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Research Article

Investigation of The Effect of Climate Change on Extreme Precipitation: Tekirdağ Case

İklim Değişikliğinin Aşırı Yağış Üzerine Etkisinin Araştırılması: Tekirdağ Örneği

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Abstract

This study examines the potential impacts of climate change on extreme precipitation in a specific location, Tekirdağ, Turkey. Trends in rainfall extremes for (1963-2015 period) observed data of 5, 10, 15, 30 minutes and 1, 2, 3, 4, 5, 6, 8, 12, 18, 24 hours are determined by using 1:1 straight line method and Mann-Kendall trend test. Also, daily (24h) future projections for Tekirdağ region are assessed and bias corrected with Quantile Mapping method for the 2015-2050 period. Subsequently, observed and bias corrected daily (24h) time series are used for the Generalized Extreme Value analyses to quantify the potential changes with respect to observation period. Most of the observed time series show increasing trend tendency. Considering the projected data driven analyses results; for shorter return periods results show smaller variations while variability increase with the increasing return period. Depending on the models and Representative Concentration Pathways, there are different results for the future extreme rainfall; yet all results indicate an increasing extreme daily rainfall magnitude at Tekirdağ Province.
Keywords: *Climate change, extreme rainfall, quantile mapping, Mann-Kendall trend test*

Öz

Bu çalışma, belirli bir alanda, Türkiye Tekirdağ ilinde iklim değişikliğinin aşırı yağışlar üzerindeki potansiyel etkilerini incelemektedir Aşırı yağışlarda (1963-2015 dönemi) gözlemlenen 5, 10, 15, 30 dakika ve 1, 2, 3, 4, 5, 6, 8, 12, 18, 24 saatlik verilerin trendi 1:1 düz çizgi yöntemi ve Mann-Kendall trend testi kullanılarak belirlenmiştir. Ayrıca, 2015-2050 döneminde Tekirdağ ili için günlük (24 saat) gelecek dönem projeksiyonları değerlendirilmiş ve kantil haritalama yöntemi ile sapmalar düzeltilmiştir. Bunu takiben, günlük (24 saat) zaman serileri kullanılarak Genel Aşırı Değer analizleri ile gözlem periyoduna göre gelecek dönemdeki potansiyel değişimler hesaplanmıştır. Gözlemlenen zaman serilerinin çoğu artan trend eğilimi göstermektedir. Öngörülen veri odaklı analiz sonuçları dikkate alındığında; daha kısa geri dönüş periyotları için sonuçlar daha küçük farklılıklar gösterirken değişkenlik artan geri dönüş periyodu ile birlikte artmaktadır. Modellere ve Temsili Konsantrasyon Senaryolarına bağlı olarak, gelecekteki aşırı yağışlar için farklı sonuçlar görülse de, tüm sonuçlar Tekirdağ ilinde günlük aşırı yağış miktarında artışı işaret etmektedir.
Anahtar kelimeler: *İklim değişikliği, aşırı yağış, kantil haritalama, Mann-Kendall test*

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Introduction

By the end of the 21st century extreme rainfall events, such as extreme rainfalls, are expected under climate change conditions (Willems, 2013; IPCC, 2013; Liew et al., 2014; Pohl et al., 2017). There are several studies that indicate the effect of climate change on the rainfall regimes and trends. It is a common acceptance that water cycle and rainfall characteristics will be effected significantly by climate change (Osborn et al., 2015). Changes in the rainfall regimes, intensification of extreme rainfall or increasing frequency are expected in some regions as a consequence of climate change (Zhou, 2012; Papagiannaki et al., 2015).

Various urban infrastructure and flood control structures (e.g. dams, culverts, stormwater networks) are designed based on the characteristics of extreme rainfall that is reflected as intensity (depth)-duration-frequency (I(D)DF) curves (Peck et al., 2012; Hosseinzadehtalaei et al., 2017).

The IDF or DDF curves are used to quantify the intensity and its frequency of rainfall considering different durations (Willems et al., 2012) and traditionally the IDF/DDF curves are based on historical rainfall properties in general (Cheng & Aghakouchak, 2014). However, it is found that neglecting the changing frequency may result in the underestimation of obtained IDF/DDF curves (Cheng & Aghakouchak, 2014). Sarhadi et al. (2017) and Cheng and Aghakouchak (2014) also urge the need of updated extreme rainfall used in the infrastructure design process. In the IDF/DDF curve generations updating is important as new records become available because some natural effects may cause alterations in the frequency or the magnitude of rainfall events (Güçlü et al., 2018). Hence future changes became into consideration to obtain appropriate and futureproofing design.

In order to close the information gap regarding future climate, currently Global Climate Models (GCMs) are the most advanced tools. GCM data is widely used for the climate change studies however these raw GCM data is quite coarse for local scale studies and impact evaluations because of resolution problem, inconsistent physical processes, and regional patterns (Emami & Koch, 2018; Bedia et. al., 2020). Therefore, regional climate models (RCMs) is one of the methods that is used for regional assessment however GCM&RCM coupling outputs cannot be used directly at a local scale for the impact studies since RCMs keep coupled GCM biases, particularly for extreme events (Kara et al., 2016). Furthermore, complexity of rainfall processes also produces larger bias between observations and model results (Dai, 2006).

To overcome the model induced, bias various methods have been developed and are now being used for bias correction (BC). Quantile mapping (QM) method is one of the most widely used BC techniques (Themeßl et al., 2011; Cannon et al., 2015; Ngai et al., 2017). QM method is based on calibrating, CDF of the modeled data into the CDF of observed data by using a transfer function. Studies support that quantile mapping or CDF matching technique yields sufficient results for rainfall data (Piani et al., 2010; Gudmundsson et al., 2012; Chen et al., 2013; Trinh-Tuan et al., 2019; Mendez et al., 2020). Piani et al. (2010) reveal that QM is well represented the simulated daily rainfall across Europe. Gudmundsson et al. (2012) also present that QM is quiet well performed in reducing bias among other techniques. Moreover Chen et al. (2013) assessed BC methods and demonstrated the advantage of distribution-based methods, including QM, over mean-based methods. Coupling bias correction methods with GCM&RCM outputs provide necessary knowledge to further climate change impact studies.

Considering the climate change effects of on extreme rainfall properties can help to improve the several methodologies regarding flood risk and potential damages investigation in urban areas or can used to perform a better decision making approach for flood risk management and infrastructure design (Notaro et al., 2015).

The aim of this study is to explore the effects of changing climatic conditions on extreme rainfall and to urge the need to update IDF/DDF curves at Tekirdağ Station, Turkey. The reason for Tekirdağ being the center of attention in this study is being one of the major cities that are on the route of 324 km long Kınalı-Tekirdağ-Çanakkale-Savaştepe Motorway project in western Turkey which is one of the key KGM “Vision 2023” Projects. Moreover, the Project consists of many highway drainage infrastructures such as culverts and open channels which their design process is directly concerned with extreme rainfall patterns.

The approach used to achieve this goal includes 1) identify, if any, trends for observed rainfall extremes, 2) parametric and nonparametric transformation of projected daily time series 3) quantification of changes by using projected daily time series

Methodology

Data and Study Area

Study area.

Tekirdağ is in northwestern Turkey. It is one of three cities in Thrace, is also one of the six coastal provinces that have coasts of two different seas in Turkey. The province, with a surface area of 6.313 km² is between 0 and 200 m above sea level. The city is surrounded by Silivri and Çatalca Districts of İstanbul from the east, Vize, Lüleburgaz, Babaeski and Pehlivanköy Districts of Kırklareli from the north, the Marmara Sea and Gallipoli District of Çanakkale from the south (Figure 1). The Mediterranean climate is dominant in the Marmara Sea coasts. However, unlike the coasts of the Mediterranean Region, snowfall can be seen in the winter. In the inner parts of the city, the continental climate dominates the summers and cold winters. It has a coast of 1.5 km to the Black Sea from the northeast. Tekirdağ, the largest city in the southern part of the Ergene Basin, was established on the shore of a large bay where the roads from the southern Ergene region and the north reach the Sea of Marmara (URL 1).

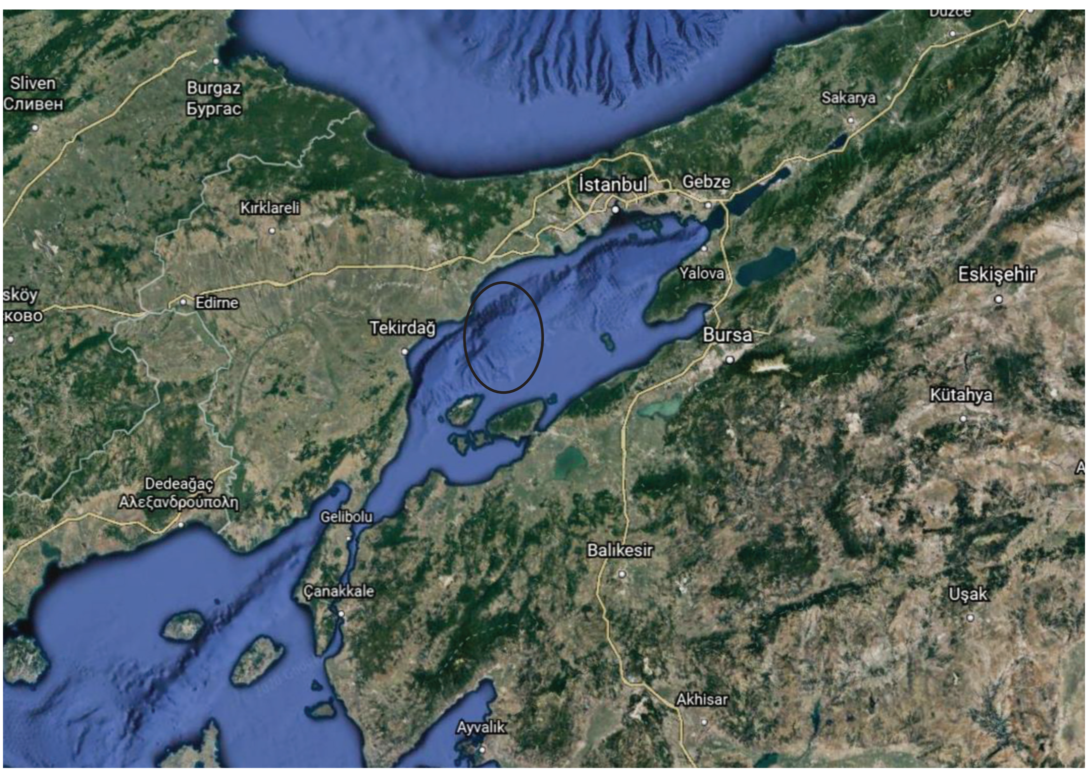

Figure 1. Map of Thrace Region and location of the stations.

Data

Observed station data.

The observed (1963-2015) annual maximum time series and daily (1940-2016) rainfall time series of Tekirdağ Station were acquired from State Meteorological Service. Daily observed time series are used for the bias adjustment of model data which then used to derive future annual maximum time series. Observed and simulated annual maximum time series are used for the extreme value analysis. Since the model data starts from 1971, 1971 and later are taken into consideration both for annual maximum and daily observed data.

Future projections.

Daily historical and future (1971-2100) rainfall projections from hydrological model E-HYPEv3.1.2 which is run by the Swedish Meteorological and Hydrological Institute (SMHI) (Hundecha et al., 2016) are used in this study. Daily projected rainfall data were obtained for the Catchment Sub-ID= 9761280, Lat: 40.98 and Lon: 27.51 that includes city of Tekirdağ. Catchments are defined as irregular catchment polygons and median catchment size is 215 km² (spatial resolution). The Hydrological Predictions for the Environment (HYPE) model is a semi-distributed, physically based catchment model (Lindström et al., 2010). The model and scenarios for the future projections can be seen from Table 1 while models and RCPs are entitled as in Table 2 and hereafter will be included in the text in this way.

Table 1

Simulations Used in This Study

RCM	Driving GCM	RCPs
CSC-REMO2009	MPI-ESM-LR	2.6, 4.5, 8.5
IPSL-WRF331F	IPSL-CM5A-MR	4.5
KNMI-RACMO22E	EC-EARTH	4.5, 8.5
SMHI-RCA4	EC-EARTH	2.6, 4.5, 8.5
SMHI-RCA4	HadGEM2-ES	4.5, 8.5

Table 2

Notation of RCM & GCM & RCP Combinations

Period	Model No	RCM & GCM & RCP Combinations
Historical	Model 1	CSC_REMO2009_MPI-ESM-LR
	Model 2	IPSL-IPSL-CM5A-MR
	Model 3	KNMI_RACMO22E_EC-EARTH
	Model 4	SMHI_RCA4_EC-EARTH
	Model 5	SMHI_RCA4_HadGEM2-ES
Future	Model 1	CSC_REMO2009_MPI-ESM-LR_rcp26
	Model 2	CSC_REMO2009_MPI-ESM-LR_rcp45
	Model 3	CSC_REMO2009_MPI-ESM-LR_rcp85
	Model 4	IPSL-IPSL-CM5A-MR_rcp45
	Model 5	KNMI_RACMO22E_EC-EARTH_rcp45
	Model 6	KNMI_RACMO22E_EC-EARTH_rcp85
	Model 7	SMHI_RCA4_EC-EARTH_rcp26
	Model 8	SMHI_RCA4_EC-EARTH_rcp45
	Model 9	SMHI_RCA4_EC-EARTH_rcp85
	Model 10	SMHI_RCA4_HadGEM2-ES_rcp45
	Model 11	SMHI_RCA4_HadGEM2-ES_rcp85

In this study the changing climatic conditions are assessed by using observed and projected daily extreme rainfall data (annual maximum). To capture any variations, trend tests are applied to the observed annual maximum time series. Observed and projected 24h annual maximum time series are used for the return level (rainfall depth in mm) calculations for 2-5-10-25-50-100-year return periods. Daily model time series data first adjusted using quantile mapping method. After that annual maximum time series are obtained from the projected data and added to the observed time series until 2050 to gain final time series for the extreme value analysis. Since historical model data covers 1971-2005 period, this period is used for calibration and validation process. The analyses period covers 1971-2050 period daily maximum time series (1971-2015 observed and 2016-2050 projected). Finally, obtained changes are used to quantify the impact of climate change over daily extreme rainfall for the area of interest that in this study is Tekirdağ.

Trend Analysis

In this study, 1:1 straight-line method (Şen, 2012), which has been awarded by American Society of Civil Engineers in 2014 as the best technical note and widely used Mann-Kendall trend test (Mann, 1945; Kendall, 1975; Gilbert, 1987) are used to trend detection.

For the 1:1 straight line method, time series are divided into two halves, sorted in ascending order. First half of the series is previous half and places on the horizontal (X) axis. Second half of the time series is latter half and places on the vertical (Y) axis. The existence of a trend is visually inspected by the position of scattered points relative to 1:1 line (Şen, 2012; Haktanir & Citakoglu, 2014; Güçlü et al., 2018; Ali et al., 2019; Alifujiang et. al., 2020).

Mann-Kendall (MK) test makes a statistical assessment of the existence of monotonic trend (upward or downward) for a chosen variable over time. A monotonic upward or downward trend indicates the consistently increase or decrease of the tested variable whether the increase (decrease) linearly or not.

The main equations of the MK test are given below (Mann, 1945; Kendall, 1975; Longobardi & Villani, 2010; Ahmad et al., 2015; Chen et al., 2016):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \qquad (3.1)$$

in which S is the MK test statistic.

$$sgn(x_j - x_i) = \begin{cases} +1 & (x_j - x_i) > 0 \\ 0 & (x_j - x_i) = 0 \\ -1 & (x_j - x_i) < 0 \end{cases} \qquad (3.2)$$

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \qquad (3.3)$$

$$z = \frac{S-1}{\sqrt{VAR(S)}}, \quad \text{if } S>0 \qquad z = 0, \quad \text{if } S=0$$

(3.4)

$$z = \frac{S+1}{\sqrt{VAR(S)}}, \quad \text{if } S<0$$

The hypothesis, H0, that there is no trend is rejected when the absolute value of Z is greater than the critical value Z_{α}, at a chosen level of significance α and the alternative hypothesis, H1, is accepted. R package trend (Pohlert, 2020) was used for the MK test.

Distribution Fitting (Bias-correction Method)

In this study two methods of quantile mapping (QM) were used. Non-parametric quantile mapping (QM) using robust empirical quantiles (REQ) and quantile mapping using parametric transformations (PT) are used for bias correction. The QM non-parametric technique which has the additional advantage of not relying on any predetermined statistical distribution of the data, is used in this study (Gudmundsson et al., 2012; Trinh-Tuan et. al., 2019). However parametric transformation is also applied to figure out discrepancies and to validate the conformity of non-parametric method. According to QM method the distribution of observed data is preserved by the distribution of simulated data (Heo et.al., 2019). More detail about this procedure can be found in (Piani et al., 2010; Gudmundsson et al., 2012; Wuthiwongyothin et. al., 2020). The QM was conducted using the available qmap package in the R software (Gudmundsson, 2016).

Extreme Value Analysis

Extreme Value Analysis (EVA) is a tool used commonly for investigating meteorological extremes (Cheng et al., 2015; Vahedifard et al., 2017; Makkonen & Tikanmäki, 2019). Extreme value theory (EVT) is concerned with the statistical properties of the tails of distributions and by providing the necessary methods to estimate the distribution of the extremes of a time series (Umbricht et al., 2013). By this way quantification of the return level values (in this study rainfall depth in mm for the duration of interest, which in this study is 24-hour (daily) rainfall and return periods of extreme events become possible.

