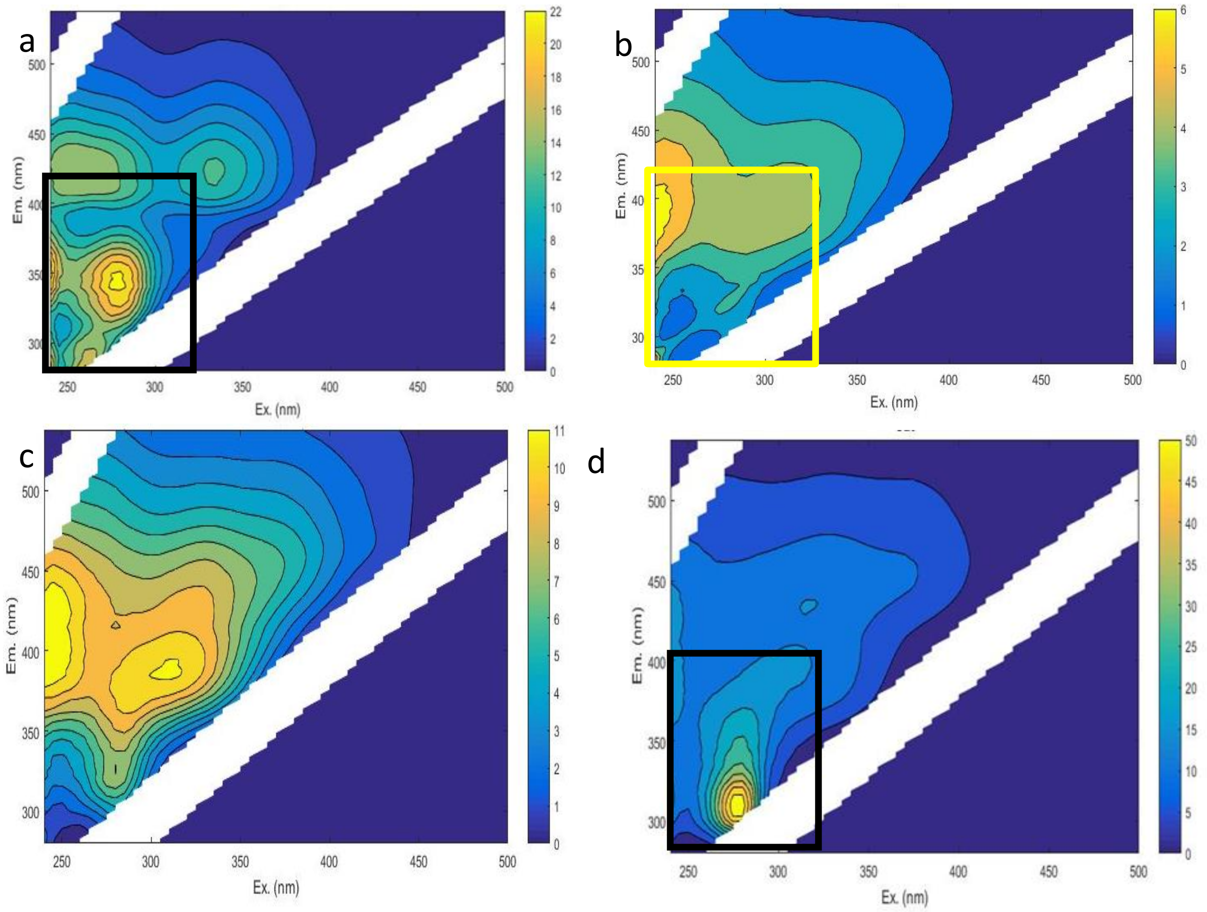

Figure 9. (a) Typical wastewater DOM Fluorescence results for project samples. Intensity is in raman units. The black rectangle outlines the fluorescence region indicative of Microbial-produced Compounds and the yellow rectangle indicates Humic, Terrestrial Fluorescence. DOM Fluorescence results for samples taken upstream sites in the post-drought period (b), adjacent (c) downstream (d) straight pipe discharges.

Conclusion

During the nine months investigation of wastewater signals in Hale County Alabama, a total of 20 water quality samples from twenty sites were collected and analyzed for physical (turbidity), chemical (anions, cations, DOM, DOC, nutrients, pH and conductivity) and microbiological (E. coli and coliform bacteria) parameters. The relationships between the water quality parameters were determined. These observed patterns led to the following conclusions.

This study analyzed the water quality parameters during and immediately following the extended drought period from September to November, 2016. The maximum E. coli measurements were recorded as 50.20, 46.13, 143.90 cfu/100 mL through its upstream, midstream, and downstream respectively during drought conditions, while the maximum E. coli measurements were 329.35, 20535.00, 116160.00 cfu/100 mL through its upstream, midstream, and downstream respectively at the site's post-drought conditions. The minimum E. coli concentrations averaged as 50.20 ± 0.00; 2, 40.98 ± 2.67; 6, 82.50 ± 30.70; 3 cfu/100 mL (mean ± SE; n) through its upstream, midstream, and downstream respectively during the drought conditions. The minimum E. coli concentrations averaged as 329.30 ± 0.05; 2, 10837.48 ± 5598.87; 4, 79373.33 ± 36786.67; 3 cfu/100 mL (mean ± SE; n) through its upstream, midstream, and downstream respectively during the site's post-drought conditions. The most likely sources of higher concentrations during the post-drought condition were the discharges of septic systems and untreated wastewater discharges from the houses, located at Newbern. Although a lot of cows were observed near Big Prairie Creek, the number of cows were up gradient from the midstream and downstream sampling sites. Fecal contamination from cow wastes were washed into the stream following rainfall, three major evidences indicated that E. coli contamination was primarily resulted from sewages: (1) the increase in E. coli was greatest downstream of Newbern, (2) the cows have constant access to Big Prairie Creek and often defecate directly into the stream during both wet and dry conditions and (3) optical brighteners, found in detergents and toilet paper also increased substantially in the downstream of Newbern.

We also found a link between optical brightener values and precipitation at Newbern as well. We observed that the maximum optical brightener values were 2.84, 6.34, 3.87 through its upstream, midstream, and downstream respectively during the site's drought conditions. After precipitation, we found that the maximum optical brightener values were 3.03, 10.19, 11.72 through its upstream, midstream, and downstream respectively during the site's post-drought conditions. This experiment showed that using optical brighteners is promising as a supplement to fecal indicator bacteria, potentially enabling identification of wastewater from straight pipes.

The PCA (varimax rotation) identified three primary components (Eigenvalue >1), accounting for 40.4%, 19.0% and 8.7% of total variance respectively. The wastewater and members have well separated from stream water and post-drought (first flush) water samples by PC1. The post-drought samples had a higher PC1 score than stream water samples, indicating precipitation mobilizes sewage associated with chemicals to nearby streams. Using base-flow stream water and wastewater as end members, we estimated that post-drought stream water contains 6.7% of wastewater.

Finally, the EEM-PARAFAC model identified three fluorescence components: 1) Terrestrial humic-like compounds derived from soils, 2) microbial humic-like compounds and 3) protein-like humic compounds respectively. The fluorescence spectra clearly demonstrate that wastewater samples have higher amounts of microbially-produced, protein-like compounds than a regular stream water sample.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Evsel Atıksuların Alabama Kırsalındaki Akarsulara Deşarjı ve Su Kalitesine Etkisi

ABD nüfusunun yaklaşık % 75'i, belediyelerin atıksu arıtma hizmetinden faydalanırken geri kalan % 25'i, 80 milyondan fazla kişi, atık sularını arıtmaktan sorumludur vebunların çoğu arıtmada geleneksel septik sistem kullanmaktadır. Septik sistemlerde, atık suları yeraltı sularına sızmakta, filtrasyon ve doğal bozulma süreçleri ile atıksu arıtımı mümkün olmaktadır. Bazı toprak ve jeolojik koşullar atık suların toprağa sızmasına engel olduğundan geleneksel septik sistemleri bu koşullarda kullanma olanağı bulunmamaktadır. Bu durumlarda maliyetli alternatif sistemler kullanılır. Böylece, kanalizasyona erişimi olmayan,, elverişsiz toprak koşullarına sahip yoksul kırsal bölge sakinleri bütçeleriyle karşılayamayacakları atık su arıtma seçeneklerine terk edilmiş oluyorlar. Alabama merkezinin büyük bir bölümünde topraklar: Geçirimsiz kil ve sert kireçtaşı tabakasından oluşmaktadır.

Alabama'nın Kara Kuşak bölgesindeki toprak ve jeoloji tipi, geleneksel septik sistemlerin bu bölge için uygun bir seçenek olmadığından, bu bölgede yaşayanlar atıksularını arıtmak için yoğun mücadele etmektedirler. Kullanıldığı durumlarda ise septik sistemler sıklıkla arızalandığından, evsel atık sular genellikle bir boru sistemiyle kırsalın ağaçlık alanlarına doğrudan boşaltı lır, buna “doğrudan deşarj” adı verilir. Kırsal alanlardaki doğrudan deşarj ve fosseptik arızası yaygınlığından dolayı atıksular yakınlardaki su yollarına deşarj edilmekte, bu da çevre ve insan sağlığı üzerinde olumsuz etkilere neden olmaktadır.

Bu çalışma, kırsal kesimlerde atıksu kirliliğini göstermeyi ve kullanılabilir bir su kalitesi yöntemini tanımlamayı amaçlamaktadır. Ayrıca, Alabama Hale County'deki akarsuların su kalitesini araştırmak için temel bir çalışma olması hedeflenmektedir. Çalışma alanındaki mevcut su kaynaklarına, yağıştan önce (kuraklık durumu) ve yağıştan sonra (kuraklıktan sonraki durum), fosseptik atık veya doğrudan deşarjlardan gelen atık suların karışıp karışmadığını belirlemek amacıyla, memba, orta akış ve mansap kaynaklarından örnekler alındı.

Bu çalışmayı, Alabama'nın batı orta kesimindeki Hale İlçesi'nde ve yakınçevresinde gerçekleştirdik. Newbern Kasabası‘nda birçok evin işlenmemiş atık suyu ağaçlık alanlara boşaltıldığından, araştırmamız için bu kasabayı seçtik. Örnekleme istasyonlarını Newbern'deki nehirlerin üst kısım, orta kısım ve aşağı kısımların akış yönünde belirledik. Kümelenmiş kolon grafikleri E. coli, DOC, S_R, $SUVA_{254}$, E2 / E3, FI, Optik parlaklaştırıcılar parametreler için gösterdik.. Bu parametrelerin Alabama akarsuları için kriterlerin ve tavsiyelerin üzerinde olduğunu gözlemledik. Sonuçları, üç örnekleme sahası arasında su kalitesi farklarını göstermek için temel bir araç olarak kullandık.

Bu çalışmada, bölgelerde E. coli, DOC, Optik Parlatıcı ve FI arasında pozitif korelasyon bulunduğunu tespit ettik. Hale County'deki yüzey sularındaki kirlilik kaynaklarının, yollardan akan yüzeysuları, doğrudan deşarjlar veya toprağın suyla yıkanmasıyla getirilen atıklar ile fosseptik sistemlerden kaynaklandığını belirledik.

Bu çalışma, 28 Eylül 2016'dan sonraki bir yıllık veri kullanılarak kuraklık koşullarının uzunluğuna göre ve kuraklık döneminden hemen sonra ölçülen su kalitesi parametrelerinin analizleriyle gerçekleştirilmiştir. Bu çalışmada elde edilen sonuçlar şu şekilde özetlenebilir: Minimum E. coli ölçümleri kuraklık sırasında sırasıyla memba, orta akım ve mansap yönünde 50.20, 46.13, 143,90 EMS/100 mL olarak kaydedilmişken, maksimum E. coli ölçümleri, kuraklık sonrası durumda sırasıyla membadan mansaba doğru 329.35, 20535.00, 116160.00 EMS/100 mL'dir. Minimum E. coli konsantrasyonları, kuraklık durumunda membadan mansaba doğru sırasıyla, ortalama 50.20 ± 0.00; 2, 40.98 ± 2.67; 6, 82.50 ± 30.70; EMS/100 mL’dir (ortalama ± SE; n). Minimum E. coli konsantrasyonları, kuraklık sonrası durumda membadan mansaba doğru sırasıyla, ortalama 329,30 ± 0.05; 2, 10837.48 ± 5598.87; 4, 79373.33 ± 36786.67; 3 EMS/100 mL’dir (ortalama ± SE; n) . Kuraklık sonrasında tespit edilen en yüksek konsantrasyonların kaynağı, foseptik sistemin deşarjı ve Newbern'deki evlerden gelen arıtılmamış atıksuların deşarjıdır. Her ne kadar büyük baş hayvanlar memba (Big Prairie Deresi) yakınlarında görülse de, onlardan kaynaklı kirlilik orta akış bölgesinde ve mansaptaki örnekleme sahalarında artış göstermektedir. Yağmur suları dışkılarını akarsulara taşımaktadır.Buna üç ana kanıt E. coli kontaminasyonunun esas olarak kanalizasyondan kaynaklanmaktadır: (1) E. coli'deki artış Newbern'in mansabında en büyük seviyededir 2) Büyük baş hayvanlar Big Prairie Deresi'ne sürekli erişime sahip olduklarından hem yağmurlu hem kuru havalarda çoğu zaman dışkılarını doğrudan akarsuyun içine boşaltırlar ve (3) deterjan ve tuvalet kâğıdında bulunan optik parlatıcılar da Newbern'in mansabında büyük ölçüde artmıştır. Ayrıca, optik parlatıcı değerleri ile

Newbern'deki yağışlar arasında da bir bağlantı bulduk. Kuraklık koşullarında maksimum optik parlatıcı değerlerinin sırasıyla membadan mansaba doğru 2.84, 6.34, 3.87 olduğunu gözlemledik. Yağıştan sonra, kuraklık sonrası koşullar altında maksimum optik parlaklaştırıcı değerleri membadan mansaba doğru sırasıyla 3.03, 10.19, 11.72 olarak bulduk. Bu çalışmanın, doğrudan deşarjlardan gelen atık suların tanımlanmasına potansiyel olarak olanak sağlaması optik parlatıcıların kullanımının fekal indikatör bakterileri tamamlayıcı olarak gelecek vaat edici bir çalışma olduğunu göstermiştir.

Case Study

MODELING OF FLOODS IN GÜVENÇ BASIN, ANKARA USING HEC-HMS

Ankara Güvenç Havzası'nda Taşkınların HEC-HMS ile Modellenmesi

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Abstract

The presented paper detaily described the flood modeling for Güvenç Basin in Ankara, Turkey through the use of the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS). In flood modeling studies, the HEC-HMS model is a widely used hydrological model in combination with the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) that works with GIS softwares. It was applied to the basin whose drainage area is totally about 15.3 km^2. Firstly, the basin physical and climatic characteristics were determined by using Hec-GeoHms and then simulations were created with using the HEC-HMS model. Data sets obtaining from five meterological stations located in the basin area and one streamflow observation station at the outlet of the basin were used for the study. Within the scope of the study, both of peak flood flows simulated with the HEC-HMS model and peak flood flows observed at specific times of 1992, 1993, 1996, 2000, 2002 and 2005 were used in calibration and validation studies. The flood modeling was evaluated by comparing the observed data of those stations with the hydrologic model results for the selected flood events. Its calibration was carried out by using the trial-error method. Validation process was applied in selected years after determining calibration parameters. As a result of the calibration and validation processes, the compatibility between the observed and simulated flood hydrographs showed us that the flood modeling for Güvenç Basin was convenient for evaluating flood risks in this area.
Keywords: *Hydrological modeling, HEC-GeoHMS, calibration and validation, Güvenç Basin*

Öz

Makalede Ankara ilinde bulunan Güvenç Havzası için Hidrolojik Mühendislik Merkezi-Hidrolojik Modelleme Sistemi (HEC-HMS) kullanılarak oluşturulan taşkın modellemesi ayrıntılarıyla verilmiştir. Taşkın modelleme çalışmalarında HEC-HMS modeli, CBS yazılımlarıyla çalışan Hec-GeoHms uzantısı ile birlikte yaygın bir şekilde kullanılan bir hidrolojik modeldir. Drenaj alanı yaklaşık 15.3 km^2 olan havzada, bu model uygulanmıştır. İlk olarak, havzanın fiziksel ve iklimsel karakteristik özellikleri modelin HecGeo-Hms uzantısı kullanılarak belirlenmiş daha sonra HEC-HMS modeli kullanılarak simülasyonlar üretilmiştir. Çalışmada, havzanın yağış alanı içerisinde bulunan beş adet meteroloji gözlem istasyonu ve havzanın çıkışında yer alan bir adet akım gözlem istasyonundan elde edilen veri setleri kullanılmıştır. Çalışma kapsamında, 1992, 1993, 1996, 2000, 2002 ve 2005 yıllarının belirli zamanlarında gözlemlenmiş pik taşkın debileri ile HEC-HMS modeli ile simüle edilen pik taşkın debileri, kalibrasyon ve validasyon çalışmalarında kullanılmıştır. Havza için oluşturulan taşkın modeli, istasyonlardan elde edilen veriler ile model tarafından simule edilen sonuçları, seçilen taşkın olayları için karşılaştırılmıştır. Model kalibrasyonu, deneme-yanılma metodu kullanılarak gerçekleştirilmiştir. Deneme yanılma metodu ile kalibrasyon parametreleri öncelikli olarak belirlendikten sonra modelin performansını değerlendirmek için validasyon işlemi uygulanmıştır. Kalibrasyon ve validasyon işlemleri süreçlerinde, model tarafından simüle edilmiş ve gözlemlenmiş taşkın hidrografları arasındaki uyum, Güvenç Havzası için oluşturulan taşkın modelin bu alandaki taşkın riskini değerlendirmek için kullanılabilir olduğunu göstermiştir.
Anahtar kelimeler: *Hidrolojik modelleme, HEC-GeoHMS, kalibrasyon ve validasyon, Güvenç Havzası*

Introduction

Accurate estimates of the peak floods and flood hydrographs are important elements of the design of hydraulic structures. Flood predictions are important in basin planning and management studies, as saving human lives and protecting properties have priority (Olivera and Maidment, 2000). Hydrologic models are the tools that represent the actual hydrologic systems of a basin by using simplified mathematical functions. Additionally, hydrologic models used in the predicition of the hydrologic response of various watersheds management practices and provides a better understanding of the impacts of these practices (Verma et al., 2010).

The HEC-HMS model (HEC, 2001) has common usage in modeling of flood processes. Gül et al. (2010) used the HEC-HMS model to evaluate the efficiency of structural flood control measures in Bostanlı Basin, Turkey. Yusop et al. (2011) use the HEC-HMS model for modeling storm flow hydrographs in an oil palm catchment in the Skudai River in Johor. Verma et al. (2010) evaluate HEC-HMS and WEPP for simulating watershed runoff using remote sensing and geographical information system. Du et al. (2012) analyse the urbanization effects on annual runoff and flood events using HEC-HMS in the Qinhuai River basin, China. Yener et al. (2011) compare flood peaks obtained using both HEC-HMS and General Directorate of State Hydraulic Works (DSI) Synthetic Method in Yuvacık Basin. Derdour et al. (2017) simulate rainfall-runoff in the semi-arid region of Ain Sefra watershed through the employing of HEC-HMS model. In the study, the frequency storm is used for the meteorological model, Soil Conservation Service (SCS) curve number is selected to calculate the loss rate and SCS unit hydrograph method have been applied to simulate the runoff rate. After calibration and validation studies, we determine that the simulated peak discharges are very close with the observed values. Mishra et al. (2018) investigate the future flood inundations under climate and land use change scenarios in Ciliwung River Basin. They utilize the HEC-HMS model to simulate the river discharge and analyse climate change impact on the basin. They find the increasing flood inundation areas and depts as 6% to 31% for different Global Climate Models (GCMs). Gumindoga et al. (2017) analyse runoff simulation in upper manyame catchment using the HEC-HMS model. The study demonstrates the suitability of the HEC-HMS for continuous runoff simulation in a complex watershed with numerous subcatchments and channel reaches.

In the study, the flood modeling for Güvenç Basin is developed with using the HEC-HMS model. For this purpose, simultaneous measurements of both rainfall and runoff are used. The model is firstly calibarated and then validated.

Study Area

Güvenç Basin is located between the coordinates of 42°08'10" N and 32°45'15"E in the city of Ankara in the mid of Turkey (Figure 1). The basin area is totally about 15.3 km^2, and the overall region is mostly covered with agricultural areas. Outlet of the basin is located at 1053 meters above sea level.

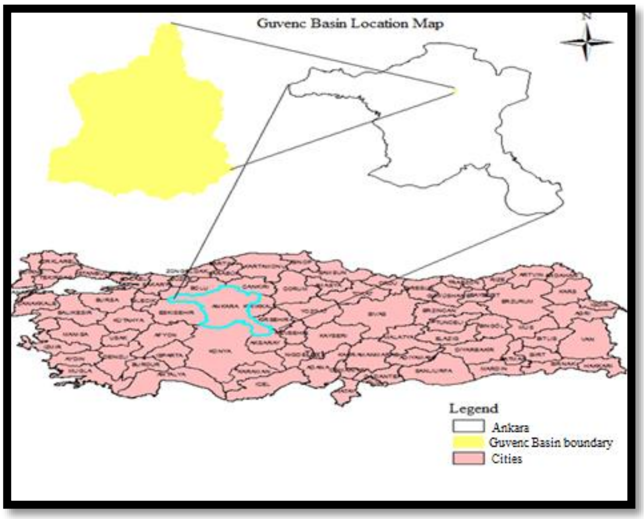

Figure 1. Güvenç Basin location map.

Method

The Hydrologic Modeling System (HEC, 2005) was developed by US Army Corps of Engineers to simulate the complete hydrologic processes of watersheds. The model combines hydrologic analysis procedures such as infiltration, unit hydrographs, and hydrologic routing. The HEC-HMS is also capable of conducting continuous simulation which requires evapotranspiration, snowmelt, and soil moisture accounting. Gridded runoff simulation using the linear quasi-distributed runoff transform (ModClark) is also possible by using the HEC-HMS. It also enables model optimization, forecasting streamflow, depth-area reduction, assessing model uncertainty, erosion and sediment transport, and water quality features. The HEC-HMS uses, together with other inputs, the design storm hyetograph and the unit hydrographs to simulate the rainfall-runoff response of a watershed by representing the entire watershed as an interconnected system of hydrologic and hydraulic components, and was designed to work with various Geographic Information Systems (GIS) data and to facilitate the use of GIS technology in hydraulic engineering. In the HEC-HMS model, precipitation can be identified by using either historical data or the generated data for design storms in order to evaluate the different parts for hydraulic structures. A userspecified unit hydrograph, can then be used in the model to obtain runoff. The HEC-GeoHMS, is an extension of ArcGIS software which was developed to serve as an assistant for deriving geospatial data (HEC, 2000). By using the HEC-Geo-HMS, it is possible to perform spatial analysis, delineate subbasins and streams, construct inputs to hydrologic models, prepare reports, and generate background map files, raster parameter files, and lumped or distributed basin models that can be directly transferred into the HEC-HMS model (HEC, 2000; Bedient and Huber, 2002).

Major data required in this study are land use information, Digital Elevation Model (DEM), observed rainfall and runoff data, and characteristics of the hydraulic structure in the basin. Corine Land Cover maps for the years of 1990 and 2012 were used for the study. The required characteristics of the Güvenç pond were obtained from the Soil Fertilizer and Water Resources Central Research Institute and DEM with 30 m resolution was obtained from U.S Geological Survey (USGS) website in digital format.

Five meteorological stations (R24, R25, R26, R27, and R28) and one flow observation station were simultaneously operated by the Ankara Research Institute of the General Directorate of Rural Services (GDRS) between the years of 1984 and 2010 (Figure 2).

Temperature, runoff and precipitation in Güvenç Basin are given in Table 1. These data were obtained from the Institute.

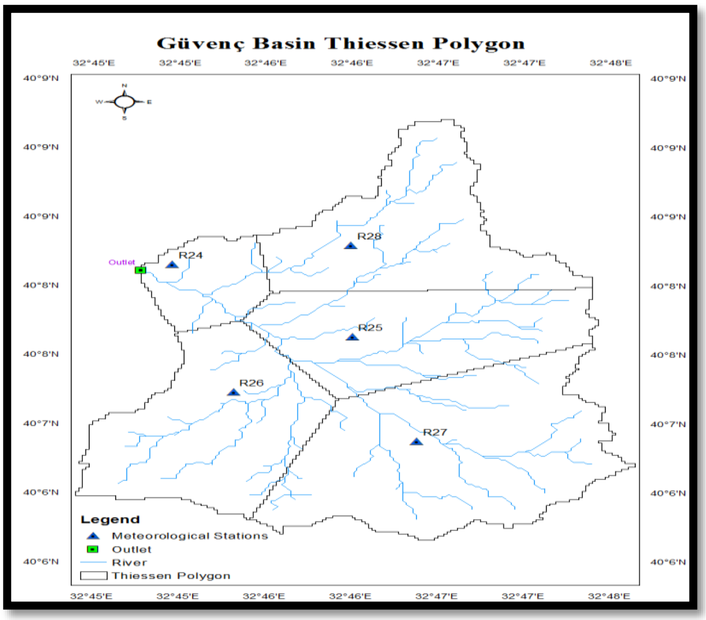

Figure 2. Güvenç Basin thiessen polygon.

Table 1

Temperature, Runoff and Precipitation Values in Güvenç Basin

26 Years Mean (1984-2010)	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Yearly
Total Precipitation (mm)	37.1	49.4	62.8	40.1	37.3	50.7	56.9	51.1	35.6	20	13.3	18.9	473.3
Total runoff (l/s)	2.96	13.27	38.58	48.49	76.41	120.4	134.6	83.07	39.98	14.62	2.3	0.73	575.1
Surface runoff (l/s)	1.82	7.62	16.91	11.18	23.35	24.38	31.15	16.21	8.26	3.73	0.72	0.39	145.68
Subsurface runoff (l/s)	0.35	3.08	5.98	7.32	9.38	19.44	14.44	7.09	3.31	1.324	0.199	0.035	71.99
Temperature (Mean) (°C)	12.8	6.7	2.3	0.4	1.3	5.6	10.7	15.1	19.2	22.6	22.2	18.2	11.4

Application

In the presented study, the first step was determination of physical and climatic characteristics of the basin such as river slope, basin centroid, longest flow path, centroidal longest flow path, and watershed drainage area by using HEC-GeoHMS (Figure 3). The HEC-GeoHMS model extension initially uses DEM. The characteristics of the basin were considered individually. As a result of HEC-GeoHMS operations, which are operated by ArcGIS program, the schematic of the basin was formed (Figure 4). With the HEC-HMS model study, the hydrological cycle of the basin was discussed extensively. Flow estimation was generated by correlating the methods used for the model and the meteorological parameter. The results were compared with actual observations and then the performance of the model was determined. Figure 4 shows basin schematic generated with HEC-GeoHMS.

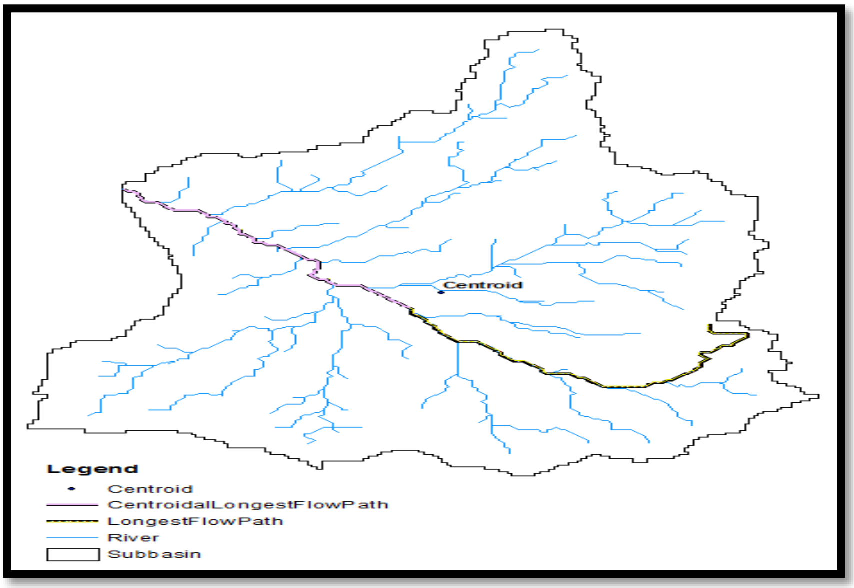

Figure 3. Güvenç Basin physical characteristics generated with HEC-GeoHMS.

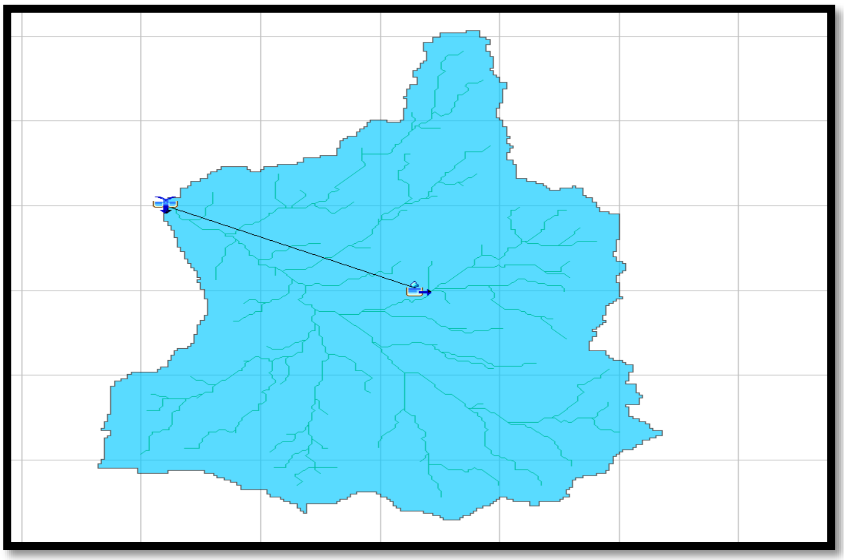

Figure 4. Schematic diagram of Güvenç Basin, generated with HEC-GeoHMS.

The Soil Conservation Service Curve Number (SCS CN) Method was selected to determine the loss rates in the basin. SCS CN method is efficient method for determining the approximate amount of runoff from rainfall. The method requires rainfall amount and CN. The curve number is based on research area's hydrologic soil group and land use. Land cover characteristics of the basin are given in Table 2. Representative CN values for the related years for the basin was obtained by using areal CN averages and then assigned to the basin for the hydrologic modeling set up. In this process, Corine maps were considered for the land cover of the basin. Table 2 also shows the CN calculation process for the year of 2012. CN value for 1990 was also calculated as 81.67 by using the same procedure.

SCS CN Model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$

From analysis of results from small experimental watersheds, the SCS developed an empirical relationship of I_a and S:

$$I_a = 0.2S$$

The cumulative excess at time t is:

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S}$$

The maximum retention, S, and watershed characteristics are related through an intermediate parameter, the curve number as:

$$S = \frac{100 - 10CN}{CN}$$

CN values range from 100 (for water bodies) to approximately 30 for permeable soils with high infiltration rates (HEC, 2005).

Table 2
Soil Conservation Service Curve Number Value for Güvenç Basin (1990 & 2012)

Land Cover	**SCS CN Value**	**Percent**	**Areal CN Value**
Sparse vegetation	78	29.44	23
Rock area	100	3.212	3
Plant cover	84	49.4	42
Meadows	70	9.189	6
Non-irrigated mixed farming	82	0.855	1
Non-irrigated cultivated land	81	7.88	6
Total	**-**	**-**	**81**

Unit hydrographs obtained by using observed hydrographs were used for rainfall-runoff transformation. In order to determine meteorological characteristics of the basin, the average amount of precipitation over the basin was computed with the observed data from the five meterological stations using the Thiessen Polygons Method (Figure 2).

In the study, runoff and rainfall data of Güvenç Basin obtained from the precipitation and flow characteristics project in Güvenç Basin (Tekeli and Demirkıran, 2010). In the project, short term maximum rainfall data for unit hydrograph analysis were analyzed and unit hydrographs were formed in 10 different time periods between 1984 and 2010. In the HEC-HMS model, the maximum rainfall data, influenced by the observed unit hydrographs and the formation of these currents in the years of 1992, 1993, 1998, 2000, 2002 and 2005, was recorded in meteorological stations at the same time scale. The model compared to the observed flow data at the same time period using the “SCS CN” Method and meteorological data at the observed time interval.

Last step for generating of the flood modeling was that the calibration of some of the HEC-HMS parameters including CN, and the validation of the simulation outputs using the best parameter estimates were conducted for the Güvenç Basin. The calibration and validation processes were carried out by splitting the observation periods. For calibration, the years of 1992, 1993 and 1998; for validation, the years of 2000, 2002 and 2005 were chosen. Applied methods, input and output parameters in HEC-HMS Model for Güvenç Basin are given as follows:

1. Loss method: SCS Curve Number
2. Transform method: SCS Unit Hydrograph
3. Baseflow method: Recession

Input parameters:

- Rainfall
- Observed runoff
- Unit hydrograph values
- Curve number
- Calibration parameters (ratio, recession, impervious)

Output parameters:

- Observed runoff
- Simulated runoff
- Hyetograph

Results

Figures 5-7, showed the simulated (marked with blue line) and observed (marked with black line) hydrographs for calibration. The flood modeling was simulated by using curve number with the values of the basin characteristics (Table 3). The calibrations parameters were determined by comparing the observed flood values with the simulated results (Table 4). The figures were generated with the HEC-HMS Model.

Table 3
Values of Güvenç Basin Characteristics

Drainage Area (km^2)	**Longestflowpath (m)**	**Centroidal Longestflowpath (m)**	**Average height (m)**	**Basin slope (%)**	**Basin Perimeter (m)**
15.3	5896	2610	1235	0-40	19000

Table 4
Calibrated Model Parameters

Years	Curve Number	Initial Abstraction (mm)	Ratio	Recession	Impervious
1992	81	1.2	0.02	1	1
1993	81	3.8	0.01	1	0.8
1998	81	13	0.01	1	1.2

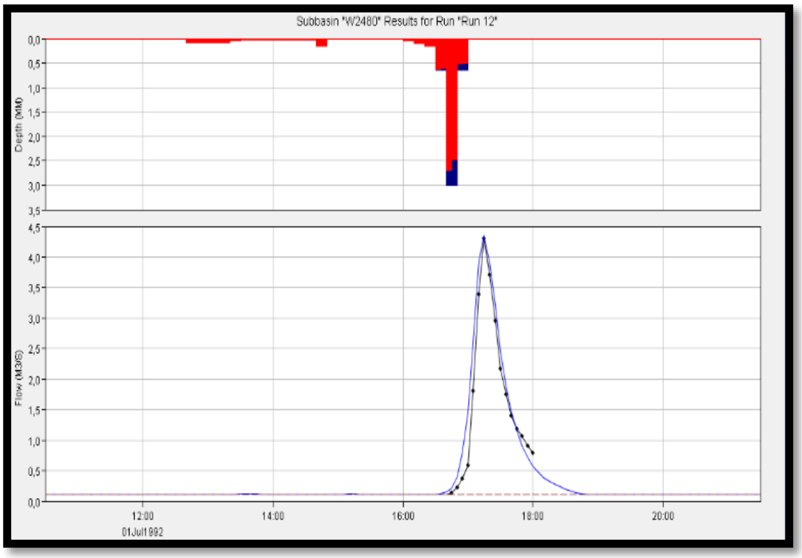

Figure 5. Observed and simulated hydrographs in 1992.

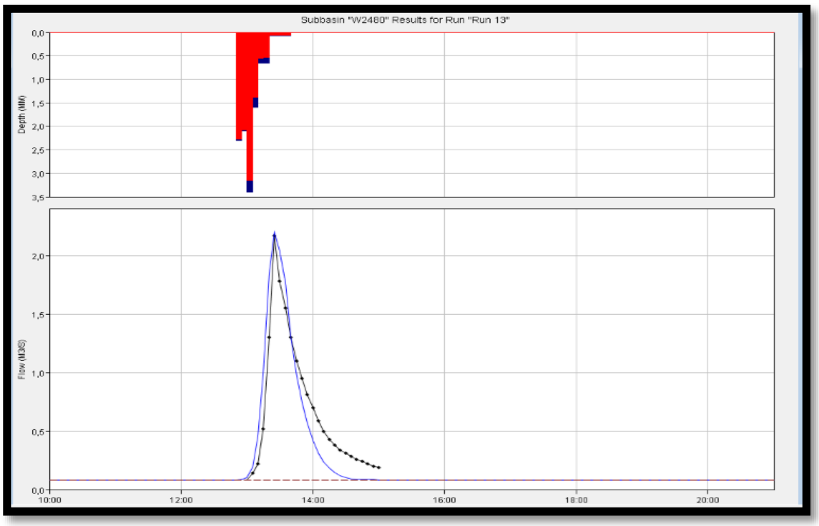

Figure 6. Observed and simulated hydrographs in 1993.