Extreme Value Theory (EVT) uses probabilistic distribution functions such as Generalised Extreme Value (GEV) or Generalised Logistic (GL) function fitted on a block of (in this study annual) maximum series, called Block Maxima (BM) approach or Generalised Pareto Distribution (GPD) function which is fitted to series over a selected threshold, called peak-over-threshold (POT) method (Collet et al., 2017). GEV distribution function is used in the present study to fit the observed and future rainfall data. The methodology is widely used in engineering applications that need an assessment of extreme environmental conditions (Coles, 2001; Coles & Sparks, 2006).

The aim of BM approach is to obtain the probability distribution of the maximums of a block. In the BM approach, equal length of blocks are selected and maximum values from each block are determined and subsequently the GEV distribution is fitted to the obtained maxima series to estimate the exceedance probability, calculate return period and its return level. The size of the block is important because the distribution of the maximum series of the parent distribution may not converge to the GEV distribution as expected for the block maxima approach because of small number of blocks and block size caused biases and errors (Cai & Hames, 2010; Umbricht et al., 2013; Wang et al., 2016). Yearly maximum time series generated from 1971 to 2050 provide time series that are relatively long enough in this study.

The generalized extreme value (GEV) distribution function is widely used to model block maxima of data with theoratical justification. The GEV df is given by (3.1);

$$G(z) = \exp\left[-\left\{1 + \xi\left(\frac{z-\mu}{\sigma}\right)\right\}_{+}^{-\frac{1}{\xi}}\right] \qquad (3.5)$$

Depending on the sign of the shape parameter, ξ, Equation 3.5 covers three types of df's. Fréchet df with $\xi > 0$, Weibull df with $\xi < 0$ and Gumbel df by with limit as $\xi \rightarrow 0$. Maximum Likelihood Estimation (MLE) and L-Moments methods are preferred parameter estimation method of models in this study (Gilleland & Katz, 2016; Lazoglou & Anagnostopoulou, 2017).

Results and Discussions

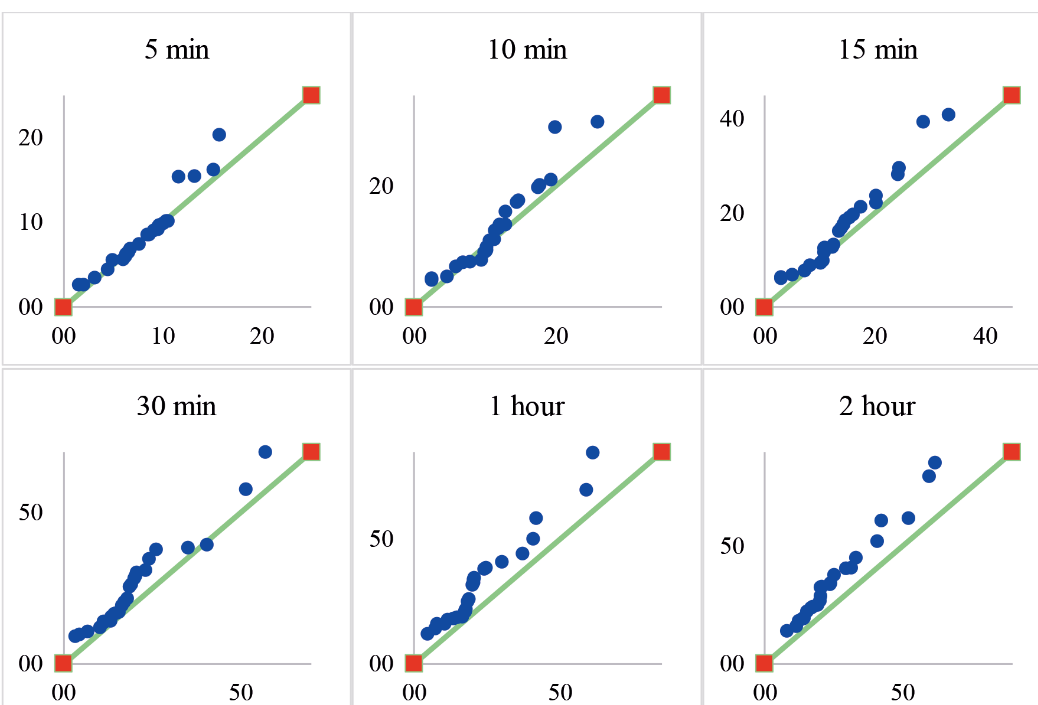

Figure 2. The results of the 1:1-line method (Şen, 2012) for annual maximum rainfall at the Tekirdağ station 1964–2015.

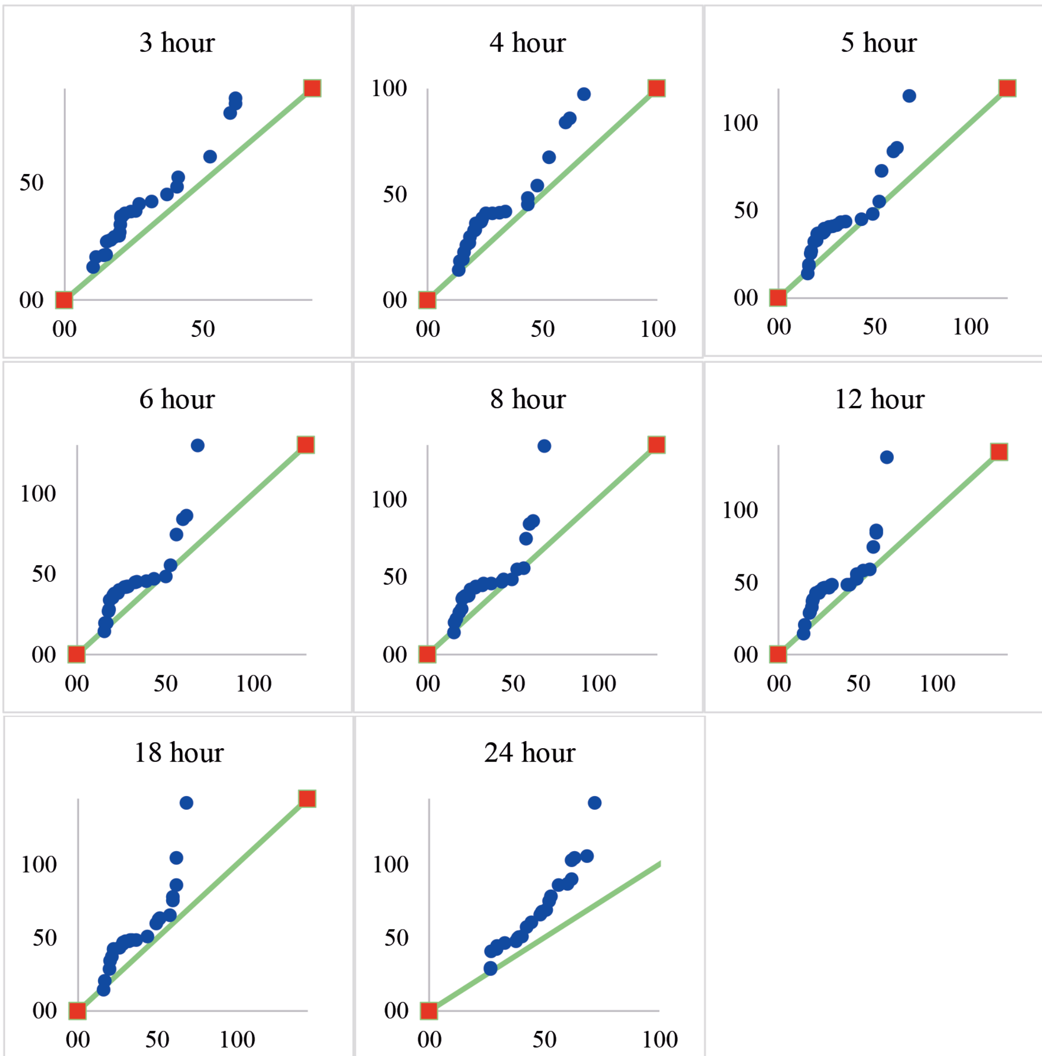

Figure 2. (continue) The results of the 1:1-line method (Şen, 2012) for annual maximum rainfall at the Tekirdağ station 1964–2015.

As mentioned in the methodology section, first (1964–1989 period) and the second (1990–2015 period) halves of the time series sorted in ascending order for the 1:1 line trend detection analysis. The trend conditions of annual maximum of 5-10-15-30 minutes and 1-2-3-4-5-6-812-18-24 hours storm durations can be seen from Figure 2 according to 1:1 straight line – Şen (2012) method. Although all storm durations show positive trend, 5-10-15 minutes data show smaller magnitudes in terms of trend tendencies when compared with the longer storm durations. With the increasing storm duration positive trend conditions become more dominant. It can be said that changing conditions over time effect both short and long duration annual maximum time series and the existence of this effect can be seen clearly from the Figure 2.

Table 3

MK Test Results of 14 Standart Duration Time Series

	5M	10M	15M	30M	1H	2H	3H	4H	5H	6H	8H	12H	18H	24H
Z value	0.952	1.189	1.488	1.757	2.347	2.424	2.769	2.578	2.662	2.647	2.478	2.370	2.624	2.685
P value	0.341	0.234	0.137	0.079	0.019	0.015	0.006	0.010	0.008	0.008	0.013	0.018	0.009	0.007

Moreover, MK trend test also applied to time series in order to support and to validate the visual inspection results of ITA method (Table 3). According to MK results, all extreme rainfall time series showed increasing trends while 30 minutes at 0,1 significance level, 1, 2, 8 and 12 hours at 0,05 significance level and, 3, 4, 5, 6, 18, 24 hours annual maximum rainfall series at 0,01 significance level show increasing trends. These results indicate consistent outcomes with the ITA analyses. Regarding annual maximum rainfall series, it can be said that the series are dominated by increasing trend tendency while hourly data is dominated with significant increasing trend compared to sub-hourly data.

Afterwards quantile mapping applied to bias correct the daily rainfall values obtained from the simulations. Because daily rainfall values of historical period (1971–2005) and future period (2006-2050) are containing catchment scale values these results it is necessary to corrected by PT and REQ approaches with observed daily rainfall results of Tekirdağ Station. Model biases were determined by computing the probability of exceedance curves and box plots between the raw model, adjusted and the observed annual daily maximum time series during the historical period. Five models are used for the historical period bias adjustment procedure.

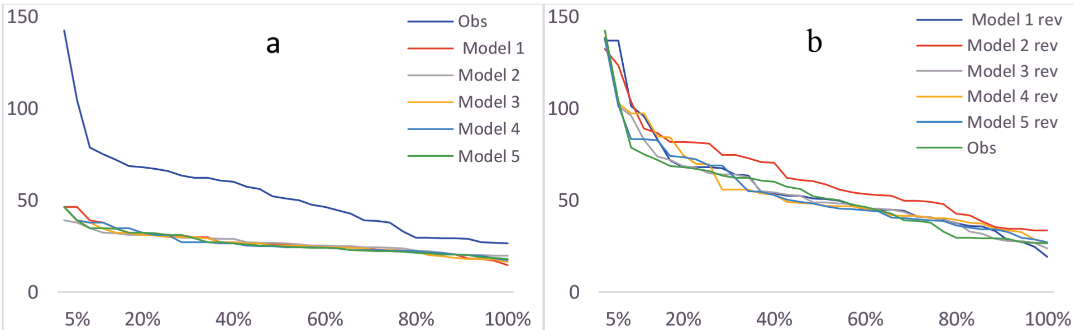

Figure 3. a) Raw model and observed annual daily maximum time series (1971-2005), b) PT bias corrected model results and observed annual daily maximum time series (1971-2005) (X-Axis is probability of exceedance in %, Y-Axis is daily annual maximum rainfall in mm).

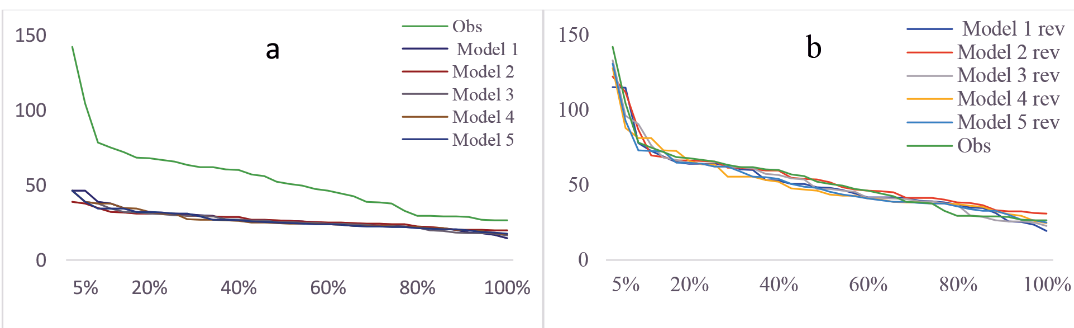

Figure 4. a) Raw model and observed annual daily maximum time series (1971-2005), b) REQ bias corrected model results and observed annual daily maximum time series (1971-2005) (X-Axis is probability of exceedance in %, Y-Axis is daily annual maximum rainfall in mm).

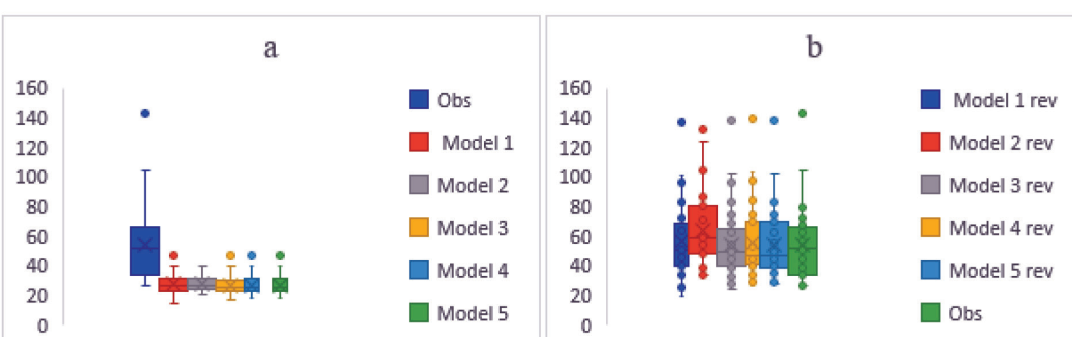

Figure 5. Boxplots showing a) raw model and observed annual daily maximum time series (1971-2005), b) PT bias corrected model results and observed annual daily maximum time series (1971-2005).

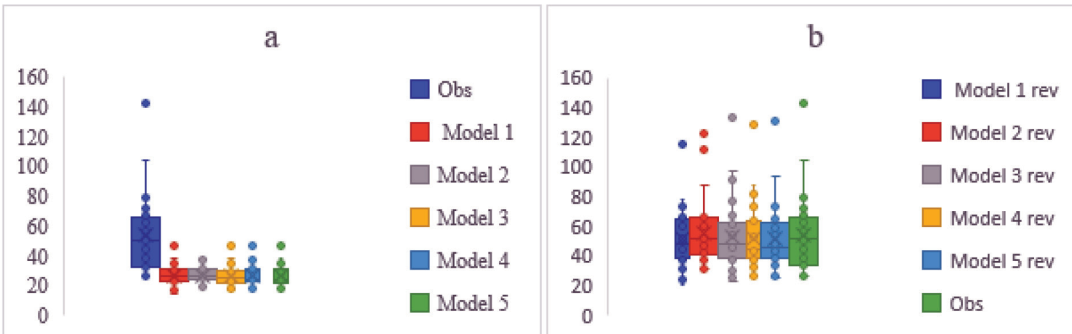

Figure 6. Boxplots showing a) raw model and observed annual daily maximum (mm) time series (1971-2005), b) REQ bias corrected model results and observed annual daily maximum (mm) time series (1971-2005).

Figures 5 and 6 show boxplots of raw model, bias corrected model, and observation results of daily annual maximum time series between 1971-2005. Bias corrected time series are constructed with PT and REQ methods can be seen. Both PT and REQ results show considerable performance however evaluating the box plot results together with probability of exceedance results that are shown in Figures 3 and 4 above, REQ model results are used for the rest of this study.

After obtaining final daily rainfall projections from bias correction procedure, it is possible to evaluate the variability amongst the different climate models and RCP combinations and observation. In total, 11 sets of rainfall projections were generated until 2050. Every data set then used to calculate the annual daily maximum time series to perform GEV analyses with BM approach. For each model GEV analyses with MLE and L-Moments methods are conducted, and 2-5-10-25-50-100-years return levels of annual daily maximum time series are calculated. Each 11 model, RCP2.6 model average, RCP4.5 model average and RCP8.5 model average and observed return level results are compared.

Results of the 11 model and observation period return level values are drawn for 2-5-10-25-50-100-years return periods. Frequency Depth Duration curves that are derived to capture the variations clearly. Estimation results are given in Figure 7 and their corresponding percent change values are given in Table 4. Rainfall depts are in mm and return periods are in years. All figures and tables are obtained for daily (24 hour) annual maximum rainfall data.

In general, all model results, both with MLE and L-Moments, yield grater return level values than observed ones. It can be easily seen that except model1 for

2 years and model 2 for 2-5-10-25 years return levels, observation-based return level values are smaller than projection results. These results also support the observation period trends that generally provide positive trends. It is apparent that results which are calculated with MLE approach produce greater return levels when compared to the results that are calculated with L-Moments approach. Furthermore, the difference between observation-based return levels and projected ones increases with the increasing return period. On the other hand, Model 1, Model 2 and Model 3 return level values revealed smaller and Model 5 and Model 6 revealed larger difference among other models. There is great variability among models in return level values on the other hand the sign of change is clearly indicated by all models.