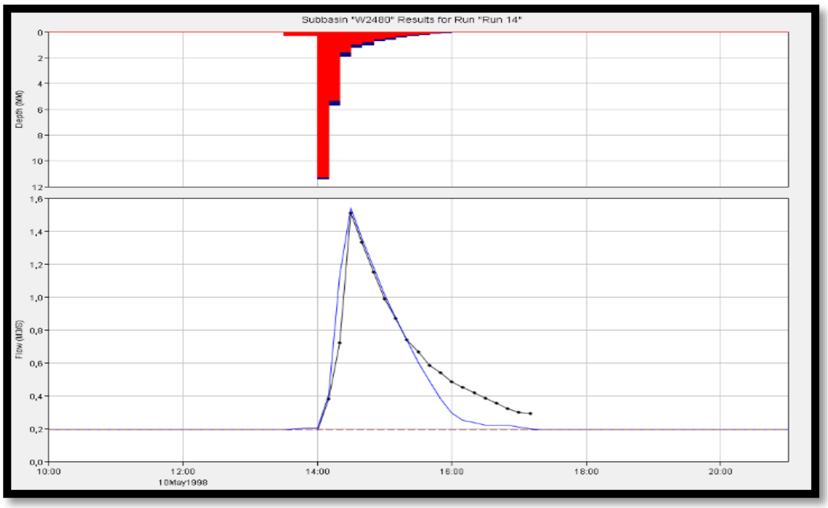

Figure 7. Observed and simulated hydrographs in 1998.

Calibrated model parameters which include CN (related to land cover), initial abstraction (soil water availability), ratio (depends on sediment), recession (base flow) and impervious (depend on urbanization) were given in Table 4.

For validation; CN, ratio, recession, and impervious parameters were chosen as 81, 0.01, 1.0, and 1.2 respectively. After determining the calibration parameters, the model performance was evaluated by validation process. As a result of the validation process, the observed and simulated flood values were shown in Table 5 and Table 6.

Figures 8-10 showed the simulated (marked with blue line) and observed (marked with black line) hydrographs for validation.

Table 5

Observed Values of Flood Hydrograph in Validation Process

Date	**Peak flow (m^3/s)**	**Initial Discharge (m^3/s)**	**Time of concentration curve (hour)**	**Time of recession curve (hour)**
02.06.2000	1.271	0.089	1	2
01.05.2002	1.18	0.233	1	3.5
26.05.2005	2.52	0.039	1	8

Table 6

Simulated Values of Flood Hydrograph in Validation Process

Date	**Peak flow (m^3/s)**	**Time of concentration curve (hour)**	**Time of recession curve (hour)**
02.06.2000	1.225	1	4
01.05.2002	1.16	1	2.5
26.05.2005	2.60	1	3

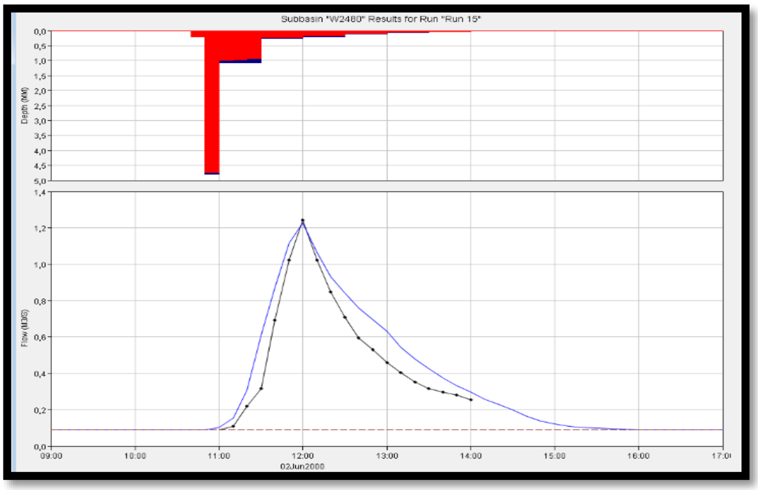

Figure 8. Observed and simulated hydrographs in 2000.

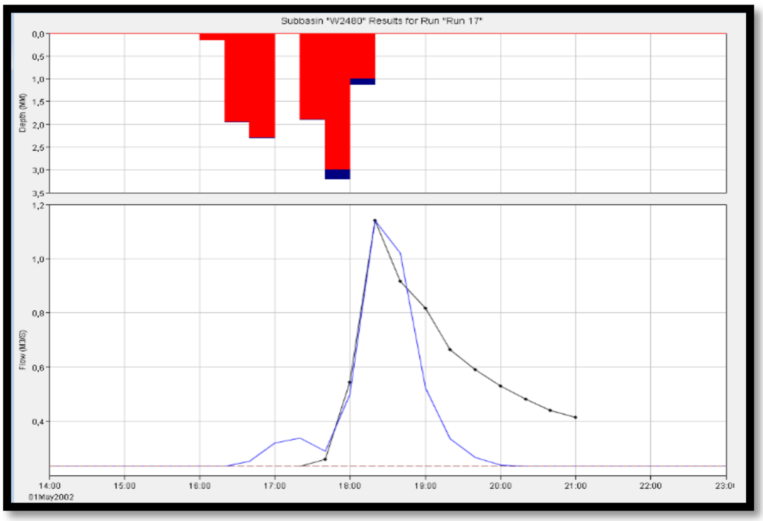

Figure 9. Observed and simulated hydrographs in 2002.

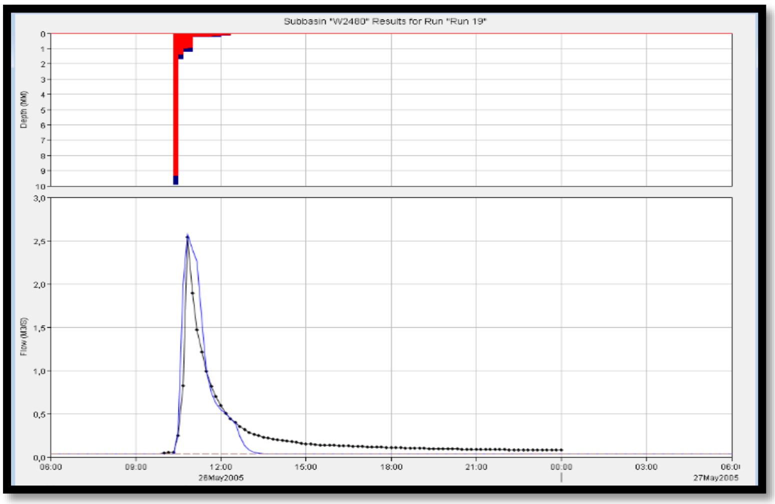

Figure 10. Observed and simulated hydrographs in 2005.

Initial abstraction values were again determined for validation simulations as 3.98 mm, 5.75 mm and 6 mm for the years of 2000, 2002 and 2005, respectively. Initial abstraction values were different for each year for both calibration and validation processes because of the different soil conditions in the basin.

For calibration work; in 1992, 1993 and 1998, hourly precipitation values were simulated using the HEC-HMS Model. In calibration process, initial abstraction, impervious, recession, ratio calibration parameters were calculated by comparing simulated and observed peak discharges optimum values. For verification work; the values of the 2000, 2002 and 2005 were evaluated. Lastly, the results of the model which was simulated with the observed peak flow rates, were found very close to each other. Observed peak values were found 1.271, 1.18, 2.52 m^3/s respectively in 2000, 2002, 2005 years. On the other hand, simulated peak flow were found as 1.225, 1.16, 2.60 m^3/s respectively for these years.

Discussion and Conclusion

The climate change has impacted the rainfall pattern, and it is resulted in flood events due to the deterioration of land structures. Flash floods often causes serious loss of life and property. In order to minimize the impacts of this situation, it is need to predict truthfully floods in any area. The short-term precipitation is a warning to any region for modeling flood phenomena that can be predicted. Therefore, in order to evaluate the flood risk using precipitation data, the relation between the observed results and the model simulations should be investigated by performing precipitation-flow modeling of the regions. In this study, the relation between the floods occurring in the Güvenç Basin and the HEC-HMS flow simulations was investigated.

The performance of the flood modeling has been evaluated by comparing observations and model simulations for the selected flood events. Model calibration parameters (impervious, recession, ratio, initial abstraction) were estimated in calibration process and by using these parameters, validation of the model was conducted for flood events. Model simulated flood datas were found to be compatible with the observed data.

The high performance of the model is not an important intervention on the water potential of the basin and it is an essential factor for the basin to be untouched. The selected periods (1992, 1993, 1998, 2000, 2000, 2002, and 2005) for the calibration and validation processes are periods that heavy precipitation occurs sufficiently to form a unit hydrograph. The presence of long term data in short time intervals is another factor that ensures high performance of the model.

As a result, the hydrological model has high performance in Güvenç Basin. The hydrologic model created for Güvenç Basin can be used for the other flood management and flood early warning studies.

Acknowledgement

This study was carried on by using the data of my master's thesis named “Risk Based Design under the Effects of Climate Change” presented to Dokuz Eylül University Faculty of Civil Engineering, Department of Hydrology and Water Resources. I would like to express my sincere gratitude to my advisor, Assoc. Prof. Dr. Gülay Onuşluel Gül for the continuous support of the study.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Ankara Güvenç Havzası'nda Taşkınların HEC-HMS ile Modellenmesi

Sanayi devrimiyle birlikte ekosistem üzerindeki antropojenik etkilerin artması sonucunda tüm dünya, küresel iklim değişikliği sorunuyla karşı karşıya gelmiştir. Küresel iklim değişikliğinin olumsuz etkileri neticesinde atmosfer tabakası kararsızlaşmıştır. Bu durum, son yıllarda, yağış trendlerinde değişikliğe ve ekstrem yağışlarla beraber taşkınlara sebep olmaktadır. Çevre felaketlerine ve can kaybına neden olan taşkınların zararlarını ve boyutlarını analiz etmek amacıyla bilim insanlarınca çeşitli metotlar geliştirilmiş ve çalışmalar yürütülmüştür. Taşkın frekans analizi, su kaynakları projelerinin ekonomik ve hidrolojik olarak değerlendirilmesinde oldukça önemli bir yöntemdir. Bu yöntem olası taşkın büyüklüğü veya belirli büyüklükteki bir taşkının frekansının tahmin edilmesini, hidrolik yapıların uygun tasarım kriterlerinin saptanmasına ve proje maliyetinin düşürülmesine olanak sağlar. İstatistiksel frekans analizi uygulanarak belirlenen olasılık dağılımlarıyla taşkın tahminleri yapılmaktadır fakat iklim değişikliği ve artan şehirleşmenin etkisiden dolayı parametrik yöntemler ile taşkın riskinin belirlenmesi tek başına yeterli değildir. Dolayısıyla, günümüz şartları gözönüne alınarak taşkın risk değerlendirmesi çalışmalarında, parametrik olmayan metotlar veya hidrolojik modellerin iklim değişikliği senaryoları ile birlikte kullanılmasıyla risk yönetimi açısından daha sağlıklı sonuçlar elde edilir.

Bu çalışmada, Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü'ne bağlı, Toprak Gübre ve Su Kaynakları Enstitüsü tarafından yürütülen "Güvenç Havzasının Yağış ve Akış Karakteristiklerinin Belirlenmesi" araştırma projesi kapsamında, gözlemlenmiş yağış ve akış değerleri, HEC-HMS modeli kullanılarak modelin performansı analiz edilmiştir. Örnek çalışma kapsamında, 1992, 1993, 1996, 2000, 2002 ve 2005 yıllarının belirli zamanlarında gözlemlenmiş pik taşkın debileri ile HEC-HMS modeli ile simüle edilen değerler, kalibrasyon ve validasyon çalışmalarında kullanılmıştır. Pik taşkın debilerinin hesaplanmasında ve model performansının ölçülmesinde kullanılan yöntem (SCS Curve Number) için gerekli olan akış eğri numarası (CN), arazi örtüsü haritaları (CORINE 1990, CORINE 2012) analiz edilerek belirlenmiştir. Sayısal Yükseklik Haritası (DEM), "usgs" web adresinden temin edilmiştir. 30 metre çözünürlükteki sayısal yükseklik haritası tiff formatında, CBS işlemlerinde kullanılmıştır. CBS tabanlı HecGeo – HMS model uzantısı ile havzanın karakteristik özellikleri (akım yönü belirleme, kümülatif akım hesaplama, nehir tanımlama, nehir bölümleme, su toplama alanı oluşturma, su toplama alanı poligonlama, drenaj çizgilerini belirleme, bitişik su toplama alanı belirleme, en uzun akarsu boyu, akarsu eğimi, akarsuya bağlı havza orta noktasının merkeze (aksa) olan uzaklığı, drenaj alanı, havzanın eğimi, ortalama kot) belirlenmiştir. Havzanın karakteristik özellikleri analiz edildikten sonra HEC-HMS model içerisinde, havza karakteristik değerleri, gözlemlenmiş meteorolojik ve hidrolojik veriler kullanılmış olup simülasyon sonucuna göre gözlemlenmiş değerler karşılaştırılarak en uygun kalibrasyon parametreleri belirlenmiştir. Doğrulama (validasyon) işlemleri ile modelin sonuç performansı değerlendirilmiştir.

Havza, 40 08 00 N enlemi ve 32 45 15 E boylamı arasında yer almaktadır. Karakteristik özellikleri değerlendirildiğinde, drenaj alanı 15.3 km², çevre uzunluğu 19 km, en düşük kotu 1053 m, en yüksek kotu 1453 m, ortalama yüksekliği 1235 m, akış eğri numarası (CN) 81, en uzun akarsu boyu 5896 m, Havzanın orta noktasının aks yerine olan en uzun akarsu boyu 2610 m, Havzanın eğimi % 0-40 arasında değişmekte olup Havzanın ortalama eğimi ise %21'dir. Modelde kalibrasyon ve validasyon işlemleri uygulanarak elde edilen gözlemlenmiş ve simüle edilmiş taşkın hidrografları birbirine çok yakın sonuçlar vermiştir. Doğrulama işlemlerinin yürütüldüğü 2000 yılında, gözlemlenmiş pik debi 1.271 m³/s, simüle edilmiş pik debi 1.225 m³/s olarak hesaplanmış ve hidrografın yükselme eğrisi her iki durum içinde 1 saat, çekilme eğrisi ise gözlemlenmiş değerlerde 2 saat, model simülasyonunda 4 saat sürmüştür. 2002 yılının doğrulama çalışması incelendiğinde, gözlemlenmiş pik debi 1.18 m³/s, simüle edilmiş pik debi 1.16 m³/s'dir. Hidrografın yükselme eğrisi, gözlemlenmiş ve simüle edilmiş sonuçlarda 1 saat sürmüş olup çekilme eğrisi ise gözlemlenmiş sonuçlarda 3.5 saat simüle edilmiş sonuçlarda 2.5 saat sürmüştür. Bir diğer doğrulama işlemi 2005 yılı için araştırılmıştır. 2005 yılında gözlemlenmiş pik debi 2.52 m³/s, simüle edilmiş pik debi ise 2.60 m³/s olarak hesaplanmıştır. Hidrografın çekilme eğrisi gözlemlenmiş sonuçlarda 8 saat, simüle edilmiş sonuçlarda 3 saat sürmüştür. Yükselme eğrisi, her iki durum için de 1 saat sürmüştür. Gözlemlenmiş ve simüle edilmiş taşkın hidrograf sonuçları değerlendirildiğinde, taşkının oluşma süresi ve şiddetinin birbirine oldukça yakın bulunmuş olup Havzada değerlendirilen HEC-HMS modelinin performansı oldukça yüksek bulunmuştur. Bu duruma etki eden en önemli husus ise havzadaki akış değerlerinin doğal olması, dereler üzerinde herhangi bir müdahale olmaması yani havzanın bakir olmasıdır. Ayrıca, havza içerisinde istatistiksel olarak anlamlı bir şekilde veri sağlayan istasyonlar değerlendirilmiş olup veriler saatlik üretilmektedir. Dolayısıyla, ani maksimum yağışların pik debileri istatistiksel yaklaşımlardan ziyade gözlemlenmiş veriler kullanılarak hesaplanmıştır. Çalışmada, ani maksimum yağışlara bağlı oluşturulan birim hidrograf değerlerinin tümü model içerisinde kullanılmıştır. Havzanın bakir olması, meteoroloji ve akım gözlem istasyonlarının havza içerisindeki uygun konumu, üretilen veri setinin sürekli ve kesintisiz olması model performansını olumlu yönde etkileyen faktörler arasındadır.

Güvenç Havzasında hidrolojik model kullanımı ile yağış akış ilişkisi analiz edilerek çalışma alanında uygulanan modelin kullanılabilirliği test edilmiştir. Model performansının yüksek olması ile çalışılan bölgede taşkın tasarım ebatlarındaki risk yönetimi çalışmaları ve taşkın erken uyarı sistemleri geliştirilebilir.

Hidrolojik model seçiminde, araştırma alanının karakteristik özelliklerini belirleyen ve Coğrafi Bilgi Sistemleri (CBS) tabanlı programlara entegre edilebilen modellerin kullanılması, havza karakteristik özelliklerini daha iyi temsil edebileceğinden dolayı diğer modellere göre avantaj sağlamaktadır. Bu sebeple, HEC-HMS ve Toprak ve Su Değerlendirme Aracı (SWAT) gibi CBS tabanlı programlarla birlikte kullanılan hidrolojik modeller araştırma çalışmalarında yaygın bir şekilde kullanılmaktadır. Bu gibi modeller kendi web siteleri üzerinden kullanıcı yorumlarına açık olduğundan kullanıcıya teknik destek sağlanabilmekte, modeller sürekli güncellenebilmektedir. Model performansında ise önemli olan araştırma sahasının karakteristik özellikleri ve mevcut veri varlığının en iyi şekilde modele tanıtılmasıdır. Araştırma bölgesindeki meteoroloji ve akım gözlem istasyonlardaki saatlik hatta dakikalık ölçümler, yeraltı suyu seviyesi, toprak haritası, arazi örtüsü, toprak katmanları, taban suyu, toprak nemi, toprak iletkenliği, kar örtüsü, kar-su eşdeğeri, referans evapotranspirasyon, gerçek evapotranspirasyon verilerinin tümü ya da bir kısmı ile simülasyonlar üretilebilir. Model performansına etki eden husus ise doğal ya da doğallaştırılmış veri varlığı ve sağlıklı ölçümlerdir.

Case Study

Estimation of Glacial Rebound Effect by Vertical Velocity Analysis Method

Buzul Geri Çekilme Etkisinin Düşey Hız Analiz Metodu ile Tahmin Edilmesi

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Abstract

The physical phenomena occurring on the Earth, which has continous dynamic structure, changes slowly. Glacial withdrawal movements variations may also result from geodetic changes such as instabilities in the angular velocity of the world. Glacial Isostatic Adjustment models can be used to estimate gravitational field of earth and oceans' response to the growth and decay cycle of ice sheets. However, big data requirements of these models and approaches in their mathematical analysis, reveal the need for a simplified and less demanding model. The aim of this paper was to estimate the post glacial rebound effect by means of Global Positioning System campaign and positioning techniques. In this study, the linear trend of vertical velocity component was observed and the solid earth rises were estimated after ice sheet mass loss was investigated. In this direction, position time series of 34 International GNNS Service for Geodynamics stations with 24-hours period of 1995-2017 were used. By means of the MATLAB program, R^2 of velocities' vertical component were calculated by the least squares method. After this process, the spatial representation of the R^2 values on the earth was figured with "ordinary kriging" which is a geostatistics technique by using ArcGIS program. The generated map was compared with the map obtained by Milne's glacial isostatic adjustment model and the results were interpreted. The results present us that the post glacial rebound rates appears to be 88% compatible with the R^2 values.

***Keywords*:** Glacial Isostatic Adjustment (GIA), ordinary kriging, Coefficient of Determination (R^2), Global Positioning Ssystem (GPS), glacial rebound effect

Öz

Sürekli dinamik yapıya sahip Dünya üzerinde oluşan fiziksel olaylar yavaşça değişim göstermektedir. Buzul geri çekilmeden kaynaklı hareketler dünyanın dairesel hızının değişimi gibi jeodezik değişimler neticesinde ortaya çıkabilmektedir Buzul İzostatik Dengeleme modelleri sayesinde yeryüzü yerçekim alanının ve okyanusların buzul tabakalarının büyümesine ve erimesine verdiği tepki net bir şekilde olmasa da hesaplanabilmektedir. Ancak söz konusu modellerin fazla veri ihtiyacı ve matematiksel analizindeki yaklaşımlar, daha basitleştirilmiş, daha az veriye ihtiyaç duyan bir model ihtiyacını ortaya koymaktadır. Çalışmanın amacı, Küresel Konumlama Sistemi kampanyası ve ölçüm değerlendirme yöntemleri ile buzul sonrası geri çekilme etkisinin tahmininin gerçekleştirilmesidir. Bu çalışmada, düşey hız bileşeninde gözlenen doğrusal eğilimin, buzul sonrası geri çekilmeden kaynaklı kabuk yükselişi ile korelasyonunun olup olmadığı araştırılmıştır. Bu doğrultuda, 1995-2017 yıllarına ait 24 saat oturum süreli 34 adet uluslararası GPS servisi istasyonuna ait hız zaman serilerinin kullanılarak MATLAB programı aracılığıyla en küçük kareler yöntemi ile R^2 değerleri hesaplanmıştır. Bu işlem sonrasında ise ArcGIS programı ile jeoistatistik tekniği olan "sıradan kriging" ile mekânsal ara kestirim yapılarak R^2 değerlerinin yeryuvarı üzerinde konumsal gösterimi elde edilmiştir. Elde edilen harita, Milne tarafından oluşturulan buzul izostatik ayarı modeli sonucunda elde edilen harita ile kıyaslanarak, sonuçlar yorumlanmıştır. Sonuçlar, buzul sonrası geri tepki oranlarının R^2 değerleriyle %88 uyumlu olduğunu göstermektedir.

***Anahtar kelimeler*:** Buzul İzostatik Ayarı**,** sıradan kriging, Belirleme Katsayısı (R^2), Küresel Konum Belirleme Sistemi (KKS), buzul sonrası geri çekilme

Introduction

The Earth is constantly on the move and the physical events on it are slowly changing. For a several-thousand-year, the great mass of ice has pushed soil underneath the ice for half a mile in some parts of the Earth, so soil around the glacier has risen up to several hundred meters. Additionally, melting of ice sheets has increased the level of oceans. As a result of this phenomenon called post glacial rebound, soils under the ice have begun to rise again. The effects of glacial withdrawal are summarized in Figure 1. Although the large ice sheets in the Northern Hemisphere melt for a long time ago, the Earth's response to this event has been continuing even today. The rises of land masses after glaciers retreat in the East Coast and Great Lakes of the United States can be clearly observed.

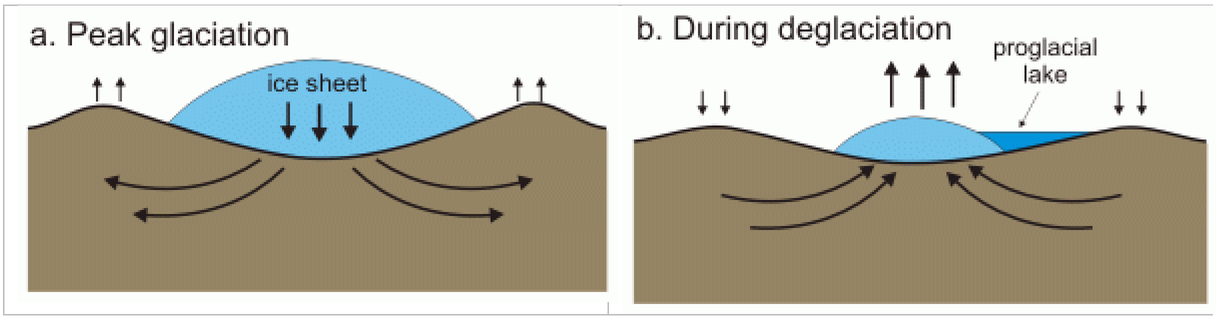


Figure 1. Glacier withdrawal (Courtesy of Tom James at Natural Resources Canada).

Glacial Isostatic Adjustment (GIA) refers to the response of the earth to the gravitational field and the oceans to the growth and melting of ice layers. The widely studied component of GIA is rising of the solid earth after the melting of ice layers. GIA, which is a relatively fast process, triggers up to100 m changes on earth and sea from sea level.

Changes caused by glacial movements can be monitored by GIA models. Global Positioning System (GPS), a geodetic dataset, Interferometric Synthetic Aperture Radar (InSAR) Altimeter and tide indicator data are used to measure surface deformation associated with GIA (King et al., 2010). The Earth's crust, oceans and ice sheets are considered as three main components of model calculations on a global scale. GIA models are designed for solving the classical geodynamic problems of solid earth responses against to the ocean and ice loading. The models also determine self-consistent redistribution of meltwater gravitationally in the ocean throughout the world.

Many GIA models have been developed by prominent researchers in this field. Peltier was at the forefront of developing the GIA's theory in the late 70s and early 80s. He has pioneered the development of finite element analysis and numerical analysis solutions to sea level equality (Peltier et al.,1976). Shennan and Milne have developed highly accurate methods to solve the sea level equation. Methods were used to investigate and explain various geophysical phenomena (Milne et al.,2013). Lambeck also developed a model for solving the sea level equation of coastal line calculation, which is a more complex process, as well as ice and ocean loading (Lambeck et al.,1998). Wu used the finite element method for modeling isostatic deformation and sea level changes associated with GIA. His studies were generally conducted on the effects of observed GIA, and the structure and rheology of Earth (Wu et al.,2005). Kaufman investigated the Earth's crustal movements, the effects of this movement and GIA observations. Those observations were used to predict the viscosity of the Earth's layers (Kaufmann et al.,1998). The German Geological Research Center in Potsdam pioneered the development of spectral finite differences. The viscoelastic response of the earth was investigated by using the finite element methods to calculate the 3-D viscosity structure of the surface loading. Additionally, Zong, Paulson and Wahr analyzed the rebound after the glacial, examined the viscous mantle convection problems using the finite element model (Zong et al.,2003). Sabadini, Gasperini, Giunchi, and Spada investigated the effects of GIA on the lateral structure of the Earth's crust (Gasperini et al., 1990; Giunchi et al., 1997). Vermeersen has developed “Analytical Normal Mode” method for viscoelastic loosening in the Earth's crust due to surface loading (Vermeersen et al., 1996). Fjeldskaar used the Fourier Transformation Method with a realistic glacier melt model to calculate the loading response against surface loading. He used the simple half space model, consisting of a viscous mantle covered by an elastic lithosphere. (Fjeldskaar et al., 1997).

As mentioned above, many models in the literature have been used to monitor the glacial withdrawal effects. In order to collect data and operate these models effectively, there is a need to establish fixed base stations where glacial retreat can be observed. Financing these type of investments with high cost is not always possible. Also operation of these establisments needs so much money and time.

In the current situation, the stations for monitoring of the GIA effects are constructed only at the designated points where have a high probability of glacial movement. Thus, GIA models may not model glacial effects for other points on the Earth efficiently. In addittion some parameters can not be clearly defined in models. For example, horizontal speeds at GPS receivers are more accurate than vertical ones, but it is necessary to remove the plate movement value from the speed outputs of the GIA model. Neither the plate movement nor the GIA effects can be fully calculated. Hence this issue can not be grasped so easily (King et al., 2010).

This study’s aim was to establish a simple method not to use large amount of data on same scale as the models really need and to monitor glacial effects with the minimum cost. In this study, the regions where glacial effects can be observed, are modeled with minimum data by using the vertical speed analysis method.

Research and Method

Satellite technologies and Global Navigation Satellite System (GNSS) are used commonly for areas where surface displacement and strain due to tectonic movements are detected. One of the most effective method to monitor crust displacements and movement is using permanent stations which can measure the surface movement continuously. It is not always possible to access to fixed ground-based stations’ data, therefore campaign measurements are usually made at regular intervals. The speed vectors are obtained by evaluating these GPS campaigns. The velocity vectors provide information to interpret crustal movements of the region (Baysal et al., 2010).

International GNNS Service for Geodynamics (IGS), which provides high quality data and products in the GNSS standard, supports world science researches and multi-disciplinary applications. In this study, it was aimed to estimate the rise of the Earth’s crust due to glacial rebound with using position time series of IGS stations by GPS campaigns. In GPS observations high accuracy of positioning is important concept. Therefore, position time series of IGS stations are obtained by Precise Point Positioning technique (PPP) which removes GNSS system errors to provide high level of position accuracy up to 3 centimeters.

Figure 2 showed the IGS stations, chosen for the operation of this study. GPS vertical component time series data of thirty four IGS stations with 24-hours period were used in the study for years between 1995-2017.

*Figure 2***.** IGS points (prepared by author).

Geodetic point velocity information with high accuracy has of great importance in studies such as modeling of crust movements, fault systems and tectonic movements deformation. For coordinate time series analysis there is a need to have accurate speed estimation. Many different mathematical models are used in coordinate time series analysis. The mathematical model, shown in equation 1, is used in this study. This equation is a simplified version of annual signal dominant equation. The explicit form of equation was shown in equation 2 & 3. For the velocity estimations, "Multiple Linear Regression Analysis" method was used. The unknowns in the mathematical model were obtained by the Least Squares Method taking into account the annual linear trend and seasonal periodic effects. The MATLAB program was used for the evaluation of the mathematical method.

The most common mathematical model;

$$y(t) = y_0 + v(t - t_0) + \sum g(t, y) + \varepsilon(t) \quad (1)$$

$y(t)$: time series observation vector,
t_0 : initial observation epoch of time series,
y_0 : initial coordinate value of time series at time t_0,
$v(t)$: other geophysical factors that affect the station linear velocity g (t, y) station speeds,
$\varepsilon(t)$: error term,
$g(t, y)$: periodic and non-periodic effects, where

$$\sum g(t, y) = \sum_{j=1} a_j \sin(2\pi f_j t_i) + b_j \cos(2\pi f_j t_i) + \varepsilon_j(t_i) \quad (2)$$

f_j : seasonal effect

a_j, b_j : coefficient amplitudes of seasonal effect

When seasonal effects are taken into account, equation 1 transformed to equation 3,

$$y(t_i) = y_0 + vt_i + \sum_{j=1} a_j \sin(2\pi f_j t_i) + b_j \cos(2\pi f_j t_i) + \varepsilon(t_i) \quad (3)$$

As a result of the evaluation of the equation 3 with the MATLAB program, R^2 values were obtained which give information about the linear trend in the vertical component. The R^2 value approaches "1" if the equation results are closer to observed values. The equation 4 of R^2 defined below.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} \hat{v_i}^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = 1 - \frac{\sum_{i=1}^{n}(x_i - \hat{x_i})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (4)$$

x_i : observed value
$\hat{x_i}$: value obtained from equation from regression equation
$\hat{v_i}$: residual value
$\bar{x}$: the average of the observed values

The IGS points shown in Figure 2 were spatially distributed over the entire Earth, but these points only give information about certain regions and positions. To define R^2 values for the entire Earth, "kriging" method as a geostatistical interpolation method has been used. It uses interpolation techniques for the non-measured points to define value from the measured points at the neighbouring locations by a linear combination. In the study, kriging method was used for transforming a continuous surface displacement by using a function that passes over or near the points representing tectonic movements. R^2 values were obtained by using ordinary kriging method on the ArcGIS® program. Mathematical formulation of ordinary kriging method is shown in equation 5.

$$Z(X_0) = \sum_{i=0}^{N} W_i \, x \, Z(x_i) \quad (5)$$

$Z(X_0)$: estimated Z value at X_0 point,
W_i : $Z(X_0)$'s weight values for each $Z(x_i)$ used in the calculation,
$Z(x_i)$: the empirical data used to estimate $Z(X_0)$
N : $Z(X_0)$ is the number of points used in the calculation.

Results and Discussions

R^2 values of the IGS stations' velocities' vertical components showed a constant trend over time. In the study, the trend component was important in terms of revealing the correlation between the rise of the shell and the glacial retrieval. The coefficient of determination values were interpreted as the ratio of changes in the prediction explained by the model. It has a value ranging from 0 to 1. R^2 value explains the variability of the predicted value (Y or Z) entirely by the model. Therefore it shows the suitability of the model for each measurement. In other words, if R^2 is 0, it indicates that the model does not disclose any variability in the estimation. The R^2 value greater than 0.50 is generally considered to be a significant correlation. Table 1 showed the R^2 values obtained from the Least Squares Method.

Table 1

R^2 Values Obtained From The Least Squares Method (Prepared By Author)

Station	City	Lat.	Lon.	R^2	Station	City	Lat.	Lon.	R^2
AIRA	Aira	31.82	130.60	0.81	**NKLG**	Libreville	0.35	9.67	0.08
ALRT	Alert	82.49	-62.34	0.94	**NYAL**	Ny-Alesund	78.93	11.87	0.98
AREQ	Arequipa	-16.47	-71.49	0.45	**ONSA**	Onsala	57.40	11.93	0.86
BAKE	Baker Lake	64.32	-96.00	0.98	**ORID**	Ohrid	41.13	20.79	0.1
BARH	Bar Harbor	44.40	-68.22	0.03	**PALM**	Palmer Station	-64.78	-64.05	0.94
BLYT	Blythe	33.61	-114.71	0.11	**PETS**	Petropavlovsk-Kamchatka	53.02	158.65	0.89
CEDU	Ceduna	-31.87	133.81	0.28	**QIKI**	Qikiqtarjuaq	67.56	-64.03	0.91
CHUM	Chumysh	43.00	74.75	0.38	**RABT**	Rabat	34.00	-6.85	0.49
CHUR	Churchill	58.76	-94.09	0.99	**RAMO**	Mitzpe Ramon	30.60	34.76	0.5
EBRE	Roquetes	40.82	0.49	0.12	**RESO**	Resolute	74.69	-94.89	0.96
HOFN	Hoefn	64.27	-15.19	0.98	**SALU**	São Luis	-2.59	-44.21	0.55
HOLM	Ulukhaktok	70.74	-117.76	0.8	**SCOR**	Scoresbysund	70.49	-21.95	0.85
IQAL	Iqaluit	63.76	-68.51	0.77	**SYOG**	East Ongle Island	-69.01	39.58	0.28
KOUG	Kourou	5.10	-52.64	0.46	**THU2**	Thule Airbase	76.54	-68.83	0.96
MAL2	Malindi	-3.00	40.19	0.4	**TIXI**	Tixi	71.63	128.87	0.32
MATE	Matera	40.65	16.70	0.53	**TRO1**	Tromsoe	69.66	18.94	0.89
NAIN	Nain	56.54	-61.69	0.91	**URUM**	Urumqi	43.59	87.63	0.63

The map in Figure 3 was generated with the R^2 values of the IGS stations in the Table 1. In the study, the accuracy of the findings compared with the map, which was published in the Quaternary Encyclopedia of Science (Milne, 2013), accepted by many researchers (Bell, M., 2014; Clark, P. U., 2002; Lambeck, K., 2002), and showed the regions affected by glacial retreat.

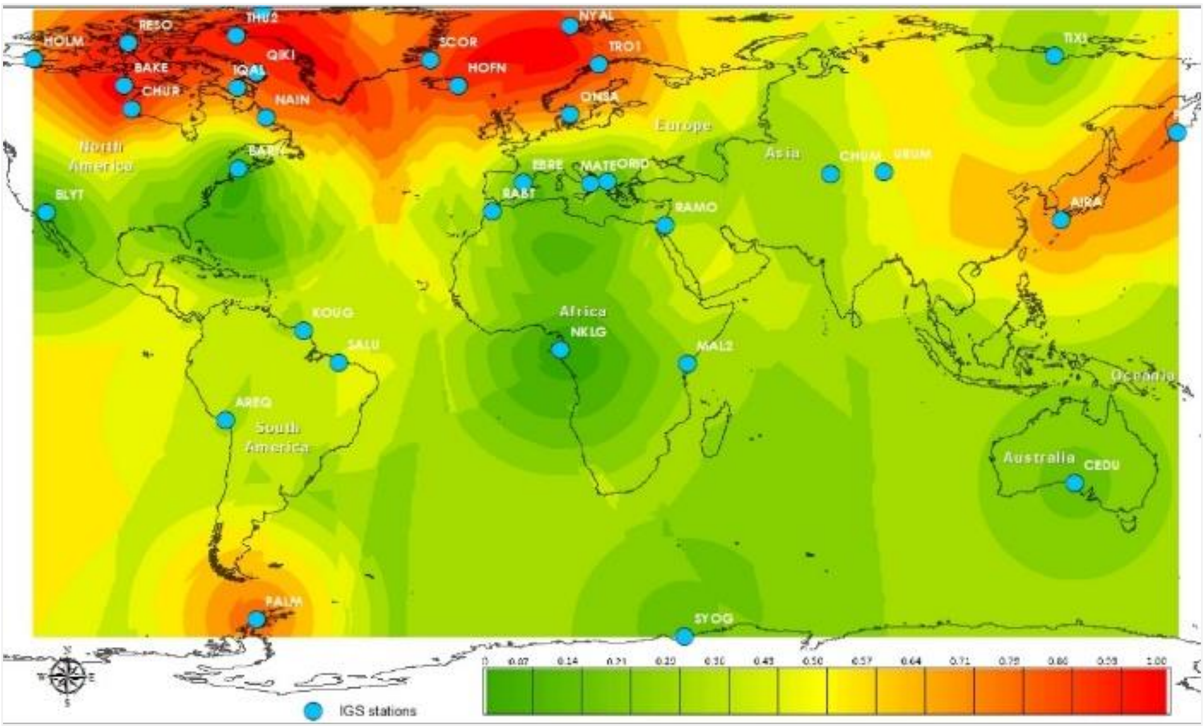


Figure 3. Map created by ordinary kriging method depending on R^2 values (prepared by author).