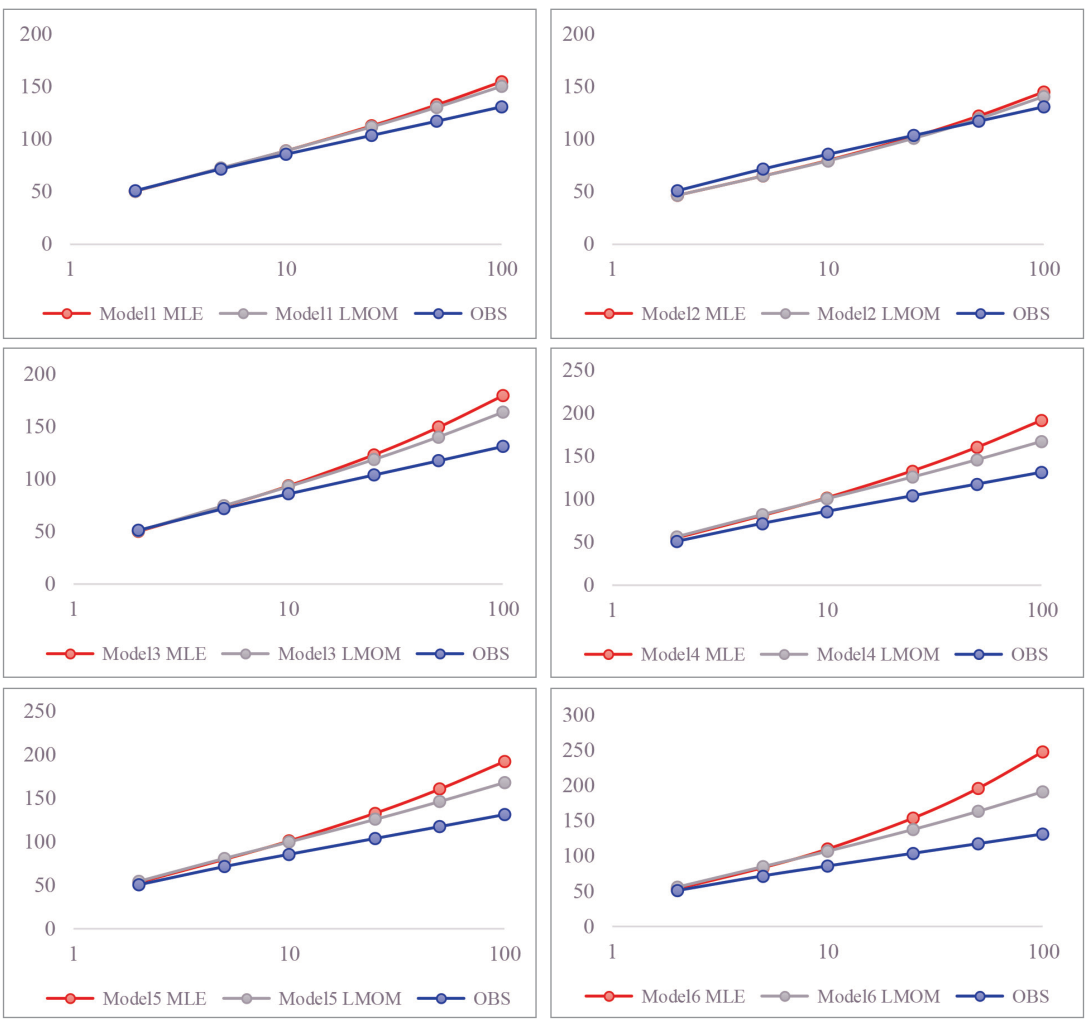

Figure 7. Depth Duration Frequency Curves of 24h data for single models - (X-Axis is return period in years, Y-Axis is return level in mm).

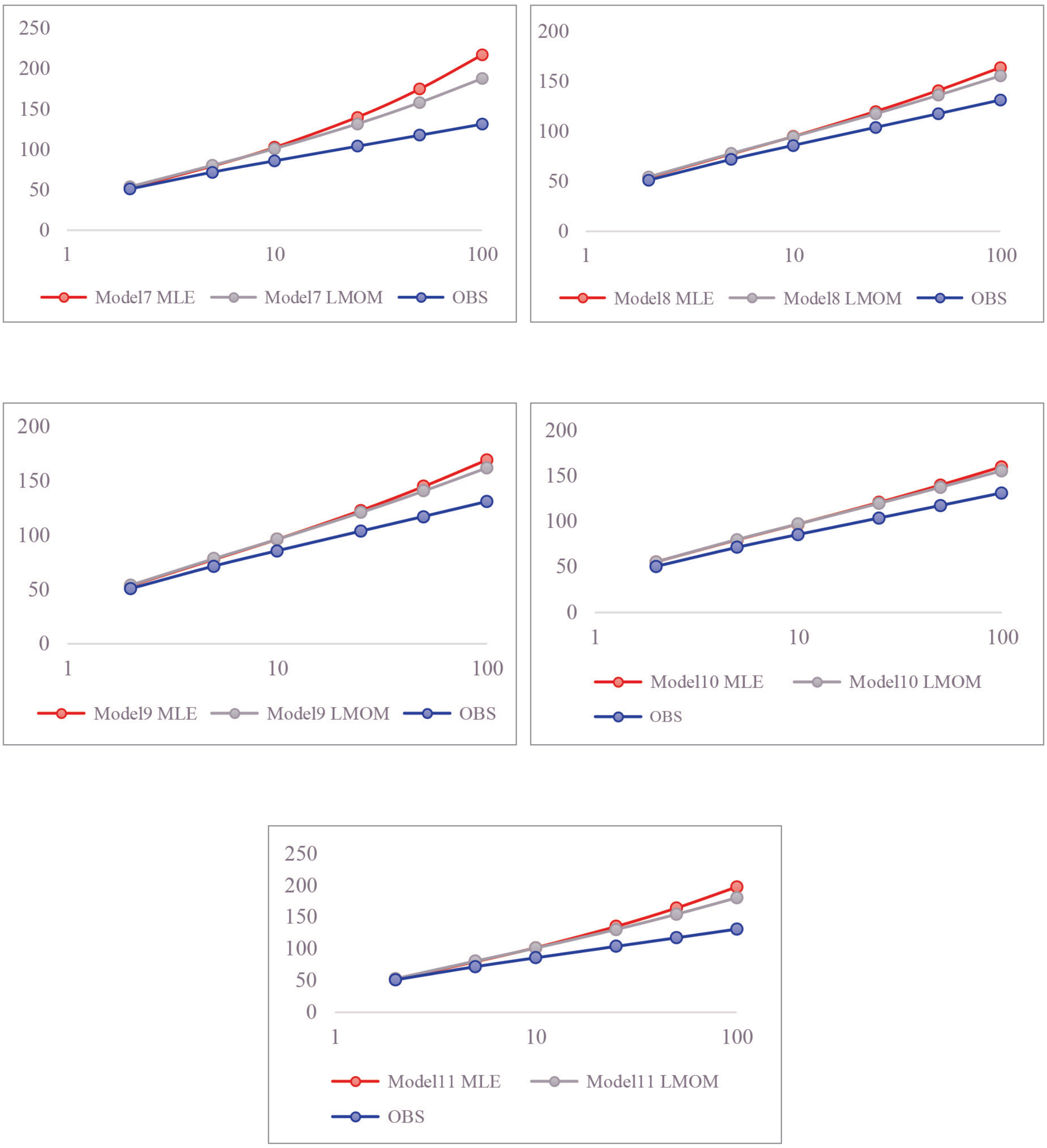

Figure 7. (continue) Depth Duration Frequency Curves of 24h data for single models - (X-Axis is return period in years, Y-Axis is return level in mm).

Table 4

Return Level Comparison (Percent Change) of Models Vs. Observation

	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
Model1 MLE	-2%	1%	4%	9%	13%	18%
Model1 LMOM	-1%	1%	4%	8%	11%	15%
Model2 MLE	-9%	-10%	-7%	-2%	4%	10%
Model2 LMOM	-9%	-10%	-7%	-3%	2%	7%
Model3 MLE	-2%	3%	9%	18%	27%	37%
Model3 LMOM	0%	4%	8%	14%	19%	25%
Model4 MLE	7%	12%	18%	28%	37%	46%
Model4 LMOM	10%	14%	17%	21%	24%	28%
Model5 MLE	5%	11%	18%	28%	37%	47%
Model5 LMOM	8%	13%	17%	21%	25%	28%
Model6 MLE	5%	16%	28%	48%	67%	89%
Model6 LMOM	10%	19%	25%	33%	39%	46%
Model7 MLE	3%	10%	19%	34%	49%	65%
Model7 LMOM	5%	12%	18%	27%	34%	43%
Model8 MLE	6%	8%	11%	16%	20%	25%
Model8 LMOM	7%	9%	10%	13%	16%	19%
Model9 MLE	6%	9%	13%	19%	24%	29%
Model9 LMOM	7%	10%	13%	17%	20%	24%
Model10 MLE	9%	11%	13%	17%	19%	22%
Model10 LMOM	10%	12%	14%	16%	17%	19%
Model11 MLE	1%	11%	19%	30%	40%	51%
Model11 LMOM	3%	12%	18%	26%	32%	38%

Figure 8 and Table 5 show differences between projected return level values of RCP scenarios and observation-based return levels for 2-5-10-25-50-100 years return periods. In general, RCP26, RCP45 and RCP85 scenario averages yield similar results with single model evaluations. 1–5 % increase for 2 years return period to 29-52% increase for 100 years return period. Comparing MLE and L-Moments results it can clearly be seen that all return level values are greater than the observation base ones. However, when two approaches compared with each other, it is the L-Moments results that yield greater values for shorter return periods whereas MLE results yield larger return level values after 25-years return periods. Considering the RCP scenarios RCP85 return level values show the larger difference between observation and projections. All models show smaller variations for the shorter return period values however RCP26 increases with return period duration and become larger than RCP45 results with increasing return period. The magnitude of change increases in accordance with the return period.

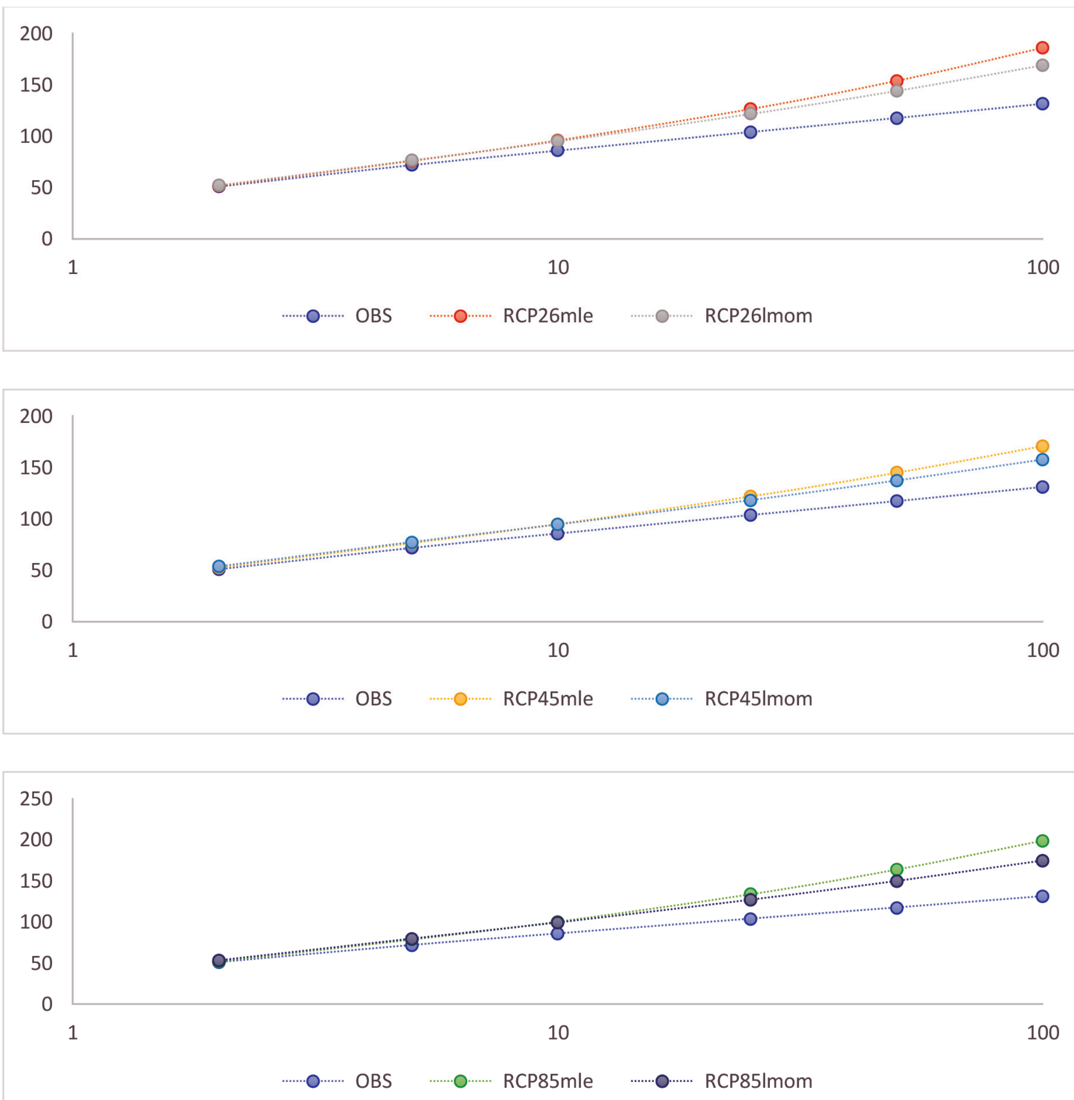

Figure 8. Depth Duration Frequency Curves for RCP averages and observation - (X-Axis is return period in years, Y-Axis is return level in mm).

Table 5

Return Level Comparison (Percent Change) of RCP Averages Vs. Observation

	2-Years	5-Years	10-Years	25-Years	50-Years	100-Years
RCP26MLE	1%	6%	12%	22%	31%	42%
RCP26LMOM	2%	6%	11%	17%	23%	29%
RCP45MLE	3%	7%	11%	17%	23%	30%
RCP45LMOM	5%	8%	10%	14%	17%	20%
RCP85MLE	2%	10%	17%	29%	39%	52%
RCP85LMOM	5%	11%	16%	22%	27%	33%

Discussion and Conclusions

In this study first trend of observed (1964-2015) annual maximum of 5-10-15-30 minutes and 1-3-6-24 hours storm durations time series of Tekirdağ province are examined by using 1:1 straight line method. Moreover, projected daily time series are used to capture the potential changes. Quantile mapping method applied, and bias corrected future time series are obtained up to 2050. After that, by using GEV analyses potential changes are quantified in terms of maximum daily (24h) rainfall for 2-5-10-25-50-100 years return periods at Tekirdağ station.

All storm durations show positive trends according to 1:1 straight line method. Both short duration and long duration time series show increasing trend while longer duration time series show higher magnitudes in terms of trend tendency. Bias corrected daily time series are used for the GEV analyses. These results reveal that future period 24h annual maximum values will probably increase based on the model results. On the other hand, variations among model results increase with the increasing return period. RCP averages are also calculated and used in comparison that reveal similar results with single model evaluation.

There are studies that cover precipitation properties of Tekirdağ region but many of these studies are not considering future extreme rainfall magnitudes with changing climatic conditions. Sirdas et al. (2016) investigated heavy precipitation at 23 meteorological observation stations in the Marmara region, including Tekirdağ, in terms of temperature, Arctic Oscillation Indices (AO) and North Atlantic Oscillation Indices (NAO) and revealed no significant relationship. Also, Gönençgil (2013) studied Thrace region and found significant dry conditions for annual precipitation series of Tekirdağ.

Considering the extreme conditions, Abbasnia & Toros (2018) indicated significant heavy precipitation trends for Rx1day and Rx5day for Edirne and Tekirdağ. In this study it is also found that annual maximum 24h rainfall have a potential increase according to model results. Considering the findings of Üstün Topal et al. (2016) that noticed the increasing rate of impervious land cover, the potential increase that is shown in this study urges to take attention in this issue. There is great variability among models in return level values on the other hand the sign of change is clearly indicated by all models.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

İklim Değişikliğinin Aşırı Yağış Üzerine Etkisinin Araştırılması: Tekirdağ Örneği

Küresel ısınmadan kaynaklanan değişiklikler, fırtınaların ve aşırı yağışlar gibi diğer ekstrem hava olayların görülme sıklığında ve şiddetinde bir artışa neden olabilecektir (IPCC, 2013). İklim değişikliğinin su döngüsü ve yağış rejimi üzerinde önemli etkileri olacağı yaygın bir görüş olarak ortaya çıkmaktadır (Osborn vd., 2015). Bazı bölgelerde, bu değişiklikler ile ekstrem yağışların görülme sıklığı ve şiddetinde artış olacaktır (Zhou, 2012; Papagiannaki vd., 2015). Diğer bir deyişle, ekstrem yağış olaylarının iklim değişikliğinin de etkisi ile 21. yüzyılın sonlarına doğru belirgin bir şekilde görülmesi beklenmekte olup bu etkiler bölgesel olarak farklılıklar gösterebilecektir (Willems, 2013; IPCC, 2013; Liew vd., 2014; Pohl vd., 2017; Seneviratne vd., 2012).

Bu çalışmanın amacı, değişen iklim koşullarının aşırı yağışlar üzerindeki etkilerini anlamak ve Tekirdağ İstasyonu'ndaki IDF / DDF eğrilerini güncelleme ihtiyacını ortaya koymaktır. Bu çalışmada Türkiye'nin batısında yer alan Tekirdağ ilinin seçilme nedeni, tasarım süreçleri doğrudan aşırı yağış düzenleriyle ilgili olan menfezler ve açık kanallar gibi birçok otoyol drenaj altyapısını barındıran 324 km uzunluğundaki Kınalı-Tekirdağ-Çanakkale-Savaştepe Otoyolu projesinin güzergahında yer alan şehirlerinden biri olmasıdır.