When the R^2 value were examined, it was found that the regions, R^2 values close to 1, were the continents of South America, Northern Europe and Antartica affected by glacial retreat. The map of Milne was used for the correctness of this inference. The regions in his map were coordinated by using Georeferencing Method (Figure 4) in ArcGIS Program. Glacial retreat rates of 34 IGS points were overlapped with the values in the his map. All R^2 values that corresponded with the rates, were found approximately (Figure 5).

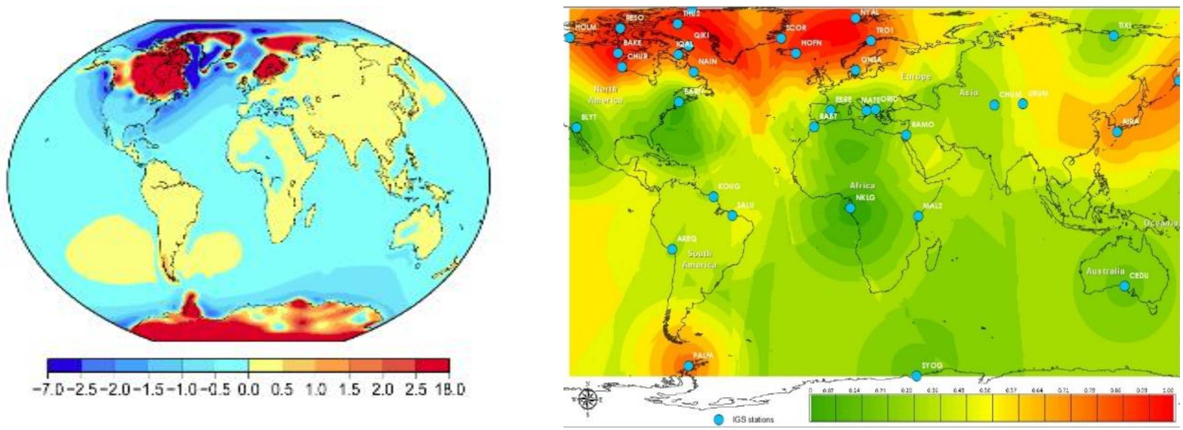
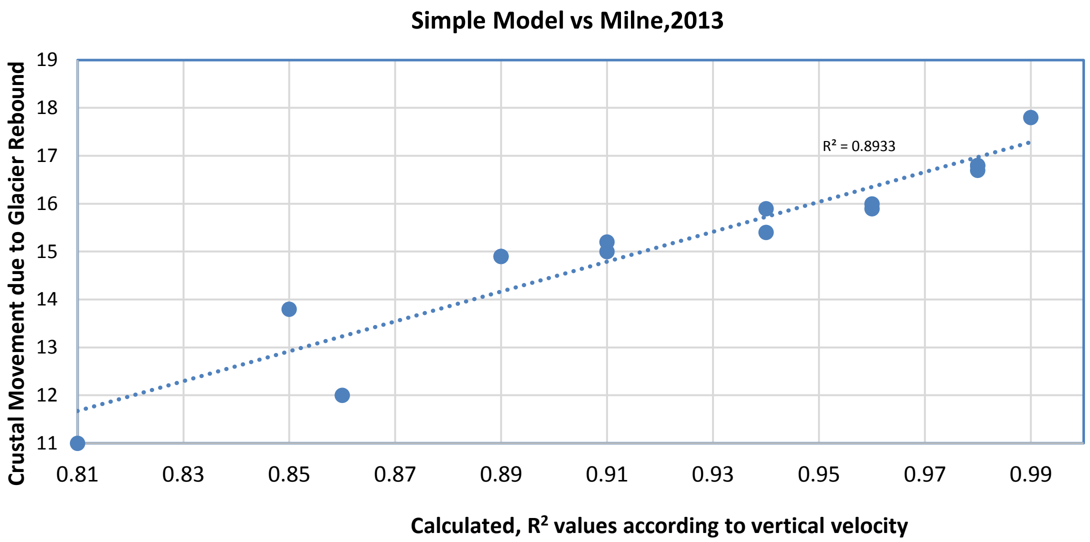


Figure 4. The map of the post glacial rebound rates and R^2 values obtained by kriging method (Milne, 2013).



Site	AIRA	ALRT	BAKE	CHUR	HOFN	NYAL	PALM	PETS	QIKI	RESO	SCOR	THU2	TRO1	NAIN	ONSA
R2	0.81	0.94	0.98	0.99	0.98	0.98	0.94	0.89	0.91	0.96	0.85	0.96	0.89	0.91	0.86
glacial	11	15.9	16.8	17.8	16.8	16.7	15.4	14.9	15	16	13.8	15.9	14.9	15.2	12

Figure 5. Map created by Milne 2013 with using GIA models (prepared by author).

The model proved that the IGS stations which have high R^2 values for velocity component was compatible with post glacial rebound in the study of Milne. It was calculated that the similarity of maps was close to 88%. This result showed that it is possible to detect and investigate glacial effects in any region on the Earth with monitoring only vertical speed.

Despite glacial movements modeling is popular subject among researchers, the glacial withdrawal effect cannot be easily predicted still. As it is well known, the basic approach of modeling is that the simple model is the best model. We can evaluate the model of the study as the best one, as it gives a chance to researchers to follow the post glacial rebound effect in a short period of time with low cost.

There is a need to carry out further comprehensive studies on the measurement of post glacial rebound effects such as vertical crustal motion, global sea levels which are substantial terms of any study. Acknowledgement

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Buzul Geri Çekilme Etkisinin Düşey Hız Analiz Metodu ile Tahmin Edilmesi

Dünya sürekli hareket halindedir ve üzerinde oluşan fiziksel olaylar yavaşça değişim göstermektedir. En son buzul çağında Dünya'nın bazı kısımlarında oluşan milyon tonluk buzul tabakaları buzulların altındaki toprakları yarım kilometreye kadar iterken buzul çevresindeki toprakların da birkaç yüz metre yükselmelerine neden olmaktadır. Buz tabakalarının erimesiyle oluşan su okyanuslara akarak deniz seviyesini yükseltmekte, bunun neticesinde buzul geri çekilme etkisi olarak adlandırılan olay oluşmakta, buzun altındaki topraklar tekrar yükselmektedir. Kuzey Yarımküredeki büyük buzul tabakaları uzun zaman önce erimelerine rağmen, yerkürenin bu olaya tepkisi, bugün bile devam etmekte,. Kuzey Amerika'da da bu etki net bir şekilde gözlemlenmektedir. Özellikle, Amerika Birleşik Devletleri'nin doğu kıyısı ve Büyük Göller bölgesinde buzul etkisi ile kabaran topraklarda, çökme hareketinin devam ettiği net bir şekilde tespit edilmiştir.

Buzul İzostatik Dengeleme (Glacial Isostatic Adjustment-GIA) yeryüzü yerçekim alanının ve okyanusların buzul tabakalarının büyümesine ve erimesine verdiği tepkiyi ifade etmektedir. GIA'nın yaygın olarak incelenen bileşeni, buzul erimesini takiben arazi yüzeyinin tekrar yükselerek eski seviyesine gelmesi ile ilgili olan "buzul sonrası geri çekilme" dir. Nispeten hızlı bir süreç olan GIA, okyanus seviyesinde 100 m lik değişimleri ve yeryüzünün deformasyonunu tetiklemektedir.

Buzul geri çekilme etkisinin izlenmesi için kullanılan birçok model literatürde yer almaktadır. Bu modellerin etkin çalışabilmesi için birçok veriye ve tepkinin net bir şekilde ölçülebilmesi içinde buzul etkisinin gözlemlenebileceği yerlere istasyon kurulma ihtiyacı bulunmaktadır. Söz konusu ihtiyaçların giderilmesi ise uzun bir zaman dilimi ve fazla mali kaynak harcanmasını gerektirdiğinden, bu modellerin her zaman kullanılması mümkün olamamaktadır. Mevcut durumda GIA etkisini izleyen istasyonlar sadece buzul hareketleri belirlenen noktalarda kurulduğundan, modeller farklı noktalarda buzul etkisinin olup olmadığı konusunda net bir sonuç verememektedir. Ayrıca modellerde bazı hususlar tam olarak ortaya konamamaktadır. Örnek vermek gerekirse, yatay Küresel Konum Belirleme Sistemi (KKS) hızları düşey hızlardan daha hassastır fakat GIA modelinin hız çıktıları ile karşılaştırıldığında GIA'nın hesaplanabilmesi için plaka hareketinin çıkartılması gerekmektedir. Ayrıca ne plaka hareketi ne de GIA tam olarak hesaplanamadığından kavranması güç bir durum olarak da karşımıza çıkmaktadır.

Global Navigasyon Uydu Sistemi (GNSS), nokta koordinatlarındaki değişim miktarının belirlenmesi, gerilimin tespit edilmesi ve tektonik hareketlere bağlı yüzey yer değiştirmesinin hesaplanmasındayaygın olarak kullanılmaktadır. Araştırma yapılacak alanda her zaman istasyon kurulması imkanı olmadığından Sabit Küresel Konumlama Sistemi (GPS) ile belli aralıklarla gerçekleşen kampanya ölçümleri, etkili bir araç olarak kullanılmaktadır. Bununla birlikte, GPS kampanyalarının değerlendirilmesiyle elde edilen hız vektörleri sayesinde yersel aktiviteler konusunda da bilgi elde edilebilmektedir.

Bu modellerin gereksinim duyduğu veri ihtiyacının minimize edilmesi, basit yöntemler ve minimum maliyetle buzul etkilerinin izlenmesi amacıyla bu çalışma ortaya konulmuştur. Bu çalışmada, seçilen örnek izleme noktaları sayesinde minimum veri ile buzul etkisinin ortaya çıkma ihtimalinin yüksek olduğu noktalar düşey hız analiz yöntemiyle modellenebilmektedir. Çalışmamızda, buzul geri çekilme etkisinden kaynaklı kabuk yükselişinin GPS kampanya ve ölçüm değerlendirme yöntemleri yardımıyla tahmini hedeflenmiştir. Örnek izleme noktalarının seçilmesinde Uluslararası GNNS Servisinden (*International GNNS Service for Geodynamics, IGS*) faydalanılmıştır. 1995-2017 yılları arasında yirmi iki yıllık zaman diliminde yirmi dört saat oturum süreli 34 adet IGS istasyonunun GPS düşey bileşenine ait zaman serisi verileri kullanılmıştır. Jet Propulsion Laboratory (JPL) tarafından değerlendirilerek GIPSYX yazılımı ile analizi yapılan ve yayımlanan bahse konu zaman serileri Hassas Nokta Konumlandırma (PPP) yöntemiyle elde edilmiştir. . Düşey hız öngörümünde: Yıllık doğrusal eğilim ve mevsimsel periyodik etkiler de hesaba katılarak "Çoklu Lineer Regresyon Analizi" ve "En Küçük Kareler" (EKK) yöntemi kulanılmış, değerlendirme ise MATLAB R2013a programı ile gerçekleştirilmiştir. IGS istasyonlarına ait R^2 değerlerinin zaman içinde sabit bir eğilim göstermesi, başka bir deyişle "doğrusal eğim bileşeni", buzul sonrası geri çekilmeden kaynaklı kabuk yükselişi arasındaki korelasyonun ortaya konması açısından önem arz etmektedir. Bu nedenle EKK yöntemi ile R^2 değerleri hesaplanmıştır. Sonrasında ise ArcGIS programı ile jeoistatistik teknik olan "sıradan kriging" ile mekânsal ara kestirim yapılarak R^2 değerlerinin yeryuvarı üzerindeki konumsal gösterimi elde edilmiştir. Elde edilen harita, Milen tarafından oluşturulan GIA modeli sonucunda elde edilen harita ile kıyaslanmıştır.

Ortaya konulan modelde R^2 değerlerinin yüzde 80 ve üzerinde olduğu bölgelerde, başka bir deyişle hızın sürekli olarak arttığı istasyonlarda, buzul geri çekilme ile R^2 değerlerinin %88 oranında uyumlu olduğu görülmektedir. Bu da sadece düşey hız izlenmesi ile dünya üzerindeki herhangi bir bölgede buzul etkileri tespit etmemize ve araştırmamıza imkan verecektir.

Buzul hareketleri modellemeleri çalışmaları yaygın olarak yapılmasına rağmen buzul çekilmesinin etkisi hala kolay bir şekilde hesaplanamamaktadır. Modelleme çalışmalarında temel kural en az veri ile en doğru sonuca yaklaştıracak modeli kurmak olduğundan, çalışmamızla elde ettiğimiz basit model ile araştırmacılar buzul sonrası geri tepme etkisini kısa sürede ve düşük maliyetle takip etmeleri mümkün olabilecektir. Düşey kabuk hareketi, manto taşınımı ve plaka tektoniği çalışmaları için önemli olan küresel deniz seviyeleri gibi buzul sonrası toparlanma etkilerini ölçmek içinse daha kapsamlı çalışmalar yapılması gerekmektedir.

Case Study

Testing of Water Quality Model SISMOD in Alaşehir Creek Sub-basin

Su Kalitesi Modeli SISMOD'un Alaşehir Çayı Alt Havzasında Test Edilmesi

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Abstract

In this study, Simple Stream Water Quality Model (SISMOD), which was developed in Turkey at 2010, was tested for Alaşehir Creek Sub-basin. SISMOD Model is a steady state and one dimensional water quality model. It is simple to develop water quality model on the basin scale and results of the model are useful for the water quality management strategies. The model was run for four periods (November, February, May and August) and for Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Organic Nitrogen (Org-N), Ammonium Nitrogen (NH_4N) & Nitrate Nitrogen (NO_3N) parameters. Alaşehir Creek Sub-basin has water quality and amount problems because of negative effects of anthropogenic activities and climate change. Diffuse loads and point loads were also included as an input in the model. Within scope of the study, calibration and validation studies were manually held on November and February terms respectively. Calibration and validation results were evaluated with using Root Mean Square Error (RMSE), Percentages of Error (pBIAS) and Mean Absolute Error (MAE) Methods that are statistical indices widely used for the water quality model performance evaluation. The developed model was utilized for creating two different scenarios in order to improve water quality of study area. The water quality of the study area was evaluated according to Annex 5 of By-law on Surface Water Quality (OG: 30.11.2012/28483). As a result of this study, SISMOD, a new and simple water quality model, could be used for having limited time and available data for any water area.
Keywords : *Water quality, SISMOD, Simple Stream Water Quality Model, Gediz Basin, Alaşehir Creek*

Öz

Bu çalışmada 2010 yılında Türkiye'de geliştirilmiş ve akarsulara uygulanabilir BaSİt AkarSu MODelleme Programı (SİSMOD) Alaşehir Çayı Alt Havzası için test edilmiştir. SISMOD modeli, kararlı bir durum ve tek boyutlu bir su kalitesi modelidir. Modelin havza ölçeğinde kurulması kolaydır ve model sonuçları su kalitesi yönetimi stratejilerinin belirlenmesinde büyük fayda sağlamaktadır. Model 4 dönem (Kasım, Şubat, Mayıs ve Ağustos) ve Çözünmüş Oksijen (ÇO), Biyolojik Oksijen İhtiyacı (BOİ), Organik Azot (Org-N), Amonyum Azotu (NH_4N) ve Nitrat Azotu (NO_3-N) parametreleri için çalıştırılmıştır. Alaşehir Çayı Alt Havzasında, antropojenik faaliyetler ve iklim değişikliği etkileri nedeniyle su kalitesinde ve miktarında problemler yaşanmaktadır. Yayılı ve noktasal yüklere ilişkin veriler de modele girdi olarak dâhil edilmiştir. Çalışma kapsamında, kalibrasyon ve validasyon manuel olarak gerçekleştirilmiş olup sırasıyla Kasım ve Şubat dönemlerindeki veriler kullanılmıştır. Kalibrasyon ve validasyon sonuçlarının performansı, su kalitesi modeli performans değerlendirmesinde yaygın olarak kullanılan istatistiksel indekslerden Ortalama Karesel Hatanın Karekökü (RMSE), Yüzdesel Hata (pBIAS) ve Ortalama Mutlak Hata (MAE) yöntemleri kullanılmıştır. Su kalitesini iyileştirmek için iki farklı senaryo analizi çalışılmıştır. Çalışma alanının su kalitesi Yerüstü Suyu Kalitesi Yönetmeliği Ek-5'e (RG: 30.11.2012 / 28483) göre değerlendirilmiştir. Bu çalışmanın sonucunda, kısıtlı zamanın ve temin edilebilir verinin olduğu durumlarda yeni ve basit bir su kalitesi modeli olan SISMOD'un kullanılması önerilmektedir.
Anahtar kelimeler: *Su kalitesi, SISMOD, Basit Akarsu Modeli, Gediz Havzası, Alaşehir Çayı*

Introduction

The components of the systems, variables that determine the behavior of these components and the responses of the system to the changes in those variables should be determined by utilization of the integrated basin management approach. In order to prepare river basin management plans effectively, it is necessary to know the temporal and spatial distributions of the predominant factors of pollution of water bodies. In addition, predictions are made for the future and the conceptual relationship between the systems that characterize the basin is revealed (Commission, 2000).

Water quality models are useful tools for identifying the ecological status of water resources and / or for estimating the recovery of the previous ecological state when certain boundary and initial conditions are changed (Lindenschmidt, 2006). River quality models seek to describe the spatial and temporal changes of constituents of concern. They characterize oxygen household, nutrients and eutrophication, toxic materials, and so on (Board and Council, 2000).

River water quality modelling has a long history beginning from 1925 with Streeter and Phelps. Streeter and Phelps described the bacterial decomposition of organic carbon characterized by biochemical oxygen demand (BOD) and its impact on dissolved oxygen conditions (Nas & Nas, 2009). Since then, countries have put on the market their water quality modeling software. Those developed software disseminated in other countries, which also provides models to be tested in a spread wide with numerous practices.