Çalışmada izlenen yol: 1) gözlem dönemi standart süreli yıllık maksimum yağışların trendlerinin belirlenmesi, 2) projeksiyon sonuçları elde edilmiş olan günlük zaman serilerinin parametrik ve parametrik olmayan yöntemler ile yanlılık düzeltmesinin yapılması, 3) projeksiyon ve gözlem dönemi günlük yağış serileri kullanılarak iki dönem arasındaki değişikliklerin belirlenmesidir.

Tekirdağ İstasyonunda gözlemlenen (1963-2015) standart süreli yıllık maksimum zaman serileri ve günlük (1940-2016) yağış zaman serileri Meteoroloji Genel Müdürlüğünden temin edilmiştir. Günlük gözlemlenen zaman serileri, daha sonra gelecekteki yıllık maksimum zaman serilerini türetmek için kullanılan model verilerinin yanlılık düzeltmesi için kullanılmıştır. Model verileri geçmiş dönemi içine alacak şekilde 1971 yılından itibaren mevcut olduğu için gözlem dönemi yağış serileri de 1971 ve sonrası itibari ile kullanılmıştır. Gelecek dönem analizleri için kullanılan veriler ise Tekirdağ şehrini (Enlem: 40.98 ve Boylam: 27.51) içeren alt havzaya ait günlük ölçekteki yağış projeksiyonlar olup (1971-2100), İsveç Meteoroloji ve Hidroloji Enstitüsü (SMHI) (Hundecha vd., 2016) tarafından işletilen hidrolojik model E-HYPE v3.1.2'den temin edilmiştir.

Gözlem ve projeksiyon dönemi günlük aşırı yağış verileri (yıllık maksimum) analiz edilerek değişen iklim koşullarının etkisi değerlendirilmiştir. Gözlem dönemi yağış serilerine ait trendler 1:1 düz çizgi yöntemi ve Mann-Kendall trend testi ile tespit edilmiştir. 2 - 5 - 10 - 25 - 50 - 100 yıllık geri dönüş periyotlarında mm olarak yağış yüksekliği hesaplamaları için gözlem ve projeksiyon dönemi 24 saatlik yıllık maksimum zaman serileri kullanılmıştır. Günlük ölçekte elde edilmiş model zaman serileri için önce kantil haritalama yöntemi kullanılarak yanlılık düzeltmeleri gerçekleştirilmiştir. Elde edilen sonuçlar karşılaştırmalı olarak incelenmiş ve düzeltme sonuçlarının yeterli performans gösterdiğine kanaat getirilmiştir. Daha sonra, projeksiyon verilerinden elde edilerek yanlılık düzeltmesi yapılan günlük yağış verilerinden yıllık maksimum yağışlar elde edilmiş ve gözlem dönemi zaman serilerine eklenmek sureti ile 2050 yılına kadar olan yeni zaman serileri elde edilmiştir. Toplamda 11 adet farklı zaman serisi elde edilmiş ve analizlerde kullanılmıştır. Bu zaman serileri farklı genel iklim modeli, bölgesel iklim modeli ve temsili konsantrasyon senaryolarına göre belirlenmiştir. Geçmiş dönem model verileri 1971-2005 dönemini kapsadığından, bu süre gözlem verileri kullanılmak sureti ile kalibrasyon ve doğrulama işlemi için kullanılmıştır. Analiz dönemi 1971-2050 günlük maksimum zaman serilerini kapsamaktadır (1971-2015 gözlemlenen ve 2016-2050 projekte edilen yağış verileri olmak üzere). Son olarak, yeni günlük maksimum yağış serileri kullanılarak Genel Aşırı Değer analizleri yapılmış ve 2 - 5 - 10 - 25 - 50 - 100 yıllık geri dönüş periyotları için yağış yükseklikleri elde edilmiş ve gözlem dönemi verileri ile karşılaştırılmıştır. Genel aşırı değer analizi yapılırken blok maksimum yöntemi kullanılmıştır. Söz konusu yöntemde zaman serileri için seçilen bloklara (bu çalışmada yıl) ait maksimum değerler elde edilmek sureti ile hesaplamalar gerçekleştirilmiştir.

Elde edilen sonuçlara göre gözlem dönemine ait tüm yağış süreleri 1:1 düz çizgi yöntemine ve Mann-Kendall trend testi sonuçlarına göre artan trend eğilimleri göstermektedir. Hem kısa süreli hem de uzun süreli zaman serileri artış eğilimi gösterirken, daha uzun süreli zaman serileri incelendiğinde (örn. 1 saat, 3 saat, 24 saat) artış eğiliminin bu serilerde daha belirgin olduğu görülmektedir. Genel aşırı değer analizleri için yanlılık düzeltilmesi yapılmış günlük zaman serileri kullanılarak yapılan analizler sonucunda; gelecek dönemde 24 saat süreli yıllık maksimum değerleri göz önüne alındığında model sonuçlarına göre bu değerlerde muhtemel bir artış beklenmektedir. Öte yandan, artan geri dönüş periyodu ile model sonuçları arasındaki farklılıklar da artış göstermektedir. Ayrı ayrı model sonuçlarının yanında temsili konsantrasyon senaryolarına göre ortalama değerler de hesaplanmış ve bu ortalama sonuçlarına göre model değerlendirmelerine benzer sonuçların ortaya çıktığı görülmüştür, gözlem dönemi değerlerinin temsili konsantrasyon senaryolarına göre ortalama değerlerden daha düşük olduğu tespit edilmiştir. Modellere ve Temsili Konsantrasyon Senaryolarına (TKS) bağlı olarak, gelecekteki aşırı yağışlar için farklı sonuçlar görülse de, tüm sonuçlar Tekirdağ ilinde günlük aşırı yağış miktarında artışı işaret etmektedir.

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Case Study

Usage and Effects of Algaecide in Kurtboğazı Dam Lake

Kurtboğazı Baraj Gölü'nde Algisit Kullanımı ve Etkileri

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Abstract

In recent years, the increased density and incidence of cyanobacteria, also known as blue-green algae, in water resources has become a growing global problem in consequence of the increasing temperature associated with climate change. The growth of cyanobacteria in dam lakes causes algae blooms and deteriorates water quality. Since it contains Methyl-Isoborneol, Geosmin and toxins, taste and odour problems in water occur and those threatens public health. Rising density of algae causes an increase in the total amount of organic carbon in water, which increases the amount of disinfection by-products. In this study, algae control applications were performed during the summer period kesin tarih parantez içinde verilmelidir. The water samples were taken before and after the algaecide application, and total organic carbon, pH, chlorophyll-*a*, dissolved oxygen, copper, turbidity, orthophosphate phosphorus and total nitrogen were analysed. In order to calculate the amount and depth of the algaecide application, we determined which cyanobacterial species would be used. Copper ethanolomine is the main constituent of the algaecide so copper contamination in water has been investigated. In general, the density of cyanobacteria in bay and stagnant waters was increase before its application. According to the results of the study, appropriate doses and times are supporters to prevent algae blooms and to control sudden increases in the number of algae. In accordance with the results of the analysis, permanent copper pollution does not occur at different depths or at different points. However, a small amount of increase in the samples taken during the algaecide effect time can be seen from time to time.

Keywords: *Algaecide, algae control, Kurtboğazı, algal bloom*

Öz

Son yıllarda, iklim değişikliği ile birlikte görülen sıcaklık artışı sonucunda, su kaynaklarında mavi-yeşil algler olarak da bilinen siyanobakterilerde artan yoğunluk ve görülme sıklığı giderek büyüyen küresel bir sorun haline gelmiştir. Baraj göllerinde sayısı artan siyanobakteriler aşırı alg artışlarına sebep olmakta su kalitesini bozmaktadır. İçerdiği Metilizoborneol, Geosmin ve toksinler sebebiyle suda tat, koku problemleri yaratmakta ve halk sağlığını tehdit etmektedir. Alglerin yoğunluğunun artması suda toplam organik karbon miktarını artırmakta bu da dezenfeksiyon yan ürünlerinin miktarını artırmaktadır. Çalışmada yaz dönemi boyunca alg kontrolü uygulamaları yapılmıştır. Uygulama öncesi ve sonrasında numuneler alınarak toplam organik karbon, pH, klorofil-*a*, çözünmüş oksijen miktarı, bakır, bulanıklık, ortofosfat fosforu ve toplam azot analizleri yapılmıştır. Uygulanacak algisit miktarı ve derinliğinin hesaplanması için siyanobakteri tür tespitleri yapılmıştır. Kullanılan algisitin

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temel bileşeni bakır etanolomin olduğu için suda oluşması muhtemel bakır kirliliği araştırılmıştır. Genel olarak uygulamadan önce siyanobakterilerin koy ve durgun suların bulunduğu bölgelerde yoğunluğunun arttığı tespit edilmiştir. Çalışmada elde edilen sonuçlara göre uygun doz ve sürede yapılan dozlama aşırı alg artışlarının önüne geçilmesine ve ani artışların kontrol altına alınmasına yardım etmektedir. Analiz sonuçlarına göre farklı derinliklerde ya da farklı noktalarda bakır kirliliği oluşmamakta bununla beraber algisit etki süresinde alınan numunelerde zaman zaman az miktarda artış görülebilmektedir.

Anahtar kelimeler: *Algisit, alg kontrolü, Kurtboğazı,* aşırı alg artışı

Introduction

Dam lakes are artificial lakes, built on rivers for the purposes of electricity generation, drinking water supply, irrigation, fishery, flood control and recreation, and also they are the places, formed by a barrier structure for the accumulating water in basin. These lakes can be narrow, long or branched. Dam lakes are different from natural lakes due to their features such as high flow rate, the presence of suspended solids in the entering water, short water resilience. Due to being larger water collection basin, they are affected by pollution in the basin more than natural lakes (Demir & Atay, 1999).

In recent years, cyanobacteria proliferate rapidly in lakes and dams, which are particularly rich in nutrients such as nitrogen and phosphorus, and thus cause poor water quality. In case of overgrowth, fish death occurs due to the depletion of oxygen in the water or toxins to the environment as a result of algal blooming. In addition, some cyanobacteria can secrete cyanotoxins, which are very dangerous chemicals for human and environmental health. In particular, Geosmin, and 2-methylisoborneol (2-MIB) produced by cyanobacteria, is the main cause of taste and odour degradation in water, characterized by soil and mouldy odours. The removal of these chemicals in treatment plants is difficult and costly. Algal blooms make water treatment difficult and causes undesirable taste and odour formation in water. Algae that cannot be processed in water release trihalomethanes and some carcinogenic products as a result of chlorination (Kotak et al., 1993).

Cyanobacteria are prokaryotic organisms with no real nuclei, membrane-bound organelles and plastids (Cirik & Cirik, 2004). The blue-green appearance of algae is due to the covering of chlorophyll pigment by phycocyanin, phycoerythrin and other pigments (Rinehart et al., 1994). Since there is no nuclear membrane, the DNA and pigment substances are dispersed in the cytoplasm. Cell wall is cellulose and pectin. The substitute food substance is glycogen, cyanophycin and volitin proteins instead of starch (Chorus & Bartram, 1999). Many types of cyanobacteria are aerobic phototrophs, but some also show heterotrophic properties. Cell shapes of cyanobacteria are single, filament or colony-shaped (Cirik & Gokpinar, 1993). Some species of cyanobacteria develop adherent to the surface, while some species are scattered throughout the water. Various factors such as water temperature, sunlight, the presence of high nutrients, grazing, and climate are effective in the proliferation of cyanobacteria (Anonymous, 2010). Some types of cyanobacteria contain toxic substances. According to their chemical structures, cyanotoxins fall into several main groups: peptides, heterocyclic compounds (alkaloids) or lipidic compounds (Sivonen & Jones, 1999).

There are 46 species of cyanobacteria that cause toxic effects in vertebrates (Sivonen & Jones, 1999). Cyanotoxins cause many diseases in humans such as liver cancer, gastroenteritis, respiratory system abnormalities, nausea, vomiting, fever flu-like symptoms, sore throat, ear and eye irritation, rash, abdominal pain, lung consolidation, kidney and liver damage (Qin et al., 2007; Miller & Tisdale, 1931; Sivonen & Jones, 1999).

The source of the first reported cyanobacterial gastroenteritis was the Ohio River in 1931 and later on children were poisoned considerably due to an increase in *Microcystis* spp. in a water tank in Zimbabwe (WHO, 2003). In Sweden, it was reported that in 1994, symptoms like nausea, vomiting, diarrhea, muscle cramps were observed in 121 out of 304 people in a sugar factory as a result of the use of untreated river water containing MCYST from *Plantktothrix agardhii* (Falconer, 2001). 117 patients, treated at a hemodialysis center in Brazil, were exposed to toxins in water used for dialysis, liver failure was detected in 100 patients and 56 of them were died. (Azevedo et. al., 2002).

In this study, the effects and efficiency of algaecide application in Kurtboğazı Dam were investigated. We expect that algae control is going to reduce the amount of odor and toxin in water treatment plants. It is also expected to prevent possible algae blooms. In this study, it is aimed to find the way of preventing possible algal blooms in Kurtboğazı Dam. Algae control is important issue to have better quality drinking water. This study was conducted to develop methods and methodology for algae control in drinking water sources

Material and Method

Kurtboğazı is a dam lake, located at the northwest edge of Ankara and far away 47 km from Ivedik Treatment Plant. It was constructed between 1963 and 1967 for supplying drinking water of Ankara. Its maximum water volume is 92.000.000

m^3. The creeks, namely Bahtılı, Mera, Kınık, Pazar, Uzunöz, Bostan, Kayıcık, Batak, İğmir, Kirazlı, Eneğim and Karaboya feed the Lake, and it is also used for a recreational area (Figure 1).

Figure 1. Kurtboğazı Dam Lake.

In this study, TOC, chlorophyll-*a*, dissolved oxygen concentration, pH, water temperature were measured and cyanobacteria species were determined before and after algaecide application in Kurtbogazi Dam Lake.

Dissolved oxygen concentration, pH, and water temperature were measured with WTW 3320 field-type equipment. Hach DR 6000 model spectrophotometer was used for chlorophyll-*a* measurements. TOC measurements and chemical analyses of ortho phosphatephosphorus, copper, total nitrogen, total organic carbon, turbidity, were performed in Accredited Laboratory of ASKI General Directorate. TOC analyzes were performed according to SM 5310B standards. Copper analyzes were performed according to EPA 200.8 standards. Total nitrogen analyzes were performed according to ISO 29441 standards. Chlorophyll-*a* analyses were performed according to SM 10200H standards. Orthophosphatephosphorus analyzes were performed according to TS EN ISO 15681-2 standards.

Turbidity measurements were obtained by the nephelometric method using a HACH 2100N Turbidimeter with turbidity units (NTUs). Plankton net was used to take samples for species determination. Plankton net hauled both vertically and horizontally.

Algicide application was planned to be routinely once a week. Application have been carried out starting from 300 meters away from the water intake structure. Algaecide containing copper ethanolamine complex, which is known to be not harmful to fish and aquatic organisms with a residence time for 14 days, was selected. Algicide was used by diluting at a rate of 1/10. Application was made on between 9 and 29 August.

Considering the residence time, it was predicted that 400 kg algaecide should be consumed weekly. The total amount of algaecide to be used was calculated as the volume of the application area. 0.3 ppm copper ethanolamine was applied in a square meter section.

At the end of the summer season, algal density increased more than predicted in the last two weeks of August and the weekly dosing of algaecide was increased from 400 kg to 700 kg. After 15 August, chlorophyll-*a* value began to increase. Algal density was increased outside the application area. The volumes of these sections were calculated and algicide dosed.

The boat used in the application had a length of 4.90 m and a 20 hp engine. There was one tank with a capacity of 300 lt on the boat. In order to make dosing into the water, a 3-meter-long installation system was built from the tank to the outside on both sides of the boat. In the filling of the tank, a pump system powered by electricity was used. Rechargeable batteries were used as electrical sources. The application was made by an aquaculture engineer and a technician.

Results

Cyanobacteria can be seen at different depths in the water body. Some types of cyanobacteria can be found in the upper layers of water, while some types of cyanobacteria can form surface scums (*Microcystis*, etc.). On the other hand, some species can be found in the thermocline layer (Albay et al., 2016). Therefore, it is important to determine the dominant species by taking samples from water column before the algicide application. The implementation strategy should be determined according to the identified species.

In this study, we ascertained that cyanobacteria was found more in stagnant and coastal waters than main water body. The route of application is shown in figure 4. Algae produces energy through photosynthesis and takes nutrients when photosynthesis is high. Because of that sunny days were preferred for algicide dosing and it was performed during the hours of a large amount of sun light.

Figure 2. Algicide application.

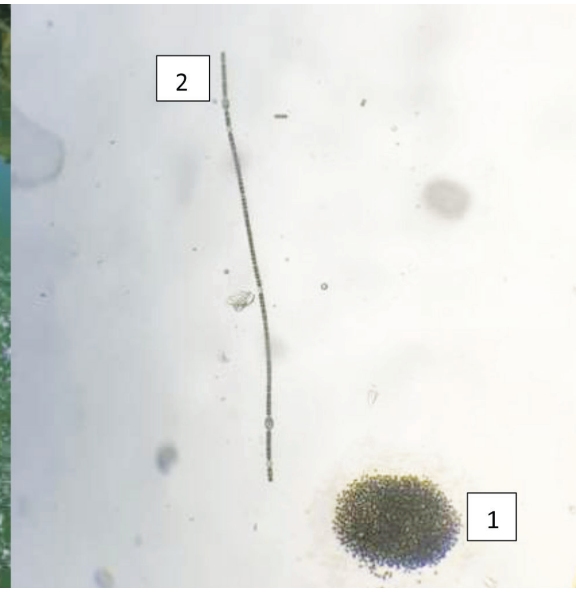

Figure 3. M. aeruginosa (1), D. planctonicum (2).

Figure 4. Application area and the sampling sites.

Five sampling points were selected and samples were taken on August 8 and 15 for the study: 1) Bay point is one of its stagnant section which had the highest algae concentration during the summer of 2019, 2)Pazar point, its stream section, was particularly rich in nutrients, 3) İğdir point, representative of its main section, was chosen to see the changes across the dam lake, 4) Water intake point represents the raw water coming to the İvedik Water Treatment Plant and 5) The point was selected as the representative of the highest water flow. Figure 4 shows the sampling points.

During the studies made for different periods of the summer 2019, *Microcystis aeruginosa and Dolichospermum planctonicum* were identified as dominant species in the samples.

Table 1

Analysis Results for August 2019

Station	Date	Copper mg/L	Turbidity NTU	Ortho Phosphate Phosphorus mg/L	pH	Total Nitrogen mg/L	Total Organic Carbon mg/L
İğdir	08.08.2019	< 0,003	4,50	< 0,02	9,3	1,09	3,60
	15.08.2019	0,012	5,00	0,03	9,3	0,70	3,59
Bay	08.08.2019	0,007	95,00	< 0,02	9,5	2,25	15,60
	15.08.2019	0,020	6,90	0,04	9,2	0,67	3,97
Port	08.08.2019	0,003	4,70	< 0,02	9,1	1,26	3,45
	15.08.2019	0,011	8,10	0,02	9,4	0,59	3,69
Pazar	08.08.2019	< 0,003	6,30	< 0,02	9,5	1,37	3,76
	15.08.2019	0,011	5,80	0,04	8,6	0,61	3,69
Water intake	08.08.2019	< 0,003	4,80	< 0,02	9,0	1,49	4,65
	15.08.2019	0,012	7,70	0,05	9,6	0,75	3,59

The first algaecide application was made on August 9 and the others were made respectively on 15th, 23rd and 29th of August. After algaecide application, TOC values in the reservoir generally began to decrease and this decrease was higher in coastal areas and bays.

Composite samples were taken from 5 points (İğdir, Bay, Port, Pazar and Water intake) for chlorophyll-*a* analysis, and the analysis results are given in Table 2.

Table 2

Chlorophyll-a Analysis Results

Date	Chlorophyll-*a* µg/L
08.08.2019	59,1
12.08.2019	47,6
15.08.2019	89,4
24.08.2019	10,2
26.08.2019	20,1
28.08.2019	35,9
31.08.2019	26,4

According to the results, the algae concentration in water decreased in 5-9 days after the application. Figures 5 and 6 show the situation of the water before and after application at the bay point and port point.

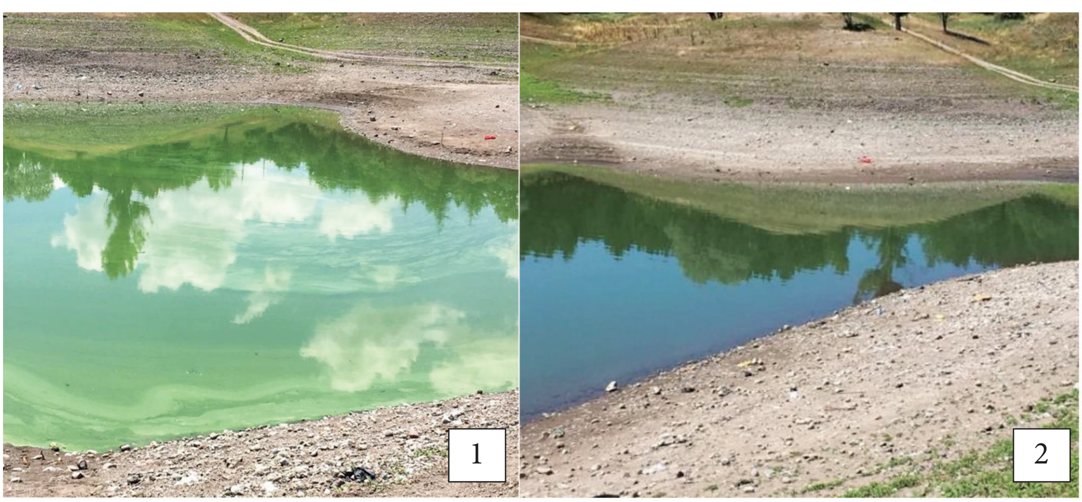

Figure 5. The changes of algae abundance in bay point before (1) and after (2) application.

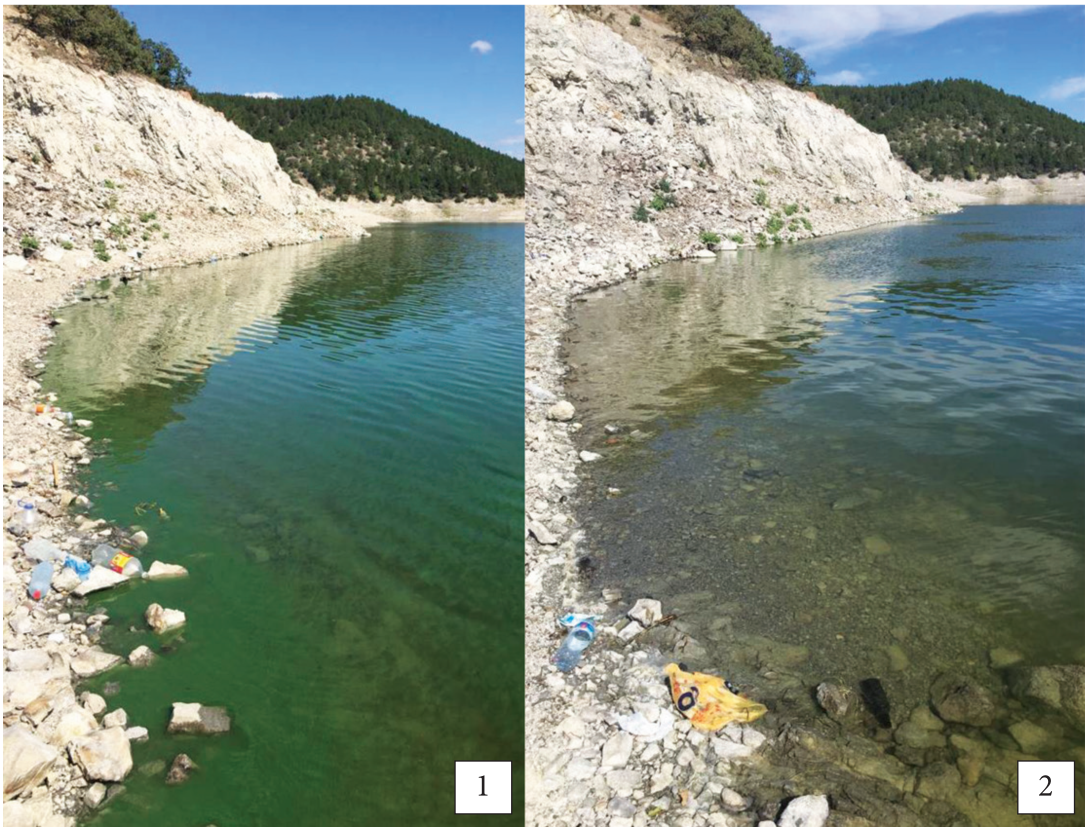

Figure 6. The changes of algae abudance in port point before (1) and after (2) application.

In order to see the effects of the algaecide application, samples were taken from different depths of the dam lake, and the effects of the application on water quality were investigated. Table 3 shows the copper concentration, turbidity, ortho phosphate phosphorus, pH, total nitrogen and total organic carbon through the water column.

Algaecide used in the study consisted of copper ethanolamine complex. The analysis were carried out to determine the changes in the amount of copper as a result of the application in the reservoir. Table 4 shows the changes in the copper concentrations in the raw water in the İvedik water treatment plant.

Table 3

Changes of Water Quality Parameters Depending on Depth

Station	Date	Copper mg/L	Turbidity NTU	Ortho Phosphate Phosphorus mg/L	pH	Total Nitrogen mg/L	Total Organic Carbon mg/L
Surface	08.08.2019	< 0,003	4,80	< 0,02	9,0	1,49	4,65
	26.09.2019	0,012	3,40	-	8,8	< 0,10	4,26
Mid (16 m)	08.08.2019	< 0,003	2,60	< 0,02	8,2	2,21	4,34
	26.09.2019	0,011	3,30	-	7,8	< 0,10	4,57
Deep (32 m)	08.08.2019	< 0,003	4,70	< 0,02	8,2	1,44	3,40
	26.09.2019	0,010	5,60	-	8,0	< 0,10	4,26

Table 4

Changes of Copper Concentrations in Raw Water

Date	Copper mg/L
01.07.2019	0,005
08.07.2019	< 0,003
16.07.2019	< 0,003
22.07.2019	< 0,003
29.07.2019	< 0,003
05.08.2019	< 0,003
15.08.2019	0,012
19.08.2019	< 0,003
26.08.2019	0,005
02.09.2019	< 0,003
09.09.2019	< 0,003
16.09.2019	< 0,003
23.09.2019	0,012
30.09.2019	< 0,003
07.10.2019	< 0,003
14.10.2019	< 0,003

As shown in Tables 3 and 4, there was a slight increase in the amount of copper after application once a week, however it was still under U.S. Environmental Protection Agency (EPA) limit values. It was observed that copper levels returned to the previous levels in one or two weeks after the application. After application, there is a decrease in the amount of total organic carbon and chlorophyll-*a*.

Discussion and Conclusion

Albay et al. (2003) reported a significant reduction in the biomass of cyanobacteria in Ömerli Dam Lake. Pascual and Tedesco (2003) studied the Eagle Creek reservoir and detected a reduction in phytoplankton biomass. Mastin et al. (2002) measured responses of *Lyngbya* from a North Louisiana reservoir and they found 78 % decrease in *Lyngbya* after application. In our study, we have seen a similar decrease in phytoplankton biomass.

According to the study's results, it was confirmed that dosing to drinking water reservoirs with algicide in appropriate doses at the proper time served to prevent algae blooms and also control sudden increases in the amount of algae. Additionally, the results of the analyses showed that copper pollution didn't occur at different depths or at different points in water column. However, a small increase in the amount of copper was detected at samples which have been taken during the algicide effect duration. It was determined that algicide containing copper ethanolamine prevented algae growth when it was used in appropriate doses at the proper time. However, in order to prevent copper pollution: 1) the properties of the algicide should be well known, 2) water quality parameters should be determined, 3) cyanobacteria species and their properties should be identified. It should be noted that the algicide was a chemical substitute and should be applied after all aspects of the application have been evaluated.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Kurtboğazı Baraj Gölü'nde Algisit Kullanımı ve Etkileri

Baraj golleri, elektrik üretimi, içme suyu temini, sulama, balıkçılık, sel kontrolü ve rekreasyon amacıyla akarsular üzerine inşa edilen ve suyu engelleyerek havzada birikmesini sağlayan yapay göllerdir. Bu göller dar, uzun veya dallanmış yapıda olabilir. Baraj gölleri, yüksek akış hızı, giriş suyunda askıda katı madde varlığı, kısa su değişim süresi gibi özelliklerinden dolayı doğal göllerden farklıdır. Su toplama havzasının daha geniş olması nedeniyle doğal göllere göre havzadaki kirlenmeden daha fazla etkilenirler (Demir & Atay, 1999).

İklim değişikliği nedeniyle sıcaklığın artmasıyla birlikte son yıllarda mavi-yeşil algler olarak da bilinen siyanobakteriler su kaynaklarında yoğun ve sıklıkla görülmüştür. Alg artışları giderek büyüyen küresel sorunlardan biri haline gelmiştir. Siyanobakteriler özellikle besin elementlerinden olan azot ve fosfor açısından zengin göl ve barajlarda hızla çoğalırlar ve bu nedenle su kaynaklarının kalitesini bozarlar. Çok aşırı çoğalmaları durumunda özellikle sudaki oksijenin tükenmesine veya aşırı alg artışları sonucunda ortama toksin vererek balık ölümlerine neden olurlar. Bazı siyanobakteri türleri ise insan ve çevre sağlığı açısından oldukça tehlikeli kimyasallar olan siyanotoksinleri salgılayabilmektedirler. Özellikle siyanobakterilerin ürettiği 2- metilisoborneol (2-MIB) ve Geosmin sularda tat ve koku bozukluklarının temel nedeni olup sularda topraksı ve küfümsü kokularıyla karakterize edilirler. Bu kimyasalların arıtma tesislerinde giderimi zor ve maliyetlidir.

Siyanobakteriler gerçek çekirdekleri, zar ile çevrili organelleri ve plastidleri olmayan prokaryotik canlılardır (Cirik & Cirik, 2004). Alglerin mavi yeşil görünümü fikosiyanin ve diğer pigmentlerin fikoeritrin pigmentini örtmesinden kaynaklanmaktadır (Rinehart ve ark., 1994). Çekirdek zarı olmadığından DNA ve pigment maddeleri sitoplazma içinde dağınık halde bulunur. Hücre çeperi selüloz ve pektindir. Yedek besin maddesi nişasta yerine glikojen, proteinlerden siyanofisin ve volitindir (Chorus & Bartram, 1999). Klorofil-***a*** içerirler. Renkleri mavi-yeşilden kırmızı renge kadar değişim göstermesine rağmen genel olarak mavi-yeşil olduğundan mavi-yeşil algler olarak da adlandırılırlar. Birçok siyanobakteri türü aerobik fototroftur, fakat bazıları heterotrofik özellik de gösterir. Siyanobakterilerin hücre şekilleri tek, filament veya koloni şeklindedir (Cirik & Gökpınar, 1993). Bazı türleri yüzeylere yapışık olarak gelişirken, bazı türleri su sütununun tamamına dağılmış olarak bulunurlar. Çoğalmasında su sıcaklığı, güneş ışığı, yüksek besin maddesinin bulunması, otlatma, iklim gibi çeşitli faktörler etkilidir (Anonymous, 2010). Kimyasal yapılarına göre, siyanotoksinler birkaç ana gruba ayrılır: peptitler, heterosiklik bileşikler (alkaloidler) veya lipitik bileşikler (Sivonen &Jones, 1999).

Aşırı alg artışları su arıtımını güçleştirmekte ve suda istenmeyen bir tat ve koku oluşumuna sebep olmaktadır. Suda arıtılamayan algler klorlama sonucu trihalometan ve bazı kansorejen ürünleri açığa çıkarır (Kotak ve ark., 1993).

Çalışmada algisit uygulaması öncesinde ve sonrasında TOC miktarı, klorofil-*a* miktarı, çözünmüş oksijen miktarı, pH, sıcaklık ölçümleri ve siyanobakteri tür tespiti yapılmıştır.

Seki derinliği ölçümleri seki diski ile yapılmıştır. Çözünmüş oksijen miktarı, pH, sıcaklık ölçümleri wtw multi 3320 saha tipi ölçüm cihazları ile yapılmıştır. Klorofil-*a* ölçümlerinde Hach

DR 6000 model spektrofotometre kullanılmıştır. TOC ölçümleri ve kimyasal analizler ASKİ Genel Müdürlüğü'ne bağlı Akredite Laboratuvarında yapılmıştır. Tür tespiti için gerekli numunelerin alınmasında plankton kepçesi kullanılmıştır.

Algisit uygulaması rutin olarak haftada bir kez olmak üzere planlanmıştır. Sulama yapısının 300 metre uzağından başlanarak çalışmalar yapılmıştır. Algisit seçiminde, sucul ortamda yaşayan balık vb. canlılara zararı olmayan ve bakır etanolamin içerikli olanı tercih edilmiştir. Algasit 1/10 oranında seyreltilerek kullanılmıştır.

Uygulamada kullanılan tekne 4,90 m uzunluğunda, 20 hp motora sahiptir. Kullanılan tekne üzerinde 300 lt kapasiteye sahip bir tank bulunmaktadır. Suya dozaj yapılabilmesi için tanktan teknenin her iki yanından dışarısına doğru 3 metre uzunluğunda tesisat sistemi yapılmıştır. Tankın doldurulmasında elektrik enerjisi ile çalışan pompa sistemi kullanılmıştır. Elektrik kaynağı olarak şarj edilebilir aküler kullanılmıştır. Uygulama 2 personel tarafından yapılmıştır.

Siyanobakteriler farkı derinliklerde görülebilir. Bazı siyanobakteri türleri yüzeyde tabaka oluşturacak şekilde (*Microcystis* vb) bazı siyanobakteri türleri suyun üst tabakalarında dağınık halde bulunabilir. Diğer yandan bazı türler termoklin tabakasında yer alabilirler (Albay ve ark., 2016). Bu sebeple uygulama öncesinde sudan numuneler alınarak baskın türün tespiti önem arz etmektedir. Tespit edilen türe göre uygulama stratejisi belirlenmelidir.

Yapılan çalışma esnasında yaz döneminde farklı zamanlarda 2 farklı tür tespit edilmiştir. Alınan numuneler sonucunda *Microcystis aeruginosa, Dolichospermum planctonicum* türlerinin baskın olduğu tespit edilmiştir. Buna göre uygulama stratejisi geliştirilmiştir. Su derinliğinin 1 metreye kadar olan bölümü uygulama için dikkate alınmıştır.

Hesaplanan su kütlesine göre etki süresi göz önüne alındığında haftalık 400 kg algasit tüketimi öngörülmüştür. Ancak yaz mevsiminin sonunda 2 haftalık süreç içerisinde yoğunluk artmış olup bu dönemde haftalık doz miktarı 700 kg'a çıkartılmıştır.