One of these models is Aquatool which is a decision support system comprised from modules such as EVALHID (water quantity module), SIMGES (water allocation module), GESCAL (water quality module) developed in Spain. Aquatool model performance was checked for Jucar River Basin in the east of Spain. The goal of the model is to estimate the effect of increasing the efficiency of several wastewater treatment plants on the water quality of the river. Water quality module was set up for following parameters; conductivity, suspended solids, cBOD, dissolved oxygen, ammonium and nitrates. Sensitivity analysis was performed individually for all the elements, and for all the calibrated coefficients. Finally, verification was carried out to test the behavior of all elements working together. Afterwards, water treatment possibilities, and other actions to improve the water quality in the lower part of the river. It has been estimated that dissolved oxygen, suspended solids and ammonium concentrations will improve respectively from 3.5 to 7.6 mg/l; from 28 to 9 mg/l and from 1.81 to 0.12 mg/l on average (Paredes-Arquiola et al., 2010).

WASP (Water Quality Analysis Simulation Program) which was developed by U.S. Environmental Protection Agency was tested for Altamaha River in Georgia. WASP is a model that calculates hydrodynamic and water quality with the options of one, two, and three-dimensional representation of a system through both vertical and horizontal segmentation. The model was calibrated and validated with data obtained from another project in the river. Average error between model predicted and observed concentrations was 39.8 % for ammonia (NH_3), 23.6 % for NO_3-N, and 7.8 % for dissolved organic nitrogen (DON). Calibration results showed that predicted DN concentrations were the highest for high DN input, high flows, and low and medium temperatures (Kaufman, 2011).

In Kenya Ndarugu River's water quality, to which untreated industrial, domestic and agricultural wastes from coffee and tea factories are discharged, was predicted with QUAL2K. Model was calibrated and validated for flow discharge (Q), temperature (T˚), flow velocity (V), BOD_5, DO and NO_3-N parameters. According to results of this study, QUAL2K gives quite accurate results according to field data. Even though there are some minor differences between measured and estimated data, model can be used where financial resources for monitoring are limited (Hadgu et al., 2014).

SISMOD is another water quality model, which was developed in Turkey at 2010 by Assoc. Prof. Ali ERTÜRK. It should be tested for the basin scale and results should be controlled whether it reflects the field data in a statistically acceptable manner.

Therefore, in this study SISMOD model performance was evaluated for river waters of Alaşehir Creek Sub-basin which is an important component of Gediz Basin. Alaşehir Creek Sub-basin has water quality problems in recent years because of uncontrolled discharges of domestic and industrial wastewaters and diffuse loads. SISMOD model results were evaluated with statistical indices to check the errors between measured and simulated data were in acceptable intervals. RMSE, pBIAS and MAE methods were used in this study.

Although many error indices are used for surface water quality models, RMSE and MAE provide easier interpretation of the result due to the results of those indices are in the same unit of the calculated values. RMSE and MAE are close to zero, it means perfect fitting. PBIAS controls the tendency of the simulation results to be greater or less than the results of the observation. The PBIAS value is expected to be zero when it is best matched.

Subsequently, developed model was then used to search two different improvement scenarios so as to improve water quality. Within scope of Scenario 1; Alaşehir, Piyadeler, Kavaklıdere, Kemaliye, Derbent, Avşar, Büyükbelen, Urganlı and Turgutlu Districts' wastewater treatment plants were assumed to be constructed & operated with a 50% decrease in diffuse load concentrations. Whereas advanced treatment process for industrial wastewater, domestic wastewater treatment plants for all direct discharging districts given in Table 3 and 70% decrease for diffuse loads were assumed in Scenario 2. Scenario analysis results were evaluated by classifying according to By-law on Surface Water Quality Annex 5 (OG: 30.11.2012/28483).

Method

Study Area

Gediz Basin is located in the Aegean region, western of Turkey with Gediz River and its branches discharges through the Aegean Sea. North Aegean, covers the area between Susurluk and Küçük Menderes Basin. The basin covers 1,703,394 hectares, which is 2.17 % of the total surface area of Turkey. Alaşehir Creek Sub-basin is located in the south-southeast extension of the Gediz Basin. It covers mainly Alaşehir Creek through the downstream of the basin Alaşehir Creek merges to the Gediz River. Alaşehir Creek and Gediz River, located at the downstream of the Demirkopru Dam, were considered as the main river branch within the scope of this study. Sarıgöl, Alaşehir, Salihli, Ahmetli and Turgutlu districts are within the borders of the basin. The map and google earth view of the study area are shown in Figure 1.

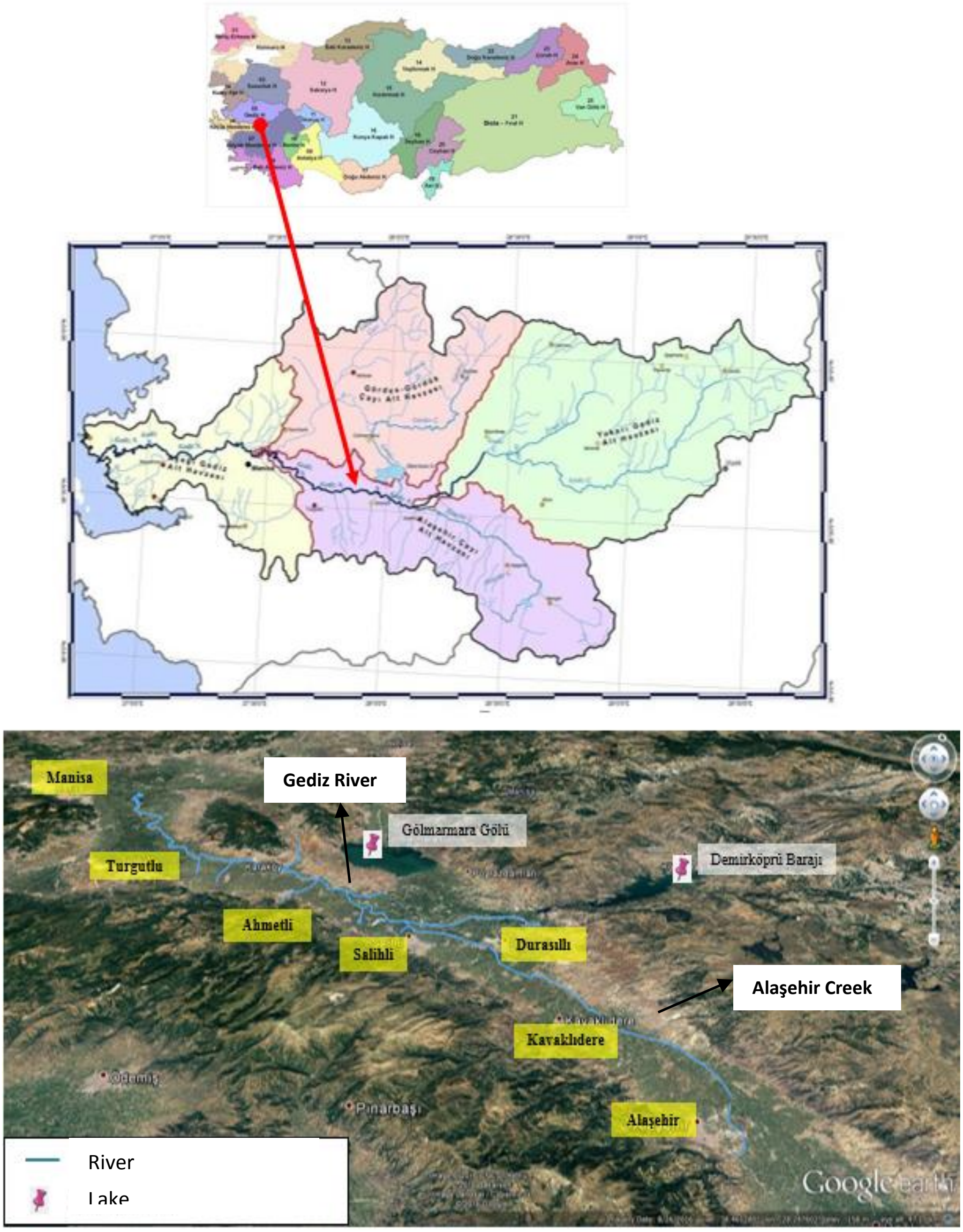

Figure 1. Side view of Alaşehir Creek Sub-basin.

According to four stations data of the years of 2014, 2015 and 2016 obtained from the General Directorate of Meteorology, monthly average temperature (^{o}C) and precipitation values (mm) are given in Table 1 and Table 2. According to results, the highest temperature in the sub-basin is measured as 28.78 ^{o}C in August and the lowest temperature is measured as 3.11 ^{o}C in December. The highest precipitation is measured as 5.44 mm in December as well.

Table 1

Monthly Average of the Temperature (°C) for the Alaşehir Creek Sub-basin

Station Name	Years/ Months	1	2	3	4	5	6	7	8	9	10	11	12
Ahmetli Station	2014	8.43	8.44	10.96	15.77	19.76	23.29	27.15	28.14	22.37	16.98	11.45	9.55
	2015	6.00	7.49	10.31	13.09	20.92	22.72	27.12	27.20	24.37	17.49	11.84	3.85
	2016	6.01	11.29	11.88	17.81	19.34	26.08	27.50	27.83	22.59	16.59	10.49	3.38
Alaşehir Station	2014	9.04	8.99	11.49	16.30	20.09	23.60	27.63	27.99	22.37	16.98	11.44	9.97
	2015	6.24	7.82	10.23	13.28	21.13	22.19	27.38	27.30	24.27	17.27	11.91	3.94
	2016	6.05	11.73	11.93	18.45	19.22	26.32	27.65	26.70	22.08	16.38	10.48	3.11
Turgutlu Station	2014	8.38	8.46	10.97	15.54	19.63	22.89	26.13	26.57	21.93	17.06	11.21	9.60
	2015	3.89	6.93	10.25	13.15	20.39	22.41	25.98	26.51	23.87	17.20	11.96	3.94
	2016	6.15	11.49	11.01	17.75	19.62	25.98	27.15	27.89	22.43	16.52	10.79	3.63
Salihli Station	2014	9.46	9.47	11.77	16.58	20.54	24.51	28.33	28.78	23.24	17.87	12.10	10.22
	2015	6.45	7.96	10.70	13.95	21.37	23.17	28.37	28.52	25.75	18.65	13.50	5.53
	2016	6.65	12.34	12.41	19.09	20.28	27.53	28.66	28.42	23.74	17.99	11.80	4.34

Table 2

Monthly Average of the Precipitation (mm) for the Alaşehir Creek Sub-basin

Station Name	Years/ Months	1	2	3	4	5	6	7	8	9	10	11	12
Salihli Station	2014	0.94	0.66	0.94	1.69	0.64	1.99	0.00	0.07	1.01	0.62	0.85	4.79
	2015	3.79	2.79	1.53	1.38	1.35	1.44	0.14	0.60	0.39	0.79	1.50	0.03
	2016	4.07	0.99	3.20	0.03	0.78	0.00	0.00	0.64	0.89	0.20	3.08	0.70
Ahmetli Station	2014	0.02	0.00	0.94	2.39	0.91	1.33	0.00	0.00	0.35	0.68	0.79	5.44
	2015	3.40	2.44	1.69	1.08	1.33	2.62	0.01	0.34	0.40	0.81	1.48	0.02
	2016	4.48	1.40	3.17	0.11	0.95	0.22	0.05	0.58	0.41	0.05	2.58	0.68

Land use percentages of Alaşehir Creek Sub-basin is given in Figure 2. As seen from the graph, 62% of the basin areas are used for agricultural purposes. This enormous value of percentage reasons to high diffuse pollution of the basins' river waters.

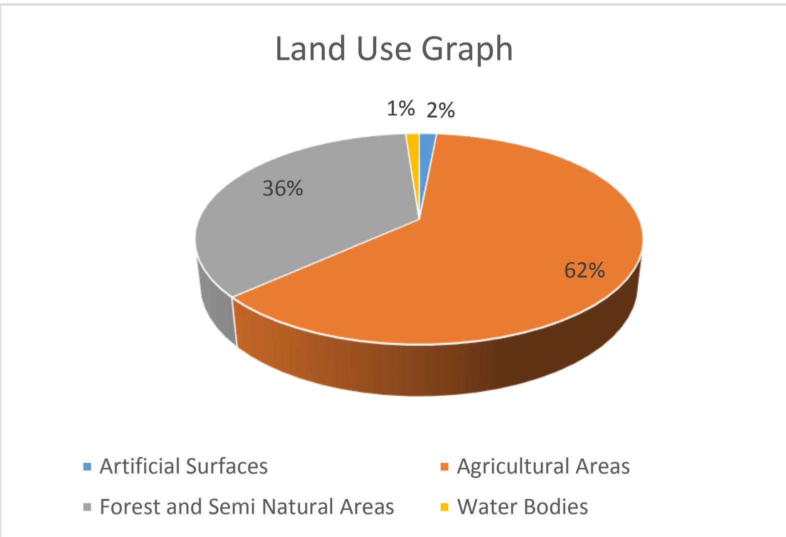

Figure 2. Alaşehir Creek Sub-basin land use percentages

Furthermore, the basin is also under a point source pressure originates from industries and domestic wastewater. Some of its districts such as Alaşehir, Ahmetli, Durasıllı and Salihli have an already operating urban wastewater treatment plants. However, Alaşehir Wastewater Treatment Plant's capacity and technology is not satisfactory. One of the most important pressure is direct discharge of Turgutlu district's wastewater. Other districts discharge their wastewater to the Alaşehir Creek and its tributaries (Table 3).

Table 3

Districts in the Model Study Area and Their Discharge Type

District/Village Names	Discharge Type	District/Village Names	Discharge Type
Alaşehir District	Urban WWTP	Saruhanlı District*	-
Kavaklıdere	Direct Discharge	Büyükbelen	Direct Discharge
Kemaliye	Direct Discharge	Gümülceli	Direct Discharge
Piyadeler	Direct Discharge	Koldere	Direct Discharge
Salihli District	Urban WWTP	Selendi District*	-
Durasıllı	Urban WWTP	Hacıhalliler	Direct Discharge
Sart	Direct Discharge		
Taytan	Direct Discharge		
Yılmaz	Direct Discharge		
Ahmetli District	Urban WWTP	Sarıgöl District	Direct Discharge
Turgutlu District	Direct Discharge		
Avşar	Direct Discharge		
Derbent	Direct Discharge		
Urganlı	Direct Discharge		

*Note.** District centers are not located in the study area

The other important pressure in the basin is industrial discharges. Especially in Salihli and Alaşehir districts, industrial activities are seen intensively. There is an organized industrial zone in Salihli which has its own WWTP. There are olive oil production facilities and raisin mills in the basin. Olive oil production facilities in the basin operates in November, December and January months by using 3 phase olive oil extraction process. This type of production process reasons also production of wastewater. In addition, there aren't any landfills through the basin; all solid wastes are being dumped.

SISMOD

SISMOD divides the system into river reaches. A new reach should be created for each point load. There are three types of streams in the SISMOD model network. These are defined as the headwater reach, the standard reach and the downstream reach. Many initial sections can be defined in a model network. The downstream reach is the reach where the model network ends and the entire flow is exited. A model network can have only one downstream reach.

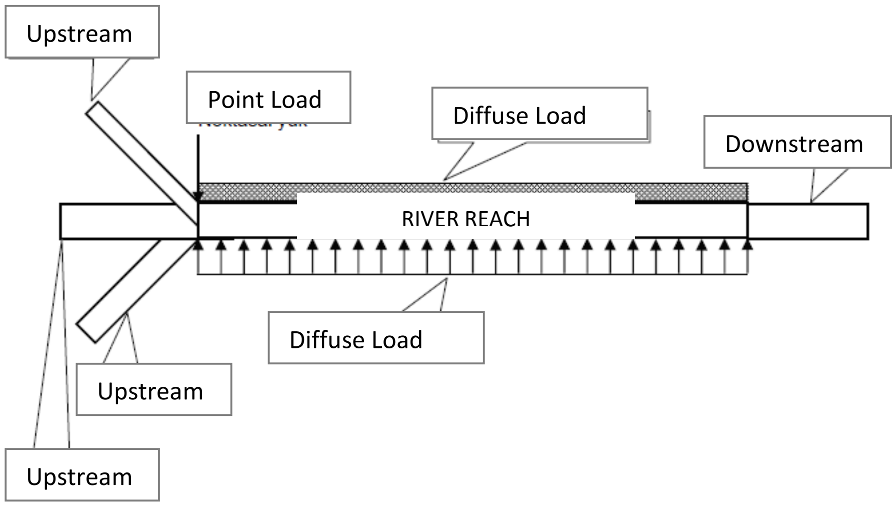

Figure 3. River reaches and components.

Hydraulic calculations are carried out according to the assumptions that the flow in the river is steady and uniform. SISMOD includes a hydraulic module that calculates according to local uniform flow assumption for steady state flows. Hydraulic calculations can be made for triangular, rectangular, trapezoidal and irregular cross sections. Water quality module have the ability to calculate parameters of DO, BOD, OrgN, NH_4N, NO_3N, Organic Phosphorus (Org P) and Phosphate (PO_4P). Water quality calculation are made by taking into account the oxygen level. Suitable equations according to aerobic and anaerobic conditions can be used.

However as all water quality models, SISMOD have some limitations as well. Since it is a simple model, it does not contain unsteady state flow conditions and assumes that uniform flow conditions are valid for the water bodies. The homogeneity of the stream along the cross-section also determines the complexity of the model to be used. If the cross-section of the stream does not change significantly, the assumption of uniform flow will not increase the error (Martin & McCutcheon, 2018).

Another limitation is that model simulates substance transport by taking into account only advection by ignoring the effect of dispersion. According to literature dispersion effect can be neglected in rivers where the pollution load is consistent. However, some regional conditions may occur in some large rivers where the velocity decreases and the dispersion in the pollutant transport is prominent. This is usually occurs at the downstream of the rivers, where they approach to the transitional water bodies. In these regions, the water velocity may decrease to zero. Therefore; In water environments, such as transitional waters where dispersion is important, modeling only by advection may not yield accurate results (Chaiwiwatworakul et al., 2005).

SISMOD's other important limitation is that nitrogen and phosphorus cycles are not connected to each other through primary productions as it happens in real systems. In a study done in Orinoco River Stream, because of turbidity, depth and relatively fast flowing conditions, less yield of phytoplankton production is observed such as 4-43 mg C m^{-2} day^{1} (Lewis, 1988).

Moreover, another study reveals that periphyton biomass increases with increasing water velocity until it reaches to a critical speed. The critical speed is between 20 cm/s and 50 cm/s. Periphyton biomass begins to diminish as a result of physical disintegration and periphyton displacement after reaching critical speed (Ahn et al., 2013).

Therefore it is seen that SISMOD model's technical characteristics are enough when compared to literature.

Conceptual Model

In order to evaluate basin's water quality in terms of DO, modelling parameters were selected as DO, BOD, Org N, NH_4N and NO_3N.

The features such as altitude, bottom slope, side slope and bottom width of the river bodies were used from the hydromorphological monitoring data conducted within the "Project on Basin Monitoring and Determination of Reference Areas" which is completed in 2013 by the Ministry of Forestry and Water Affairs (abolished in 2018). Due to the lack of up-to-date data, Google Earth satellite imagery of water bodies had also been used.

Spatial and point loads data were obtained from the "Project on Implementation of Total Maximum Daily Load (TMDL) Approach in Gediz Basin". For some industries, instead of performing measurements, similar sectors of industries' measurements were used. Point source discharges were also obtained from TMDL Project where taken from Environmental Permit License documents of industries provided by Provincial Directorates of Ministry of Environment and Urbanization.

Annually total diffuse loads were gathered from the "Project on Determination of Sensitive Areas of Basins and Water Quality Targets in Turkey" which was completed by the Ministry of Forestry and Water Affairs (abolished in 2018). Since study area water quality was monitored monthly, annually diffuse loads were distributed to monthly values by using base flow ratios belonging to each months. This calculation was held by the help of SWAT Baseflow Program using flow observation stations data of the General Directorate of State of Hydraulic Works (DSI).

Water quality data was measured for November, February, May and August months so that SISMOD was run for 4 periods. When the measured data was evaluated, in November period the downstream of the basin and in August period the upstream of the basin were dry. Model boundary area is shown in Figure 4. Totally, 246 km of water bodies were modeled and during modelling 61 reaches were segmented according to point source discharge and typological characteristics of water bodies.

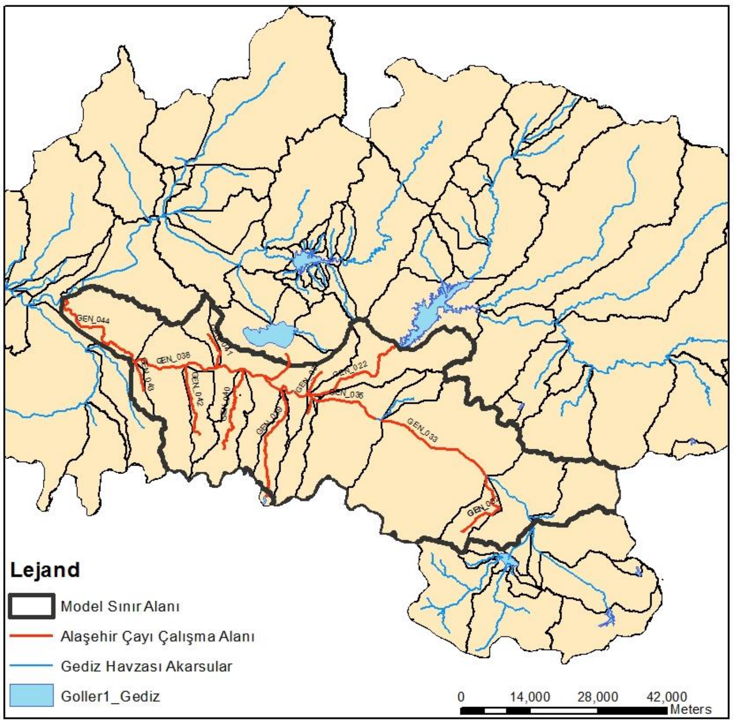

Figure 4. Model boundary area.

Water Quality Improvement Scenarios

After the conceptual model was constituted, water quality improvement scenarios were defined and scenario models were run for the study area. Two scenarios were studied. Scenario 1 focused on only already planned domestic wastewater treatment plants to be constructed & operated and diffuse pollution to be decreased by 50% assumptions. Scenario 2 focused on an advanced treatment process for industrial wastewater, constructing domestic wastewater treatment plants for all the districts discharging directly and 70% decrease in diffuse loads assumptions.

In Alaşehir, Piyadeler, Kavaklıdere, Kemaliye, Derbent, Avşar, Büyükbelen, Urganlı and Turgutlu Districts wastewater treatment plants are being planned or constructed. In scenario analysis only Alaşehir and Turgutlu WWTPs were planned as extended aeration activated sludge system and the remainings were planned as a conventional activated sludge process.

Results & Discussion

Calibration of the model was carried out manually and systematically. When the data of the 4 periods were examined, it was seen that the flow was at average values on May month. For this reason, its calibration was held at 4 different measurement points for the May period. Error evaluation indices as RMSE, pBIAS and MAE for each parameters are provided in Table 4.

According to model performance results for calibration period, DO parameters' RMSE and MAE values were 1.11 and 0.77 respectively. Since these values were closer to each other, it was understood that there was a little difference between mean errors and individual errors for DO parameter. This showed that the individual errors were in the average and there were no major deviations. RMSE and MAE values of BOD and TKN parameters had the similar results as DO parameter.

When the pBIAS results were evaluated, the most accurate result was obtained for BOD parameter with 13.88% error. Percentage of error for DO parameter was -23.24% and for TKN parameter -20.78%.

Table 4
Evaluation of Calibration Period (May) Error for Water Quality Parameters

Parameter	**RMSE (mg/L)**	**PBIAS (%)**	**MAE (mg/L)**
DO	1.11	-23.24	0.77
BOD_5	5.62	13.88	3.71
TKN	4.73	-20.78	4.15

The model was validated for February period. RMSE, pBIAS and MAE for each parameters are given in Table 5. In the validation period, DO parameters' RMSE and MAE values were 1.96 and 1.45 respectively. RMSE and MAE results of BOD and TKN parameters were also close each other as in DO parameter. It was found out that there was a little difference between mean errors and individual errors such as calibration period.

According to pBIAS results, the most accurate result was calculated for BOD parameter as in calibration period. Percentage of error for DO and TKN parameter were respectively 19.62% and 24.90%.

Table 5
Evaluation of Validation Period (February) Error for Water Quality Parameters

Parameter	**RMSE (mg/L)**	**PBIAS (%)**	**MAE (mg/L)**
DO	1.96	19.62	1.45
BOD_5	1.65	-3.87	1.47
TKN	1.18	-24.90	1.12

The water quality has improved greatly during August, a dry period. This is the result of releasing water with high DO and low BOD concentrations from Demirköprü Dam and Marmara Lake to the study area from. When the graph of November period was examined, it was seen that BOD level increased to 60 mg/L in the main river branch which was also observed for NH4N and Org N parameters. This was obviously result of olive oil extraction industries process in November.

According to the model results, annual average values showed that 64%, 38% and 58% of water bodies were in IV. Class respectively for parameters of DO, BOD and TKN. Water bodies were in III. Class with 48% rate for BOD parameter. For TKN parameter, 38 % of water bodies were in III. Class.

Model results of DO, BOD and NH_4N parameter concentrations for the main river branch are given in Figure 5, Figure 6 and Figure 7 for November, February and August periods.

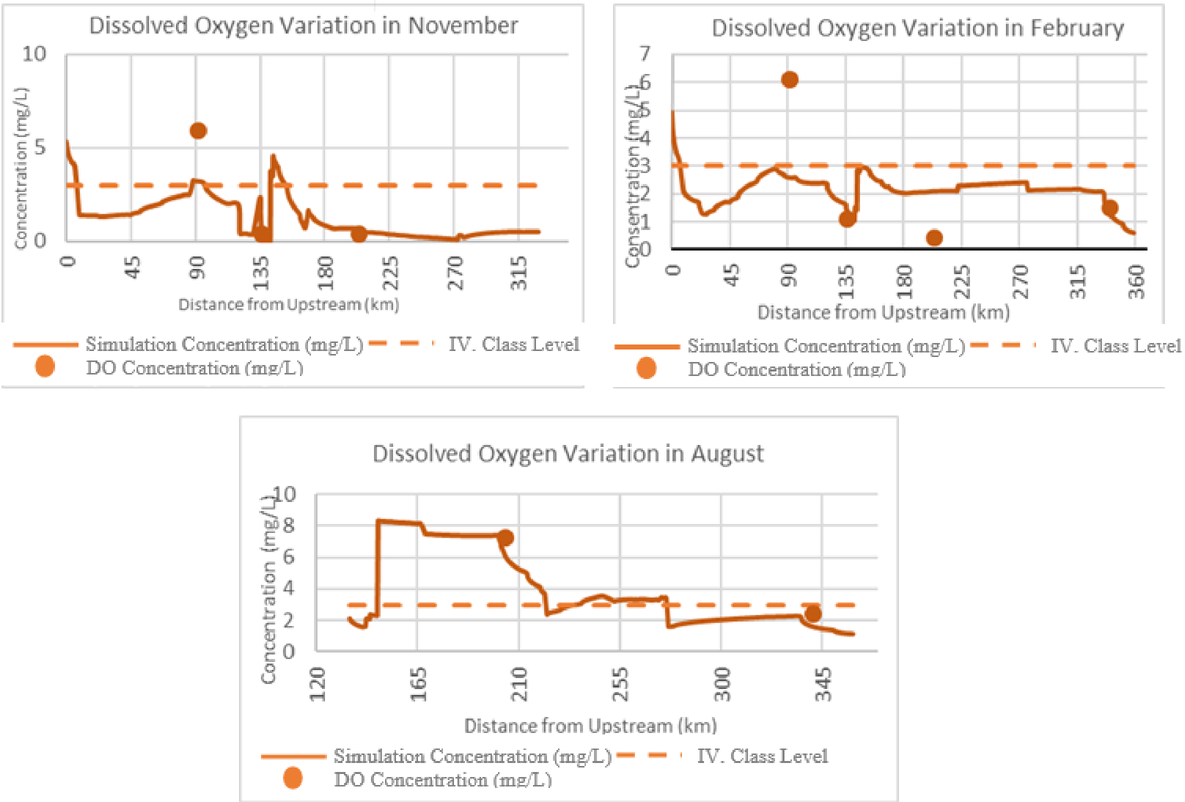

Figure 5. November, February and August Dissolved Oxygen Concentration through the main river branch.

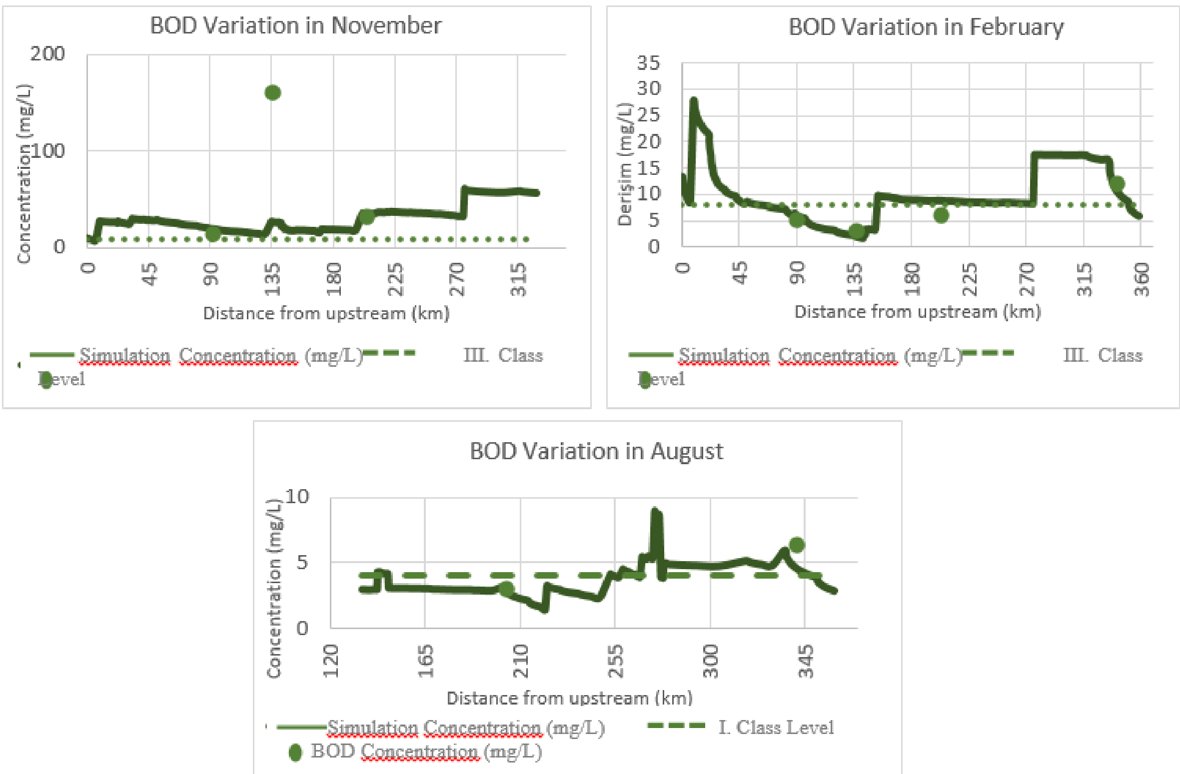

Figure 6. November, February and August BOD concentration through the main river branch

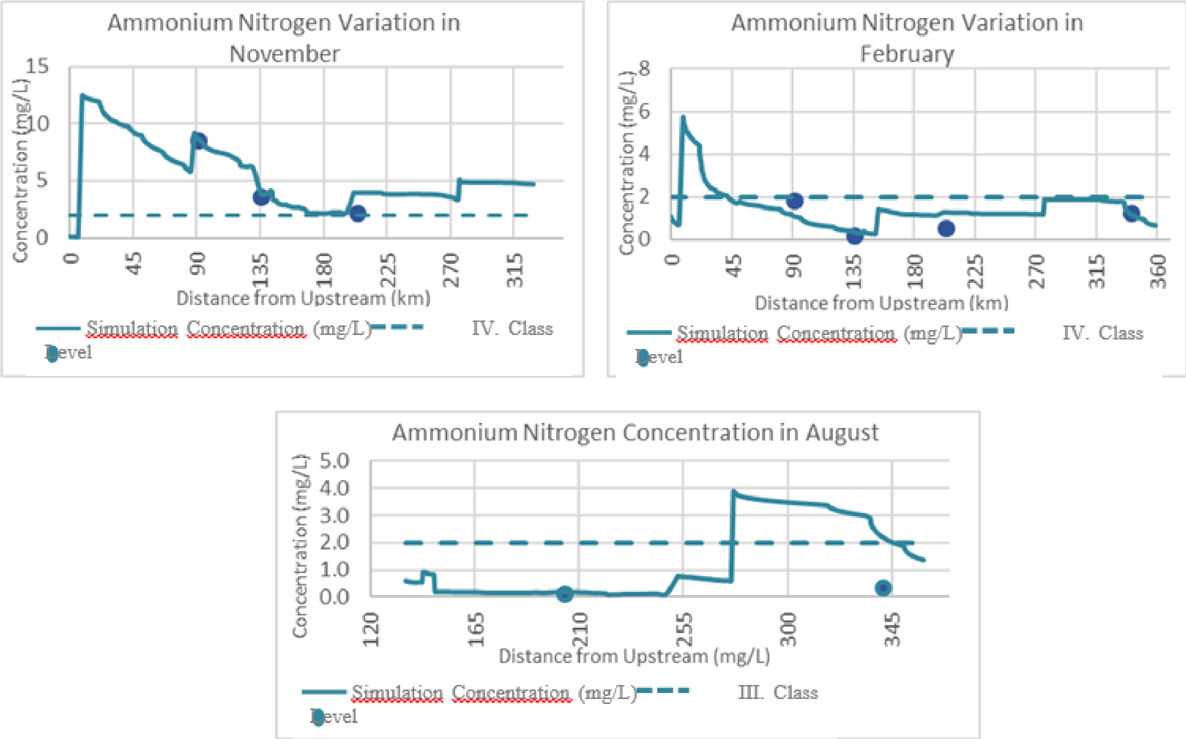

Figure 7. November, February and August NH4N Concentration through the main river branch.

Results of scenario analysis showed that the best improvement percentage was obtained for BOD parameter. Approximately 80% of water bodies were in I. Class according to Scenario 2 situation. TKN parameter results showed a less improvement since 86.56 % of water bodies

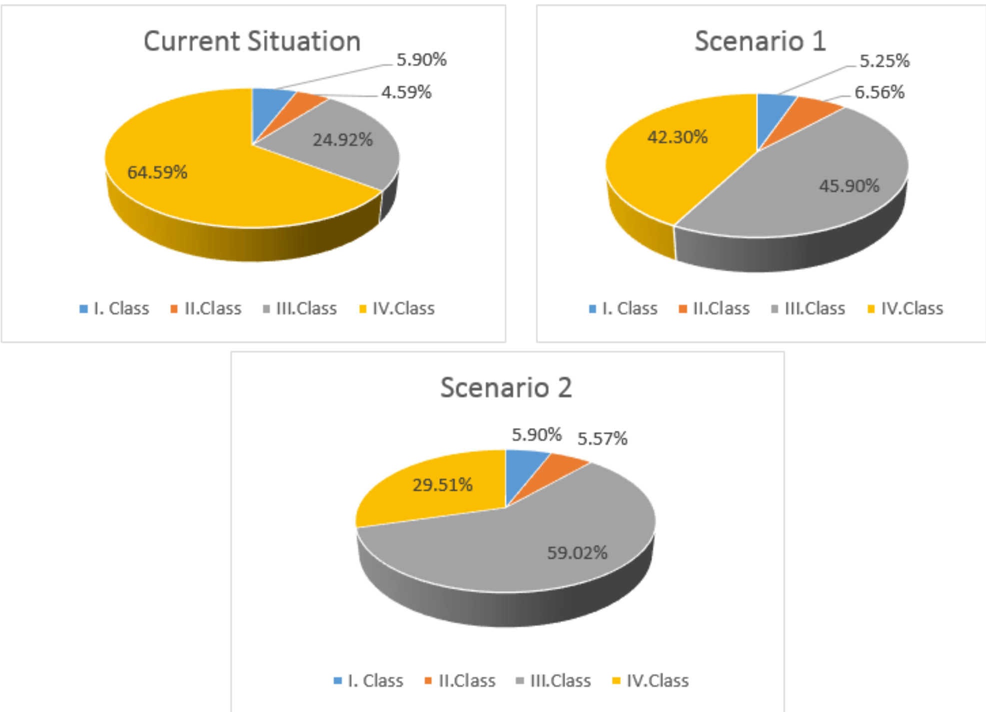

Figure 8. Water quality class percentages for DO parameter.