Yapılan çalışmada siyanobakterilerin durgun su ve kıyı sularında daha fazla geliştiği ana su kütlesinde bulunma miktarlarının az olduğu tespit edilmiştir. Rota elde edilen verilere göre düzenlenmiş ve Şekil 4' te gösterilmiştir. Ayrıca ana su kütlesi içerisine koruma amaçlı uygulama yapılmıştır. Çalışmada güneşli günler tercih edilmiş olup dozlama güneş ışınlarının yoğun geldiği saatlerde yapılmıştır.

İlk uygulama 9 Ağustos tarihinde yapılmıştır. Diğer uygulamalar ise 15 Ağustos, 23 Ağustos ve 29 Ağustos tarihlerinde yapılmıştır. Numune noktalarından dördü kısmen akıntıya sahip değişken bir su yapısına sahipken bir nokta akıntı alanı dışında kalmakta ve hareketsiz su kütlesinde bulunmaktadır. Elde edilen bulgulara göre TOC değerlerinde genel olarak bir düşüş olmakla beraber bu düşüşün hareketsiz bölümde fazla olduğu görülmektedir.

Yapılan çalışmada elde edilen sonuçlara göre uygun doz ve sürede yapılan dozlama aşırı alg artışlarının önüne geçilmesine ve ani artışların kontrol altına alınmasına yardım etmektedir. Analiz sonuçlarına göre farklı derinliklerde ya da farklı noktalarda bakır kirliliği oluşmamakta, bununla beraber algisit etki süresinde alınan numunelerde zaman zaman küçük miktarlarda artış görülmektedir.

Bakır etanolamin içeren algisit, uygun doz ve sürede kullanıldığında alg artışının önüne geçtiği tespit edilmiştir. Ancak bakır kirliliği oluşturmaması için kullanılması planlanan algisitin özelliklerinin yanı sıra sudaki siyanobakteri türlerinin ve özelliklerinin iyi bilinmesi, su kalite parametrelerinin tespit edilmesi gerekmektedir. Kullanılacak olan algisitin bir kimyasal olduğu unutulmamalı yapılacak olan çalışmalar tüm yönleriyle değerlendirildikten sonra uygulanmalıdır.

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Technical Note

Evaluation of Reuse of Wastewater in Agriculture in Turkey: Outbreak Perspective of Covid-19

Kovid-19 Pandemisi Çerçevesinde Türkiye'de Kullanılmış Suların Tarımda Yeniden Kullanılmasının Değerlendirmesi

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Abstract

The recent outbreak of novel coronavirus disease 2019 has become a public health emergency worldwide. The virus, SARS-CoV-2 is spread by human to human transmission via droplets or direct contact. Although there is no evidence of its transmission from wastewater, the virus has been discovered in wastewater. Recent studies showed that SARS-CoV-2 is very sensitive to oxidants such as chlorine. Therefore, disinfection units of treatment plants need to be operated to avoid virus existence in the environment. Moreover, the disinfection process is vital if treated water is going to be used in irrigation. More than one-third of the effluents of wastewater treatment plants in Turkey reaches to agricultural irrigation facilities. The majority of these waste water treatment plants do not have a disinfection unit. Agricultural areas irrigated with treated wastewater have a rich crop pattern in Turkey. Almost half of these agricultural areas used to grow raw-consumable products. Therefore, disinfection units need to be operated properly and the facilities without disinfection unit should be revised. Moreover, regulations are not comprehensive to prevent public health in terms of reuse of wastewater in agriculture in Turkey. There are one regulation and one standard available considering reuse of wastewater in irrigation but neither of them is not covering indirect reuse of treated wastewater in the downstream. Therefore, to prevent public health it is needed to update regulations to include indirect reuse of wastewater.
Keywords: *Sars-Cov-2, Covid-19, reuse of wastewater, irrigation, waste water treatment plants*

Öz

Yakın zamanda ortaya çıkan Kovid-19 hastalığı sebebi ile dünya çapında acil durum ilan edilmiştir. Yapılan araştırmalar bu hastalığa yol açan SARS-CoV-2 virüsünün damlacıklar vasıtasıyla veya temas

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yolu ile bulaştığını göstermiştir. Atıksular yoluyla bulaşmasına ilişkin herhangi bir kanıt olmamasına karşın yapılan çalışmalarda atıksulardaki varlığı gösterilmiştir. Ayrıca, zarflı bir virüs olduğundan klor benzeri oksidanlara karşı dayanıksız olduğu ortaya konulmuştur. Dolayısıyla, virüsün çevredeki varlığının elimine edilmesi için atıksu arıtma tesislerinin dezenfeksiyon ünitelerinin çalıştırılması önem kazanmıştır. Özellikle arıtılmış atık suları doğrudan veya dolaylı olarak sulamada kullanılan tesislerin deşarj işlemi öncesi dezenfeksiyon uygulaması yapılması hayati önem taşımaktadır. Türkiye'deki atıksu arıtma tesislerinin üçte birinden fazlasının suyu sulama tesislerine ulaşmaktadır ve bu tesislerin çoğunluğunda dezenfeksiyon ünitesi bulunmamaktadır. Türkiye'deki arıtılmış atıksular ile sulanan arazilerin ürün deseni çok çeşitlidir ve yarısından fazlasında çiğ tüketilen ürünler üretilmektedir. Bu sebeple, dezenfeksiyon ünitesi bulunan tesisler uygun şekilde dezenfeksiyon işlemi uygulamalıdır ve dezenfeksiyon ünitesi bulunmayan tesisler revize edilmelidir. Ek olarak, kullanılmış suların sulama amaçlı tekrar kullanılması konusunda halk sağlığını korumaya yönelik kapsamlı bir mevzuat bulunmamaktadır. Kullanılmış suların sulama amaçlı yeniden kullanılması konusunda 1 adet mevzuat ve 1 adet standart olmasına rağmen kullanılmış suların mansaplandığı yerlerden dolaylı olarak tekrar kullanılmasını kapsamamaktadır. Dolayısıyla halk sağlığının korunması amacı ile kullanılmış suların dolaylı olarak yeniden kullanılmasını kapsayan mevzuat hazırlanmalıdır.

Anahtar kelimeler: *Sars-Cov-2, Kovid-19, kullanılmış suların yeniden kullanılması, sulama, atıksu arıtma tesisleri*

Introduction

The major portion of the available water, around 70% in the use of agricultural irrigation, globally (Pimentel & Pimentel, 2008). Therefore, it has been always an issue to diversify water sources to irrigate. Since ancient times reuse of wastewater in agriculture for crop irrigation has been applied (Angelakis & Synder, 2015). The main reason for reusing brings many advantages. The main advantages of wastewater reuse are an increase in agricultural productivity, reduction in energy need of production-treatment, and distribution of water. Moreover, the reusing of wastewater nutrient discharge into the environment decreases (EPA, 2012). Additionally, it is known that to prevent water resources, the reuse of wastewater is an effective method (Manga et al., 2001). Reusing wastewater is not only beneficial to decrease the need for water sources but also gives the opportunity to irrigate during dry seasons or under water shortage situations. On the other hand, dealing with wastewater may become challenging since it includes the following pathogens and chemical substances shown in Table 1.

Table 1

Chemical and Biological Risks Associated with the Use of Raw Wastewater in Agriculture (WHO, 2006)

Type of Risk		
Biological	Bacteria [1]	*E. coli, Vibrio cholerae, Salmonella* spp., *Shigella* spp.
	Helminths [1]	*Ascaris, Ancylostoma, Tenia spp.*
	Protozoans [1]	*Intestinal Giardia*, Crysptospridium,
	Virus [1]	Entamoeba spp. Hepatitis A and E, Adenovirus, Rotavirus, Norovirus
	Schistosoma [2]	Blood-flukes
Chemical	Substance of sanitary interest Heavy Metals [2] Hydrocarbons [2]	Arsenic, Cadmium, Mercury Dioxins, Furans, PCBs
	Pesticides [1]	Aldrin, DDT

Note. [1]Contact and/or consumption, [2]Consumption.

During the 19th century, wastewater may did not include all pathogens and chemicals listed in Table 1. However, transporting wastewater and disposing it to the open peri-urban areas resulted in catastrophic epidemics of water-borne diseases like cholera and typhoid fever (Felizatto, 2001). Accordingly, the importance of sanitation promoted and organizations such as the World Health Organization (WHO) or the Food and Agriculture Organization (FAO) investigated and published documents to prevent such problems (Seguí, 2004). These organizations still in duty and nowadays they are trying to understand and help countries to deal with Covid-19 disease.

Coronavirus (officially SARS-CoV-2), which cause a respiratory disease called Covid-19, was first detected during an epidemic in the city of Wuhan, China on 12 December 2019, and then spread all over the World. Coronavirus, a family member of Coronaviridae identified during 1960s'. Including SARS-CoV-2, Middle East respiratory syndrome virus (MERS-CoV - 2012), and severe acute respiratory syndrome virus (SARS-CoV, 2003 - China), highly pathogenic strains of Coronaviridae family emerged within last two decades. The size of the coronaviruses is between 60 to 220 nm and they are enveloped single strained RNA viruses with crown-like spikes on their surfaces (Naddeo & Liu, 2020). Especially for experts working on water and wastewater, it is very important to have information about the ways of spreading the virus, the problems it causes, and the measures that can be taken to protect workers and public health. For this reason, WHO issued an information note on 19 March 2020, covering viruses, water, public health, and hygiene (WASH), including coronavirus, as a contribution to existing infection prevention and control (IPC) documents. It is stated in the information note that COVID-19 has two main ways of transmission which are inhalation and contact. Respiratory transmission is usually caused by the inhalation of viruses on the droplets that are spread around the environment when an infected person coughs or sneezes. Additionally, scattering of the viruses on the surrounding surfaces and getting contact with another person is defined as another way of transmission (WHO, 2020). Although coronavirus has been detected in wastewater and sludge samples (Kocamemi et al., 2020), there is no satisfactory evidence that the virus has been transmitted through water sources or wastewater. Additionally, studies on how long the surrogate coronavirus survives in water and wastewater have pointed out different existence lifetime form month to days (Casanova et al., 2009; La Rosa et al., 2020). However, considering that the risk of infection will increase during epidemic diseases, it is beneficial to take more protective measures for those who are at risk of coming into contact with raw wastewater or wastewater (Medema et al., 2020). Coronavirus in an emerging issue today but, a list of water-borne diseases transmitted directly or indirectly via water listed below in Table 2 also needs to be considered especially in case of reusing wastewater.

WHO published an initial guideline document, “Reuse of effluents: methods of wastewater treatment and health safeguards” in 1973. The latest version of the document published in 2006 and it gives an opinion to decision-makers on the wastewater application. The main purpose of the document is the standardization of the wastewater management within the specific objective of the country (WHO, 2006; Mara et al., 2007; Mara & Kramer, 2008). Additional to the WHO document, FAO published wastewater quality guidelines to use wastewater in agriculture in 1987 and focused on the degree of restriction of water use of salinity, infiltration, and toxicity parameters of specific ions. After that, the document updated in 1999 and guided about treatment requirements and treated water reuse in agriculture (Ayers & Wescott, 1985; Pescod, 1992). Not only WHO and FAO focused on the issue but also Environmental Protection Agency (EPA) supports the idea of wastewater reuse might have toxic effects on health and environment when it is used for irrigation and published guidelines document in 1992 and updated the Guidelines for Wastewater Reuse in 2012 with United States Agency for International Development (USAID) (EPA, 2004; EPA, 2012).

Table 2

Wastewater Related Water-Borne Diseases (Romero, 1996; Von Sperling, 1996; Jiménez & Rose, 2009; Evans & Mara, 2011)

Disease	Cause
Typhoid fever	*Salmonella typhi*
Paratyphoid fever [2]	*Salmonella paratyphi*
Gastroenteritis [1]	*Salmonella typhimurium*
Cholera [2]	*Vibrio cholerae*
Bacillary dysentery [2]	*Shigella dysenteriae*
Amebiasis [2]	*Entamoeba histolytica*
Giardiasis [1]	*Giardia duodenalis*
Cryptosporidiosis [1]	*Cryptosporidium*
Cyclosporiasis [2]	*Cyclospora cayetanensis*
Infectious hepatitis [1]	Hepatitis A
Gastroenteritis [2]	Enterovirus, parvovirus, rotavirus
Infantile paralysis	Poliovirus
Leptospirosis [1]	*Leptospira icterohaemorrhagiae*
Ear infections	*Pseudomonas aeruginosa*
Scabies	*Sarcoptes scabiei*
Trachoma	*Chlamydia trachomatis*
Schistosomiasis [2]	*Schistosoma*
Malaria	*Plasmodium*
Yellow fever	Flavivirus
Dengue	Flavivirus

Note. [1]Human and/or animal excrement, [2]Human excrement.

In Turkey, wastewater reuse in agriculture is partially regulated. The first regulation accepted on December 1989, is a standardization of irrigation water and called “irrigation water – TS 7739”. This standard applies to irrigation water used in the culture of vegetable production, such as water of rivers, lakes, brooks, artesians, spring and other water sources. It does not apply water used for the purpose of drinking and commercial use. The second regulation is published by Ministry of Environment and Forestry of Turkey in 2010, called technical procedure communiqué of wastewater treatment plants given under annex 7 (TSE, 1989; Mevzuat, 2010). However, both of the regulations do not cover pathogenic risks may occur due to de facto reuse of wastewater in the downstream of the effluent. Nowadays, the importance of the subject is rising since it is approved Sars-Cov-2 virus exist in wastewater and increased the need of measure should be taken by governments.

The main objective of this study is to reveal the results of the "Assessment of Reuse Alternatives of Wastewater" project run by the Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Water Management. Moreover, sharing the situation of wastewater reuse in agriculture in Turkey and determining the actions need to be taken.

Method

In the project of 2017/294533 run by Republic of Turkey Ministry of Agriculture and Forestry General Directorate of Water Management "Assessment of Reuse Alternatives of Wastewater", municipal wastewater treatment plants (WWTPs) with the equal or higher capacity of 2000 m^3/d are focused between years 2017 to 2019. At first 598 WWTPs identified and in addition to these facilities 3 smaller than 2000 m^3/d capacity treatment plants included in the inventory and a total of 601 WWTPs were evaluated. Moreover, the data of 328 irrigation facilities operated or transferred by State Hydraulic Works (DSİ) with more or equal to 1000 ha evaluated within the project.

Municipalities, DSİ and farmers are the main stakeholders of the project. Many of the WWTPs are visited on-site and gathered detailed information about the process and the current situation of the facilities. Furthermore, data request forms sent to municipalities to share; quantity of water they treat within the last 3 years, water loss rates, water reuse alternatives if it is already available and treatment plant location information with General Directorate of Water Management. Moreover, to have a better understanding of water quality, samples from the effluents collected and analyzed by an accredited commercial lab.

One of the major reuse alternatives was using wastewater in agricultural irrigation. Therefore, the literature reviewed and during on-site visits product pattern of the available agricultural sites investigated and met with local people to understand their needs. Geographical information systems used to evaluate the size of the available agricultural area and to check the potential route of water transportation.

Results

The performed study showed that 384 of the total 601 facilities are in operation in terms of inventory of the wastewater treatment plants. The number of WWTPs in the project is 89, 78 are planned, 35 are under construction, 12 are not operating and 3 are under revision shown in Figure 1. Additionally, the number of WWTPs with varying projected flowrates under 7 categories given in Table 3. It is figured that 258 treatment plants applying advanced treatment with a total flowrate of 9.6 hm^3/d which is 49 % of the total treated wastewater covered within this project in a day in Turkey. Moreover, 217 WWTPs having biological treatment and treat 5.2 hm^3/d and it is 27 % of the total. There are also 17 stabilization ponds and 11 WWTPs with different treatment techniques summarized in Figure 2.

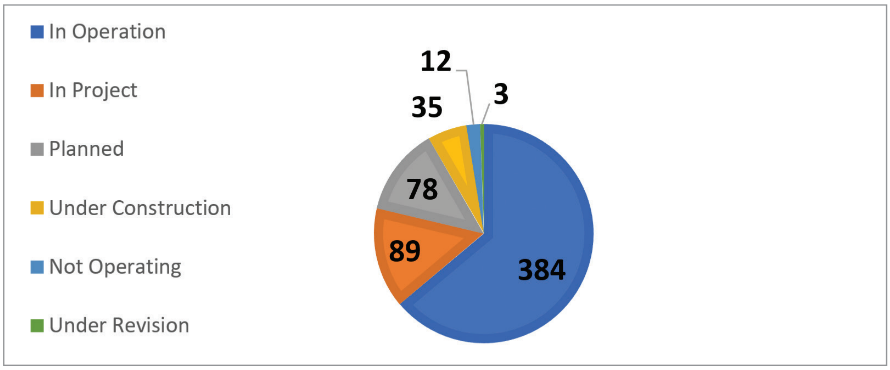

Figure 1. Condition of WWTPs in Turkey with an equal or higher capacity of 2000 m^3/d.

It was evaluated that the total flowrate of wastewater treated by 601 WWTPs is 7113 hm^3/year. The reuse option is available for 5615 hm^3/year wastewater. In other words, the amount of wastewater that is not possible to reuse is 1498 hm^3/year. Although the reuse option is available, in some cases depending on priorities of the stakeholders 47 % of the total wastewater, 3375 hm^3/year is recommended to reuse. Furthermore, 60 % of the amount of wastewater recommended to reuse, 2026 hm^3/year, is available for agricultural irrigation. In addition, 774,679 m^3/year wastewater pointed to reuse in landscape irrigation.