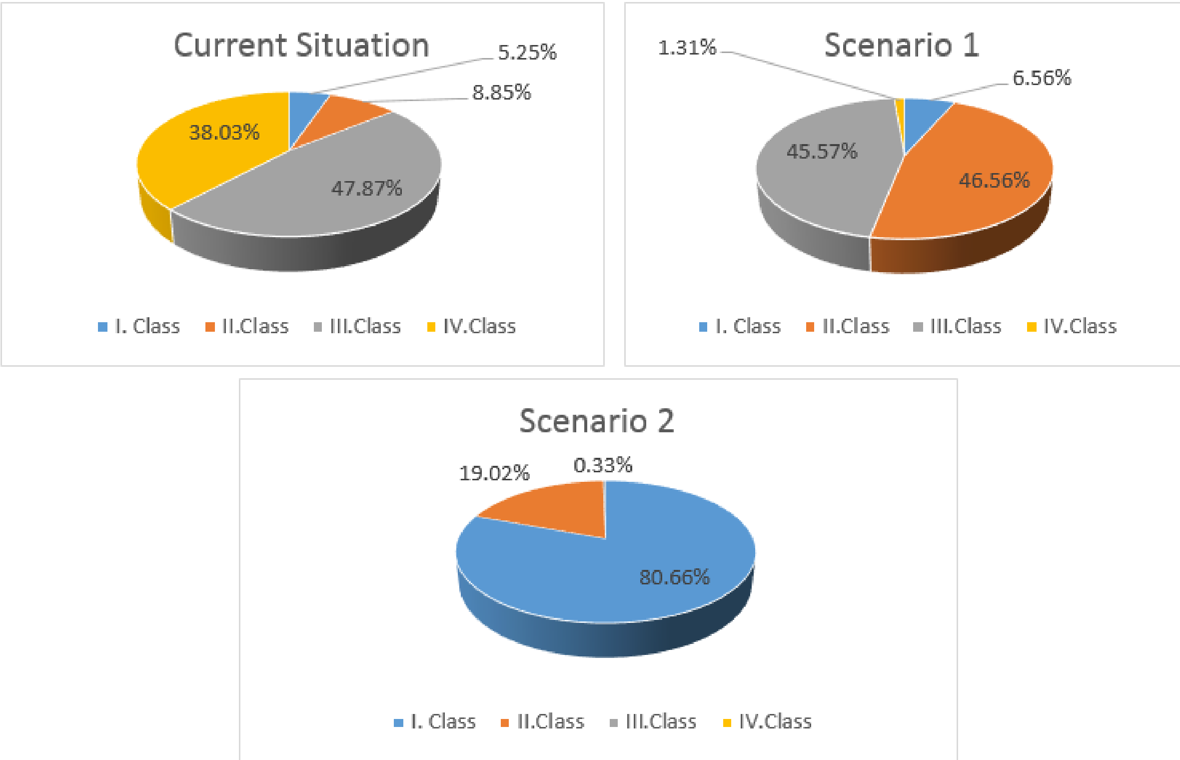

Figure 9. Water quality class percentages for BOD parameter.

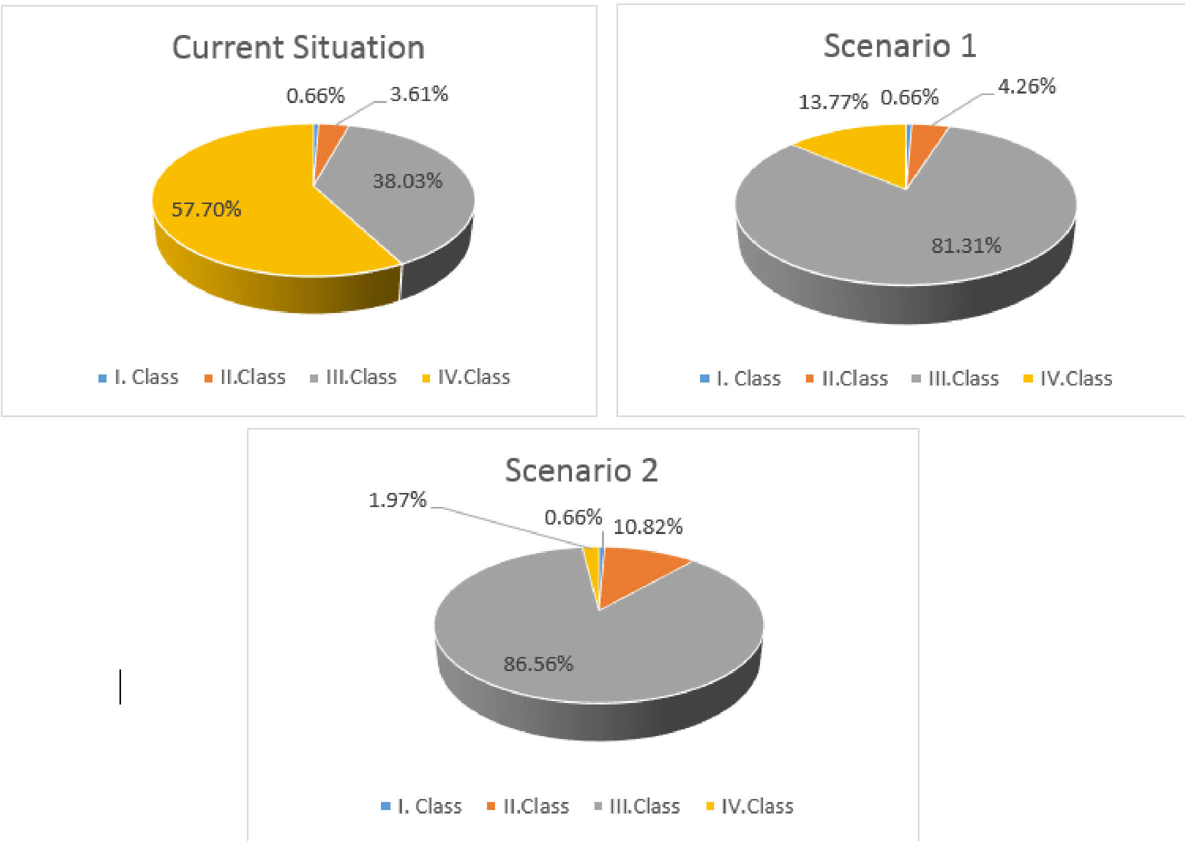

Figure 10. Water quality class percentages for TKN parameter.

Conclusion

Within this study the performance of SISMOD model, developed in Turkey, was tested to Alaşehir Creek Sub-basin of the Gediz Basin. Alaşehir Creek Sub-basin was not only under domestic and industrial pressures but also diffuse pollution especially arising from agricultural activities.

When the results of accuracy were examined, it was seen that estimated data reflected the measured data in an acceptable manner. SISMOD is an applicable model for the basin studies. The model gives the best results for BOD and DO parameters. For the nitrogen components, the model results are satisfactory but the model would give better results with a basin specific calculation of diffuse source input.

We tested SISMOD model for current situation than used it for two different scenarios. According to those results the best improvement ratios were obtained for BOD parameter. We found out that even though IV. Class water percentages decreased for all parameters, still water quality improvements were not enough for DO and TKN parameters. This shows us that not only local improvements but also some measurements should be taken in the upstream side of the study area. Once upstream basin's water quality improved, headwater concentrations will be lower and therefore improvements will be higher as expected.

For the future studies, it is recommended long term period monitoring of water quality and advance of the model with updated data. This will provide more accurate model results. Point sources concentrations were taken from similar sectors of industries' measurements. Especially industrial point sources' discharge concentrations should be measured for at discharge point. Thereby model results will reflect the field data more accurately. Furthermore this study was held with the diffuse source data obtained from "Project on Determination of Sensitive Areas of Basins and Water Quality Targets in Turkey" which was completed by the Ministry of Forestry and Water Affairs (abolished in 2018). Diffuse load data obtained from basin specific calculations used in literature with some assumptions will provide more accurate results for the nitrogen components.

Acknowledgement

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Su Kalitesi Modeli SİSMOD'un Alaşehir Çayı Alt Havzasında Test Edilmesi

Bu çalışmanın maksadı: Türkiye'de geliştirilmiş olan ve akarsulara uygulanabilen BaSİt AkarSu MODelleme Programı (SİSMOD) ile Alaşehir Çayı Alt Havzası için su kalitesi modeli kurularak, modelin performansının değerlendirilmesidir.

SİSMOD akım yönünde, tek boyutta, basit hidrolik ve su kalitesi hesapları yapabilen diğer yazılımlarla tümleşik olarak çalışabilecek şekilde tasarlanmış, kullanımı kolay bir su kalitesi modelleme yazılımıdır. Türkiye'de Doç. Dr. Ali ERTÜRK tarafından geliştirilen model (Sürümü 0.9.5) açık kaynak kodludur ve Fortran yazılım dilinde oluşturulmuştur.

Söz konusu modelin uygunluğunun değerlendirilebilmesi maksadıyla su kalitesini etkileyen süreçler araştırılarak, literatürde yer alan su kalitesi modelleri ve uygulamaları incelenmiştir. Su kalitesi modellemesi uygulamalarının performans değerlendirme kriterleri irdelenmiştir. SİSMOD modelinin havza bazında test edilmesi öncesinde yeteneklerinin yanı sıra bazı sınırlamalara da sahip olduğu görülmüştür. Söz konusu sınırlayıcı özelliklerin hangi durumlarda yanlış sonuçların çıkmasına sebep olacağı değerlendirilmiştir.

Sınırlayıcı özelliklerinden biri hidrolik hesapların, kararlı durum altında üniform akım kabulü ile yapılmasıdır. Ancak her bir hesap elemanında en kesit özelliklerine göre farklı hız ve derinlik hesabı yapmaktadır.

Bir diğer sınırlayıcı özelliği ise yalnızca adveksiyon ile madde taşınımının benzetimini yapmakta, dispersiyonun etkisini göz ardı etmesidir. Akarsularda dispersiyon prosesinin kirletici taşınımı açısından önemi adveksiyona oranla daha düşüktür. Dispersiyon etkisi kirlilik yükünün sürekli olduğu nehirlerde ihmal edilebilmektedir. Ancak bazı büyük nehirlerde hızın azaldığı ve kirletici taşınımında dispersiyonun öne çıktığı bazı bölgesel koşullar oluşabilmektedir. Bu genellikle nehirlerin mansabında, denize veya halice yaklaştığı yerlerde olmaktadır. Bu bölgelerde suyun hızı sıfıra kadar düşebilmektedir. Bu nedenle; dispersiyonun önemli olduğu, akarsuların denize ulaştığı geçiş suları gibi su ortamlarında yalnızca adveksiyon ile taşınıma göre modelleme yapmak doğru sonuçlar vermeyebilmektedir.

SİSMOD azot ve fosfor döngülerini gerçek sistemlerde olduğu gibi birbirlerine birincil üretim üzerinden bağlamamaktadır. Akarsularda; algler, yüksek bitkiler (makrofitler) ve bazı bakteriler ile tek hücreli canlılar birincil üreticilerdir. Akarsularda birincil üreticilerin varlığı, o akarsuyun hızına yani hidrolik bekleme süresine bağlıdır. Hızlı akan ve hidrolik bekleme süresi 3-7 günden daha az olan nehir suları için birincil üretim azot ve fosfor konsantrasyonuna etkisi ihmal edilebilir seviyede olmaktadır. Türkiye akarsuları genel olarak eğimin ve rakımın yüksek olması nedeni ile yüksek hızda akmaktadır ve hidrolik bekleme süresi kısalmaktadır. Bu süre ise birincil üreticilerin büyüme hızından düşük olduğu için birincil üretim ihmal edilebilir seviyededir.

SİSMOD'un test edilmesi için Alaşehir Çayı Alt Havzası seçilmiştir. Söz konusu havza Ege Bölgesinde Gediz Havzasında yer almaktadır. Alaşehir Çayı'nın tamamı ve Gediz Nehri'nin bir kısmı havza içerisinde kalmaktadır. Sarıgöl, Alaşehir, Salihli, Ahmetli ve Turgutlu ilçeleri havza sınırlarında yer almaktadır.

Gediz Havzası'nın önemli bir kolu olan Alaşehir Çayı Alt Havzası'nda yer alan akarsu kütlelerinin kalitesinin değerlendirilmesi maksadıyla çözünmüş oksijen (ÇO), biyokimyasal oksijen ihtiyacı (BOİ), amonyum azotu (NH_4-H), nitrat azotu (NO_3-N) ve organik azot (Org-N) değişkenleri SİSMOD ile modellenmiştir. Kasım, Şubat, Mayıs ve Ağustos dönemleri için kurulan model, Mayıs dönemi için kalibre edilmiş, diğer dönemlere de uygulanarak kurulan modelin doğrulaması yapılmıştır.

Kalibrasyon (Mayıs) ve validasyon (Şubat) performans değerlendirmesinde yaygın olarak kullanılan istatistiksel indekslerden Ortalama Karesel Hatanın Karekökü (RMSE), Yüzdesel Hata (pBIAS) ve Ortalama Mutlak Hata (MAE) yöntemleri kullanılmıştır.

Kalibrasyon performans sonuçlarına göre ÇO parametrelerinin RMSE ve MAE değerleri sırasıyla 1.11mg/L ve 0.77 mg/L'dir. Bu değerlerin birbirine yakın olması ÇO parametresi için bireysel hatalar ile ortalama hatalar arasındaki farkın az olduğunu göstermektedir. Bireysel hatalar ortalama değerlerde olmakta ve önemli sapmalar olmamaktadır. BOİ ve TKN parametrelerinin RMSE ve MAE değerleri de ÇO parametresi ile benzer

sonuçlara sahiptir. PBIAS sonuçları değerlendirildiğinde, en düşük hata oranı %13.88 ile BOİ parametresi için elde edilmiştir. ÇO parametresi için hata yüzdesi %-23.24 ve TKN parametresi için ise %-20.78'dir.

Validasyon performans sonuçlarına göre ise ÇO parametresi RMSE ve MAE değerleri sırası ile 1.96 mg/L ve 1.45 mg/L'dir. ÇO, BOİ ve TKN parametrelerinin RMSE ve MAE değerleri de birbirlerine yakın olup ortalama hatalar ve bireysel hatalar arasında küçük bir fark olduğu bulunmuştur. PBIAS sonuçlarına göre, kalibrasyon periyodunda olduğu gibi hata oranının en düşük olduğu parametre BOİ'dir. ÇO ve TKN parametresi için hata yüzdeleri sırasıyla % 19.62 ve % 24.90 olarak hesaplanmıştır.

Model sonuçlarına göre; çalışma alanındaki su kütleleri ilgili parametreler bazında 30.11.2012 tarihli ve 28483 sayılı Resmi Gazete'de yayımlanarak yürürlüğe giren Yerüstü Su Kalitesi Yönetmeliği Ek-5'de verilen su kalitesi sınıf kıstaslarına göre değerlendirilmiştir.

Mevcut durum sonuçlarına göre dört dönemin ortalama değerlerine bakıldığında ÇO, BOİ ve TKN parametrelerine göre sırası ile su kütlelerinin %64, %38 ve %58'i IV. Sınıf olmaktadır. BOİ parametresine göre su kütlelerinin %48'i III. Sınıf su kütlesidir. TKN parametresine göre ise III. Sınıf su kütleleri oranı %38 olmaktadır.

Su kalitesinin iyileştirilmesi maksadıyla iki tane senaryo modeli çalışılmıştır. Senaryo 1'de mevcut durumda planlaması yapılan atıksu arıtma tesislerinin kurulması ve yayılı kaynaklardan gelen yüklerin %50 oranında azaltılması varsayımı yapılmıştır. Senaryo 2'de ise endüstriyel atıksu arıtma tesislerinde ileri arıtmanın eklenmesi ve doğrudan deşarj edilen evsel atıkların tamamının arıtılması ile yayılı yüklerin %70 oranında azaltılması varsayımı yapılmıştır.

Senaryo modellerinin sonuçlarına göre ise alınan önlemler sonucunda en çok iyileşme BOİ parametresinde gözlemlenmiştir. Senaryo 1'e göre su kütlelerinin %6,56'sı I. Sınıf iken Senaryo 2'ye göre %80,66'sı I. Sınıf olmaktadır. ÇO parametresine göre ise Senaryo 2 ile su kütlelerinin %59,02'si III. Sınıf olup IV. Sınıf su kütlelerinin yüzdesi %64,59'dan Senaryo 2 ile %29,51'e düşmektedir. TKN parametresine göre ise IV. Sınıf su kütleleri yüzdesi %1,97'lere düşmekte olup III. Sınıf su kütleleri oranı %86,56 olmaktadır.

Çalışma sonucunda, kalibrasyon ve validasyon değerlendirme kıstasları kabul edilebilir düzeylerde olduğundan SISMOD modelinin havza bazında modelleme çalışmalarında kullanılabileceği ortaya konulmuştur. Bununla birlikte Alaşehir Çayı Alt Havzası su kalitesinin iyileştirilmesi maksadıyla yapılan Senaryo 1'e göre ÇO, BOİ ve TKN parametreleri bazında IV. sınıf su kütleleri yüzdelerinde ciddi oranlarda azalma olmaktadır. Senaryo 2 incelendiğinde ise BOİ parametresi bazında yüksek oranda iyileşmeler olmasına karşın ÇO ve TKN parametreleri bazındaki iyileşmeler istenilen düzeyde olmamaktadır.

Söz konusu çalışmanın geliştirilmesi maksadıyla, modelin uzun dönem su kalitesi izleme verileri ile güncellenmesi önerilmektedir. Uzun dönem verileri ile modelin daha doğru sonuçlar vereceği düşünülmektedir. Bu çalışmada kullanılan yayılı yük verisi mülga Orman ve Su İşleri Bakanlığı tarafından tamamlanan "Türkiye'de Havza Bazında Hassas Alanların ve Su Kalitesi Hedeflerinin Belirlenmesi" Projesinden alınmıştır. Modelin daha doğru sonuçlar verebilmesi için yayılı yükün daha doğru tahmin edilmesi gerekmektedir.

DISCLAIMER: It is declared that writers of the technical paper with the heading "**Management of Water Losses in Water Supply and Distribution Networks in Turkey**" published in Volume: 2 Issue: 1 of our Journal were rearranged after the process carried out on Dergipark and the writers were determined respectively as Ayşe MUHAMMETOĞLU, Habib MUHAMMETOĞLU, Alev ADIGÜZEL, Özlem İRİTAŞ, and Yakup KARAASLAN.

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