Table 3

Number of WWTPs with Different Flowrates

No	Projected flowrate (m^3/d)	Amount
1	<2.000	3
2	=2.000	15
3	>2,000 – 5,000≤	193
4	>5,000 – 10,000≤	131
5	>10,000 – 50,000≤	180
6	>50,000 – 100,000≤	40
7	>100,000	39
	TOTAL	601

Agricultural reuse of wastewater has a high potential in Turkey. But, it should be applied carefully. Analyzes in the effluent of the wastewater treatment plant have shown that wastewater will have to be subjected to additional treatment before it can be reused even if it is currently treated. It is found that salinity of wastewater is high and incorrect reuse of high salinity wastewater cause salting in the soil. Moreover, microbiologically effluent waters may be a problem in terms of fecal coliform and Escherichia coli. De facto reuse of 221 treatment plants` effluents with a total inflow rate of 6.7 hm^3/day are already in use in agriculture. Unfortunately, the result of this study showed that both treatment plants and regulations need to be improved.

The total irrigated area of Turkey is around 6.5 million ha out of the irrigable area. In the activity report (2018) published by DSI, there are 320 irrigation facilities (2.27 million ha) with an area of 1000 ha and more delegated to irrigation unions in charge of operation-maintenance and management responsibilities. 1.8 million ha, 28% of 6.5 million ha, irrigation facilities operated by the unions indirectly irrigated by wastewater. Provided that in winter and autumn season wastewater is stored in order to be reused, 13% which is around 245,000 ha (as a comparison, 1.56 times bigger than Harran Irrigation) of the irrigated areas of the facilities operated by the unions can be potentially irrigated with the wastewater shown in Figure 2.

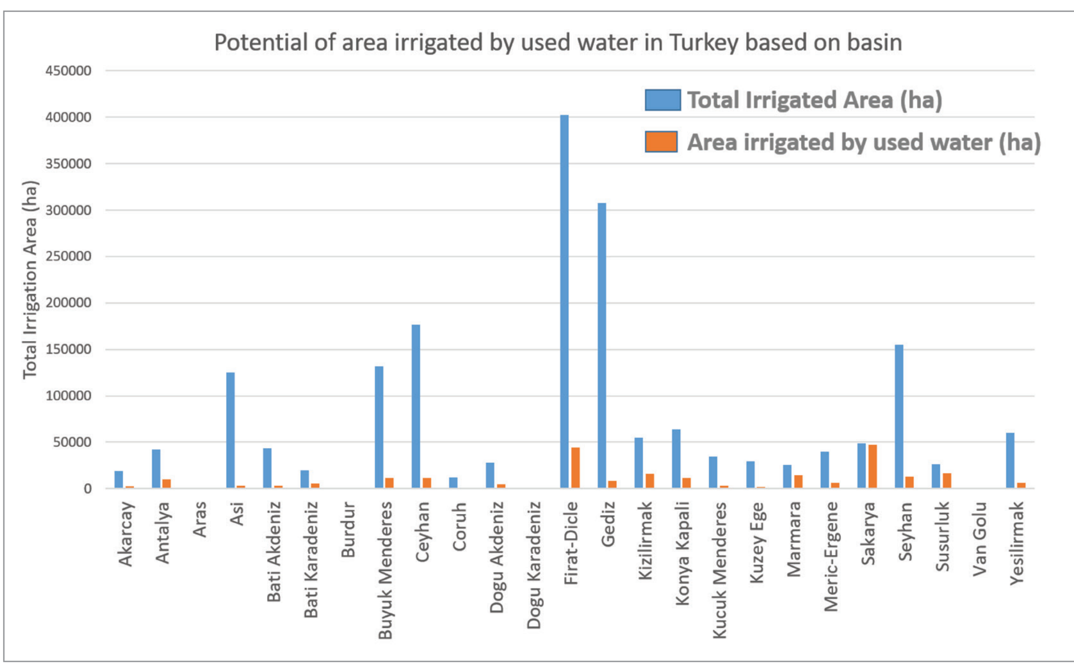

Figure 2. Irrigation area in de facto use of wastewater in Turkey.

Firat-Dicle and Gediz river basins almost cover 40% of 1.8 million ha area. There is a wide variety of product patterns in the irrigation areas. For instance, wheat, barley, sunflower, sugar beet, melon, vegetable, fruit, vineyard, citrus, cotton, olive, sesame, corn, etc. many products are irrigated with wastewater. Moreover, it is known that treated wastewater from 92 out of 221 treatment plants is in use to irrigate raw consumable vegetables. Additionally, 50 WWTPs` effluent with the total flowrate of 1.4 hm^3/day flow through dams and the majority of them are irrigation dams.

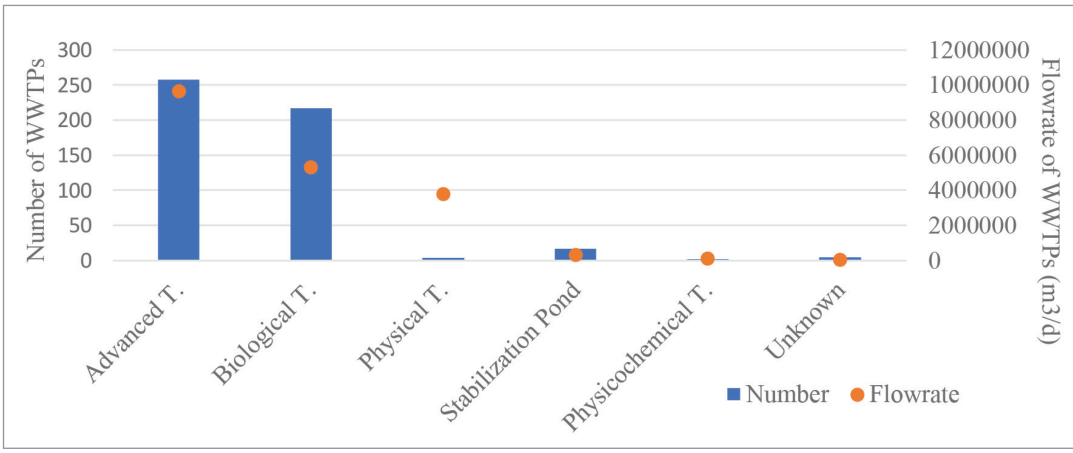

Figure 3. Flowrate and number of WWTPs according to their treatment process.

Only 53 WWTPs with the total flowrate of 1.3 hm^3/day in Turkey include disinfection unit between 601 of them. Treatment plants of 221 which are already in use to irrigate, only 42 of them have disinfection unit.

Discussion and Conclusion

The purpose of this study is to define the current situation and evaluation of actions need to be taken in Turkey in terms of reuse of wastewater in agriculture.

The recent outbreak of coronavirus disease in 2019 has become a public health emergency worldwide. The virus, SARS-CoV-2 is spread by human to human transmission via droplets or direct contact. Although there is no evidence of its transmission from wastewater, the virus has been discovered in wastewater. Recent studies showed that SARS-CoV-2 is very sensitive to oxidants such as chlorine. Therefore, disinfection units of treatment plants need to be operated to avoid virus existence in the environment. Moreover, the disinfection process is vital if treated water is going to be used in irrigation. More than one-third of the effluents of wastewater treatment plants in Turkey reaches to agricultural irrigation facilities. The majority of these WWTPs do not have a disinfection unit. Agricultural areas irrigated with treated wastewater have a rich crop pattern. Almost half of these agricultural areas used to grow raw-consumable products. Therefore, disinfection units need to be operated properly and the facilities without disinfection unit should be revised. The disinfection process is important to kill not only the SARS-CoV-2 virus but also especially to destroy pathogens of water-borne diseases.

It is clear that this virus includes uncertainties about infection through wastewater reuse in agricultural irrigation. More detailed research studies should be carried out on this subject. However, this shows that it is an undeniable fact that the process from the wastewater treatment plant to the agricultural irrigation and consumers should be improved and implemented, with a holistic approach to the reuse of treated wastewater, especially in the case of an outbreak. There are one standard and one regulation in terms of reuse of wastewater in irrigation in Turkey. The first regulation called "irrigation water standard" includes several chemicals but does not cover microbiological parameters. The second regulation, "technical procedure communiqué of wastewater treatment plants given under annex 7", published by the abrogated Ministry of Environment and Forestry of Turkey in 2010, and it sets both chemical and biological limits. However, the second regulation only covers direct effluent reuse of treated wastewater. In other words, it does not include de facto reuse of treated wastewater in the downstream. It is inevitable to reuse treated wastewater indirectly in agriculture which may end up with public health tragedy. Therefore, to prevent public health it is needed to update regulations to include indirect reuse of wastewater.

Disinfection process is a vital application in water treatment but, it is also very complicated. Even the aim is protecting public health by disinfection it may end up with formation of disinfection by-products (DBPs), toxic substances in water. Although literature is rich with studies focusing on DBPs formation from natural organic matter (NOM) and in fresh waters, there is still limited information about DBPs formation and speciation from effluent organic matter (EfOM) in treated wastewater effluents. The EfOM of treated wastewater includes more nitrogen-containing compounds than NOM (e.g N/C mass ratios of EfOM and NOM are ~ 0.20 and 0.01-0.06, respectively). Additionally, the concentrations of bromide and iodide are higher in wastewater effluents compared to surface waters. Thus, formation of iodinated and brominated DBPs which are more toxic than their chlorinated analogues is favored. Therefore, water quality data and reuse application need to be considered to decide on the suitable disinfection process.

Treated wastewater is an important alternative to a water source, especially when it comes to the top of climate change adaptation strategies. While these waters will have strategic importance in the water supply in the future, it is obvious that they contain some health risks. However, taking the necessary steps to eliminate these risks has become an indispensable necessity in today's conditions.

Acknowledgement

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Kovid-19 Pandemisi Çerçevesinde Türkiye'de Kullanılmış Suların Tarımda Yeniden Kullanılmasının Değerlendirmesi

Dünya üzerinde suların %70'i tarımsal sulama amacı ile tüketilmektedir. Bundan dolayı alternatif su kaynaklarının tarımsal sulamada kullanılması her zaman gündeme gelmiş ve antik çağlar da dahil bitkiler kullanılmış sularla sulanmıştır. Kullanılmış suların tekrar kullanılmasının çeşitli avantajları vardır. Tarımsal verimin artması, kullanılmış suyun arıtılması ve dağıtımı için gerekli enerjinin azaltılması başlıca avantajları arasındadır. Ek olarak, atıksular çevreye daha az miktarda deşarj edilir. Ancak, kullanılmış suların tehlikeli kimyasal maddeler ve patojenik mikroorganizmalar içermesi sebebiyle geri kullanımında dikkatli olunması gerekmektedir.

19.yy'da kullanılmış suların kentlerin çevresindeki alanlarda yeniden kullanılması kolera ve tifo epidemisine sebep olmuştur. Sonrasında, sanitasyonun önemi artmış ve Dünya Sağlık Örgütü (WHO), Gıda ve Tarım Organizasyonu (FAO) ve Çevre Koruma Ajansı (EPA) vb. kurumlar konu üzerine çalışmalar yapmış ve kılavuzlar yayımlamışlardır. Yayımlanan kılavuzlarda; atıksuların tarımsal amaçlı tekrar kullanılmasında, kullanılmış sulara uygulanması gereken arıtma metotları ile suyun ulaştırılması gereken kalitesi için kimyasal ve biyolojik parametreleri detaylı olarak ortaya konmuştur.

Yakın zamanda ortaya çıkan Kovid-19 hastalığı sebebi ile dünya çapında acil duruma geçilmiş ve Dünya Sağlık Örgütü tarafından pandemi ilan edilmiştir. Yapılan araştırmalar bu hastalığa yol açan SARS-CoV-2 virüsünün damlacıklar vasıtasıyla veya temas yolu ile bulaştığını göstermiştir. Atıksular yoluyla bulaşmasına ilişkin herhangi bir kanıt olmamasına karşın atıksulardaki varlığı yapılan çalışmalarda gösterilmiştir. Ayrıca, virüsün klor benzeri oksidanlara karşı dayanıksız olduğu ortaya koyulmuştur. Dolayısıyla, virüsün çevredeki varlığının elimine edilmesi için atıksu arıtma tesislerinin dezenfeksiyon ünitelerinin çalıştırılması önem kazanmıştır.

T.C. Tarım ve Orman Bakanlığı, Su Yönetimi Genel Müdürlüğü tarafından yürütülmüş olan "Kullanılmış Suların Yeniden Kullanım Alternatiflerinin Değerlendirilmesi" projesi kapsamında Türkiye'deki 2000 m^3/gün ve daha yüksek kapasiteli 598 atıksu arıtma tesisi ile 3 adet daha düşük kapasiteli olmak üzere toplam 601 atıksu arıtma tesisi, toplam atıksu arıtma kapasitesi 19,5 hm^3/gün, değerlendirmeye alınmıştır. Bu tesislerden 384 tanesinin işletmede olduğu tespit edilmiştir. Ayrıca, değerlendirmeye alınan tesislerin 258 tanesinin, 9,6 hm^3/gün debi ile ileri arıtma tesisi olduğu belirlenmiştir. Biyolojik arıtma tesislerinin sayısının ise 217 olduğu ve toplam 5,2 hm^3/gün debiye sahip olduğu görülmüştür. Yürütülen projede arıtılan toplam atıksuyun %47'si yani 9,2 hm^3/gün arıtılmış atıksuyun geri kullanımı önerilmiştir. Yeniden kullanılması önerilen suların ise %60'ı, 5,6 hm^3/gün, tarımsal sulama amaçlı kullanımının uygun olacağı ifade edilmiştir.

Türkiye'nin toplam sulanabilir alanı yaklaşık 6,5 milyon ha'dır. DSİ tarafından yayımlanan raporda (2018), 1000 ha ve daha fazla işletme-bakım ve yönetim sorumluluklarından sorumlu sulama birimlerine devredilmiş 320 sulama tesisi (2,27 milyon ha) bulunmaktadır. 1,8 milyon hektar, 6,5 milyon hektarın % 28'i olup, kullanılan su ile dolaylı olarak sulanmaktadır. Kış ve sonbahar mevsiminde kullanılan suyun yeniden kullanılmak üzere depolanması şartıyla, birlikler tarafından

işletilen tesislerin sulanan alanlarının % 13'ü [karşılaştırma olarak 245.000 ha (Harran Sulamadan 1,56 kat daha büyük)] kullanılmış su ile sulanabilecek potansiyeldedir. Güncel olarak 221 atıksu arıtma tesisinin çıkış sularının fiili olarak tarımsal amaçlı kullanıldığı belirlenmiştir. 92 tesisin arıtılmış atıksularının çiğ tüketilen sebzelerin yetiştirildiği alanlarda kullanıldığı tespit edilmiştir. Ayrıca 50 atıksu arıtma tesisinin çıkış sularının sulama amaçlı kullanılan barajlara mansaplandığı belirlenmiştir. Çıkış sularının tarımsal alanlarda kullanıldığı belirtilen 221 tesisin yalnızca 42 tanesinde dezenfeksiyon ünitesi bulunmaktadır.

Bu çalışmanın amacı arıtılmış atıksuların tarımsal amaçlı kullanılması açısından Türkiye'deki güncel durumu ve atılacak adımları belirlemektir. Özellikle arıtılmış atık suları doğrudan veya dolaylı olarak sulamada kullanılan tesislerin deşarj işlemi öncesi dezenfeksiyon uygulaması hayati önem taşımaktadır. Türkiye'deki atıksu arıtma tesislerinin üçte birinden fazlasının çıkış suyu sulama tesislerine ulaşmaktadır ve bu tesislerin çoğunluğunda dezenfeksiyon ünitesi bulunmamaktadır. Dezenfeksiyon ünitesi bulunan tesislerin de bir kısmı doğru şekilde işletilemez iken bir kısmı dezenfeksiyon işlemi uygulamamaktadır. Türkiye'deki arıtılmış atıksular ile sulanan arazilerin ürün deseni çok çeşitlidir ve yarısından fazlasında çiğ tüketilen ürünler üretilmektedir. Bu sebeple, dezenfeksiyon ünitesi bulunan tesisler uygun şekilde dezenfeksiyon işlemi uygulamalıdır ve dezenfeksiyon ünitesi bulunmayan tesisler revize edilmelidir. Ek olarak, kullanılmış suların sulama amaçlı tekrar kullanılması konusunda halk sağlığını korumaya yönelik kapsamlı bir mevzuat bulunmamaktadır. Kullanılmış suların sulama amaçlı tekrar kullanılması konusunda 1 adet mevzuat ve 1 adet standart olmasına karşın kullanılmış suların mansaplandığı yerlerden dolaylı olarak tekrar kullanılmasını kapsamamaktadır. Dolayısı ile halk sağlığının korunması amacı ile dolaylı olarak kullanılmış suların yeniden kullanılmasını kapsayan mevzuat oluşturulmalıdır. Arıtılmış atık su, özellikle iklim değişikliğine uyum stratejileri konusunda hayati bir su kaynağı olarak önemli bir alternatiftir. Bu sular gelecekte su temininde stratejik bir öneme sahip olsa da, bazı sağlık riskleri içerdikleri açıktır. Ancak, bu riskleri ortadan kaldırmak için gerekli adımları atmak günümüz koşullarında vazgeçilmez bir ihtiyaç haline gelmiştir.

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Research Article

Infaunal Community Responses to the Gradient of Heavy-metals in Langstone Harbour, UK

Langstone Limanı (Birleşik Krallık) İçfaunal Komünitesinin Ağır Metal Değişimlerine Tepkileri

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Abstract

The complex nature of the marine environments including a broad array of factors seems inconvenient to have specific indicator organisms alerting the changes in ecological quality based on pollutant inputs to water bodies. Benthic infauna, however, may respond to the pollution-induced spatial quality changes in a tidal inlet as they are incapable to avoid from the pollution sources and hence, from low quality of sediment and water. This research suggested that the interaction of sediment metal stressors and the possible associated factors finer grain fractions, estuary position and depth is likely to encounter with a specific distributional pattern of infauna. The communities of macroinfauna in Langstone Harbour were studied spatially from 36 samples collected across four subtidal stations, two each to the upper northern and the southern of the platform. The distinct variations in communities between and within stations and the most contributed species to variations were determined using multivariate analysis techniques. The structured model showed that the measured environmental factors explained 29.4% of infaunal community structure in the harbour with the highest contribution of chromium (6.6%). Environmental patterns suggested the increasing metal deposition in the finer-grained muddy sediments towards the innermost basin with stagnant and shallower waters.
Keywords: *Macroinfaunal distribution, infaunal community, subtidal sediment, heavy metals, Langstone Harbour*

Öz

Denizel ortamların çok çeşitli faktörler içeren karmaşık doğası, kirlilik kaynaklı ekolojik kalite değişimlerinde uyarı veren spesifik indikatör organizmalar barındırabilme açısından elverişsizdir. Kumun içerisinde hareketsiz veya sınırlı hareketle yaşamını sürdüren bir canlı grubu olan bentik içfauna ise; kirlilik kaynaklarından ve dolayısıyla da sediman ve suyun düşük kalitesinden uzaklaşamaz. Bu nedenle, kıyı-geçiş sularında kirlilik ile tetiklenen konumsal kalite farklılıklarına cevap verebilecek bir grup olarak görülmektedir. Bu çalışma, sediman stres etkenlerinden ağır metaller ve ilişkili faktörler olan sediman tanecik fraksiyonu, haliç pozisyonu ve derinlik interaksiyonunun; bentik içfaunada spesifik dağılımsal bir örüntü ile karşılaşabileceğini önerir. Langstone Limanı makroiçfaunal komünite, ağır metal dağılımı ve sediman granülometrisi, platformun kuzeyi ve güneyinde ikişerli konumlanan

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4 farklı gelgit altı istasyon boyunca 36 noktada gerçekleştirilen örneklemeler ile çalışılmıştır. Komünitelerin istasyon içi ve istasyonlar arası ayırt edilen varyasyonları ve bu varyasyonlara en çok katkıda bulunan türler çok değişkenli analiz yöntemleri kullanılarak belirlenmiştir. Yapılandırılan modellere göre, ölçülen çevresel faktörler ve interaksiyonlarının, halicin bentik içfaunal yapısını %29.4 oranda açıkladığı, ve krom metalinin %6.6'lık oran ile bu açıklamaya en büyük katkı yapan faktör olduğu belirlenmiştir. Analizler sonucu çevresel patern; çok ince kum ve silt-kil partiküllerinin havzanın durgun sulara sahip sığlaşan iç alanlarına doğru artışıyla birlikte yükselen ağır metal birikimini ortaya koymaktadır.

Anahtar kelimeler: *Makroiçfaunal dağılım, içfaunal komünite, gelgit altı sediman, ağır metaller, Langstone Limanı*

Introduction

The analysis of benthic infaunal communities has been a widely used environmental monitoring tool for the transitional and coastal marine environments over the years (Bilyard, 1987; De Jong & Tanner, 2004; Salas et al., 2006). The relative longevity and stable living conditions of infauna as compared with other monitorable biological groups such as plankton increase the reliability and strength of their responses to altered environmental conditions (Pearson & Rosenberg, 1978; Bilyard, 1987; Ritz et al., 1989; Persaud et al., 1993; Weisberg et al., 1997; Salas et al., 2006). The environmental disturbance is a considerable mortality source for these organisms and therefore is a critical component of community structuring (Woodin, 1978). The expected responses from macroinfaunal communities exposed to contaminated sediments in estuaries are shifts in community structures followed by the dominance of few resistant species (Gray & Mirza, 1979; Gray, 1989; Dauer, 1993).

Increasing human activities in coastal areas have been resulting in elevated concentrations of heavy metals and higher pressure on the biological equilibrium of marine ecosystems (Förstner, 1981; Jiao et al., 2018). The main sources of metal input produced by human activities in transitional coastal marine areas are the loads from industrial, domestic and agricultural runoffs, ship-related anti-foulant paints and waste dumping, shipbreaking and mining activities (Weichart, 1973; Davutluoglu et al., 2011). A large amount of discharged heavy metals initially forms part of suspended matter and hence, accumulate in sediments (Groot et al., 1982; Usero et al., 1998) which is the living space and feeding ground of benthic infauna. Grain size, the size of sediment particles, is the primary environmental factor determining the distribution of heavy metals by affecting their binding to the sediments (Singovzka et al., 2016). The feeding modes of infauna, deposit and suspension-feeding, enable the organisms to contact inescapably with the sediment and hence, cause to the greatest exposures to these contaminants present in the sediments and the pore water (Dean, 2008). Thus, these organisms could be affected directly by heavy metal concentrations because of their interactions with the substratum throughout their lifespan (Persaud et al., 1993; Geffard et al., 2005; Jiao et al., 2018).

Heavy metals have toxic, environmentally persistent, undegradable and unremovable nature alongside their ability to being included in the food chain of marine systems (Wood, 1974; Förstner, 1981; Demirbas et al., 2005; Sharifuzzaman et al., 2016; Gheorghe et al., 2017). These chemicals mainly affect the process of growth, metabolism, and the reproduction system of an organism by inducing toxic effects (Stankovic et al., 2014). The metal-related stress on the marine environments and organisms could be strong and long-acting since the recovery of these contaminants is extremely hard and tend to remain inconclusive (Gall, 2010; Jiao et al., 2018). Hence, sediment monitoring relative to heavy metals could greatly contribute to biological monitoring studies to evaluate the impact of human-related disturbance. The studies examining the biological responses against the potential toxicity of heavy metals in tidal estuaries in the UK and France demonstrate that copper, zinc, cadmium and lead are of the major concerns for these aquatic systems (Wright & Mason, 1999; Statham, 2000; Geffard et al., 2005; Callier et al., 2009). The pressure by these synthetic chemicals is likely to occur particularly in the estuaries that function as harbours and recreational waters with concentrated human uses and the related vessel density such in Langstone Harbour.

Langstone Harbour is a tidal basin of the English Channel locating in the centre of three extensive adjacent connected harbours on the south coast of the UK. The inlet locates within the East Hampshire catchment with its intense urbanization and agriculture activities (Environment Agency, 2016). There are several reported outfalls with unidentified sources across the harbour (Thomas et al., 2016). A wastewater treatment plant (WWTP), Budds Farm WWTP, where situates at the northern end of the harbour have had difficulties resulting in stormwater discharges directly into the water from various points during the periods of heavy rainfall (Southern Water, 2011) which is likely to cause contaminant inputs into the water system. The last performed intertidal survey in Langstone Harbour under the authority of Natural England (Thomas et al., 2016) reported the benthic infauna as relatively diverse however with spatial distributional differences. These spatial dissimilarities may illustrate their responses to gradients in stressor and certain environmental parameters that are addressed for subtidal sediments in the present project.

The objectives of the present study are: (1) To observe the pattern of macroinfaunal species concerning potential spatial variations in heavy metal loads in surface sediments of the harbour; (2) To evaluate the probable impacts of station position and sediments grain sizes on the gradient in heavy metal concentrations in the harbour and hence, on distributions of macroinfaunal communities. In line with these objectives, the project was underpinned by two hypothetical scenarios for better understanding of transitional estuarine ecosystems and factors which affect the distribution of sensitive benthic organisms residing in sediments: (1) The sediments with different metal contamination levels among the stations could be characterised by certain species of infauna based on their physiological or functional tolerance and hence could result in different compositions in specified stations. (2) The environmental variables of site positions and sediment very fine grain size proportion may contribute to the variation in macroinfaunal benthic communities between stations by affecting their community structure directly and also indirectly through having impacts on the distribution of sediment metals in the estuarine environment.

Materials and Methods

Sampling Design of the Project

The study was carried out along the channels of the inlet in 4 determined subtidal stations (Table 1) named as Budds, Hayling, Milton and Salterns at 3 randomly chosen sites in each station (Figure 1). Samples for infauna and surficial sediment were collected in triplicate at each site.

Figure 1. A map of Langstone Harbour (50.8167° N, 1.0000° W) indicating the field sampling stations in the studied areas (The abbreviations of Bu, Sa, Mi and Ha represents the Budds, Salterns, Milton and Hayling stations, respectively; and A, B, C within the codes indicates the three different sites for each station)

Table 1

GPS Coordinates for the Stations Shown in Figure 1

Station	Longitude (X)	Latitude (Y)
Budds	N 50˚ 49.704′	W 0˚ 59.849′
Hayling	N 50˚ 48.079′	W 1˚ 01.483′
Milton	N 50˚ 48.138′	W 1˚ 01.867′
Salterns	N 50˚ 49.142′	W 1˚ 02.133′

The sampling process was performed over a period of two months, November and December 2018. Time, water depth, the height of tide and GPS coordinate were recorded during each sampling interval. The charted depths are the approximate values as they were calculated without reference to wind and atmospheric pressure.

Collection and Process of Benthic Macroinfauna Samples

Infaunal samples were collected by applying Van Veen grab sampler with 0.1 m^2 diameter for each station. Each collected grab sediment sample was sieved on a 0.5 mm mesh screen onboard, using gentle hose pressure to extract the macroinfauna. The organisms retained in the mesh were placed into labelled plastic bags along with some seawater covering the samples. Transported animal samples to the laboratory were fixed in 25% formaldehyde and then transferred to polyethylene bottles with 70% ethanol to preserve for later sorting. Identification was performed to the possible lowest taxonomy, mainly to species level, using the literature and keys (Campbell, 2005; Sterry & Cleave, 2012; Plass, 2013) under a stereo microscope.

Collection and Process of Sediment Samples for the Analyses of Heavy Metals and Grain Size

The sediment core samples were extracted by taking subsamples from the upmost centimetres (~5 cm) of Van Veen grab sediments (used for macroinfauna collection) using a polyethylene 50 ml syringe applied onto the inspection doors of grab. The samples were placed into polystyrene cooler boxes on board to stop the possible biological activity and prevent any chemical transformation within. Samples were frozen (–20 Cº) until analysed to prevent microbial degradation.

Before starting the treatment of sediments for the analysis of heavy metal concentrations, the samples were placed into the beakers and dried in oven cabinet at 60 °C through 48 hours following defrosting at room temperature. Dried samples were digested in Aqua Regia solution (2 ml HCl + 9 ml HNO_3 + 1 ml 30% hydrogen peroxide for each dried sample placed into vessels) using microwave accelerated reaction system (model-CEM, The MARS 6™) based on US EPA Method 3051 (Environmental Protection Agency, 1994). Acid digested samples were filtered using glass microfibers filter papers with 0.45 mm thickness (Fisher Scientific, MF 300) to remove the undissolved sediment residuals within the samples and diluted up to 50 ml in polypropylene tubes (Fisher Scientific, 50 ml). Digests produced by the method were analysed by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) analytical technique for the detection of total concentrations of Cr, Cu, Ni, Pb and Zn (ppm = mg L- wet weight) in sediment samples.

The rapid partial analysis of the sediment samples from each site was conducted following the dry sieving technique by Bale and Kenny (2005) to determine the quantitative distribution of particle sizes to characterize the physical type of the sediments.

All fractions of ten sizes along with the particle size classifications and the sediment types corresponding to them were defined following the Wentworth (1922). As to corresponding sediment types, the criteria were: gravel (>2 mm), sand (63 µm-2 mm), silt and clay (<63 µm).

Data Analyses

Associated environmental data set to the community structure included water depth (m), the grain sizes (***µ***m) and sediment concentrations (mg L^{-1} wet weight) of five high metals (Ni, Cu, Cr, Zn and Pb). The particle sizes of very fine sand (125-63 µm) and silt clay (<63 µm) were matched to the data set for the multivariate analyses to examine the effects of very fine particulates on metal distribution in the harbour.

The abundance data on macroinfaunal invertebrate species and the environmental data set were subjected to multivariate analyses using the software packages PRIMER (Plymouth Routines in Multivariate Ecological Research, version 6) (Clark & Gorley, 2006). An add-on package for PRIMER, PERMANOVA+ (Anderson et al., 2008), was also used due to the suitability to the complex design of the presented study involving multi factors.

Multivariate analyses of environmental variables.

The environmental dataset was examined through the draftsman plot and a log-transformation was applied to the sediment particle size values. Because of the different ranges of measurements, all environmental data were normalised prior to multivariate analyses. Euclidean distance matrix, the accepted default resemblance measure for environmental data (Clark & Gorley, 2006), was applied to environmental normalised values to see the pattern of similarity/dissimilarity and also as an underlying construction for other multivariate analyses. The data subjected to an ordination using a correlation based principal component analysis (PCA). The significant differences between stations and sites were tested by applying the Permutational Analysis of Variance (PERMANOVA) routine.

Univariate measures of infaunal community structures.

Diversity (Shannon-Wiener index, H') and species richness (Margalef's diversity, d) were calculated for each associated station for the further spatial information about the structure of assemblages. Because the number of different species (S) is greatly affected by sampling effort and size (Melo et al., 2003), Margalef's richness was rather applied to data. One-way analysis of variance (ANOVA) and Tukey's tests were conducted to examine the significance of differences between stations and compare these differences between the station pairs.

All the infaunal assemblages were classified according to their feeding characteristics to interpret the possible spatial changes in community structure based on their different intake mechanisms of contaminants as well as grain size preferences to living in comply with their feeding mode.

The data relative to some community characteristics from related soft bottom benthic invertebrates -opportunistic and/or invasive species- were used to compare the species composition by stations.

Multivariate analyses of ınfaunal species composition with associated environmental variables.

For the biological data, the triangular matrix of similarities between every pair of samples from four stations was constructed by using data transformations and Bray-Curtis (dis)similarity coefficient (Bray & Curtis, 1957) for further analyses. The abundance data of species were pre-treated before the analyses with fourth root transformation to reduce the influence of very abundant species. The resemblance of infaunal communities between every pair of samples (Clark & Warwick, 2001) were analysed using non-parametric multi-dimensional scaling (nMDS) ordination (Kruskal, 1964) and canonical analyses of principal coordinates (CAP) to visualise any pattern of similarities in species composition. PERMANOVA was used for formal significance tests. To find the individual species having the highest contribution to significant dissimilarities among the stations were visualised using the CAP analysis which includes the rank correlation (Spearman) vector overlays of the species data.

A distance-based linear modelling (DISTLM) routine-a regression type analysis- based on dbRDA (distance-based redundancy analysis) was used to model the infaunal community structure using the associated environmental variables (Anderson et al., 2008).

Results

Environmental Variables

The northern inner stations Budds and Salterns had remarkably higher sediment contamination with metals whereas heavy metal content of sediments decreased in southern stations Milton and reached their lowest mean values in Hayling, towards the mouth of the harbour (Table 2). Budds station, near the WWTP, had the most metal contaminated sediments with by far higher mean concentrations at all metals with approximately the difference of changing between tenfold and twentyfold compared with the mean concentration of Hayling, the least contaminated area of the study (Table 2). It is worth noting that the B site of Budds, which is the nearest site to WWTP, had the highest mean concentrations of all metals in the station (Cr: 26.5 ± 1.0, Cu: 8.9 ± 2.0, Ni: 23.3 ± 5.1, Pb: 41.5 ± 1.5, Zn: 122.1 ± 6.8 mg L^{-1} ww). The same trend was observed in Salterns station which had the greatest metal concentrations in its innermost site, site B (Cr: 22.4 ± 1.4, Cu: 29.3 ± 1.1, Ni: 19.6 ± 1.2, Pb: 41.5 ± 2.9, Zn: 147.5 ± 26.7 mg L^{-1} ww).

The concentrations of all five metals were found below the Effects Range-Low (ERL) which is a derived value to estimate for the potential biological adverse effects of metals in sediments by Long et al. (1995) through the data from excessive numbers of lab-based, field and modelling studies. For Budds station, however, the mean concentration of nickel (20.3 ± 4.0 mg L^{-1} ww) was found at almost low-effect threshold level (20.9 mg kg^{-}).

Table 2

Means and Standard Deviations (SD) of Charted Water Depths (m), % Sediment Types (Gravel, Sand, Silt/Mud), % Very Fine Sand + Silt/Clay Particle and Heavy Metal Concentrations (mg L^{-1} wet weight) in Sediment Core Samples

Stations	% gravel (<2 mm)	% sand (63 µm-2 mm)	% silt and mud (<63 µm)	% very fine sand + silt/clay	Cr	Cu	Ni	Pb	Zn	Water depth
Budds										
Mean	16.5	78.5	5.0	36.1	25.0	28.7	20.3	39.7	119.1	1.9
SD	18.4	16.8	5.9	18.4	3.9	3.2	4.0	3.3	11.8	0.8
Hayling										
Mean	0.0	100.0	0.0	4.9	2.0	0.3	1.2	3.5	18.2	4.3
SD	0.0	1.00E $^{-14}$	0.0	1.9	0.4	0.6	0.2	1.0	2.0	1.7
Milton										
Mean	1.2	98.5	0.2	19.1	6.8	4.1	5.2	11.1	35.5	3.5
SD	2.2	2.1	0.5	15.2	2.5	2.3	2.6	3.7	8.0	0.8
Salterns										
Mean	0.2	96.6	3.2	38	13.6	15.8	11.9	25.6	86.2	2.2
SD	0.5	2.9	2.9	26.9	7.3	10.8	6.5	13.2	50.2	1.2

Note. Sediment core samples from four stations in Langstone Harbour, November and December 2018, Cr=Chromium, Cu=Copper, Ni=Nickel , Pb=Lead, Zn=Zinc

The sediment of Budds, Salterns and Milton had a heterogeneous character which was comprised of mud and coarse-mixed materials, whereas sediments from Hayling comprised only sand classes indicating comparatively a homogeneous sediment structure in this station (Table 2). Particularly Budds was found gravellier in nature despite the general-sand characteristic of the harbour. There was a clear occurrence of blackened sludge layer intensely on the seabed of the sites within the station Budds (the highest silt and mud of 5% among the stations) and Salterns where locate in the inner part of the harbour.

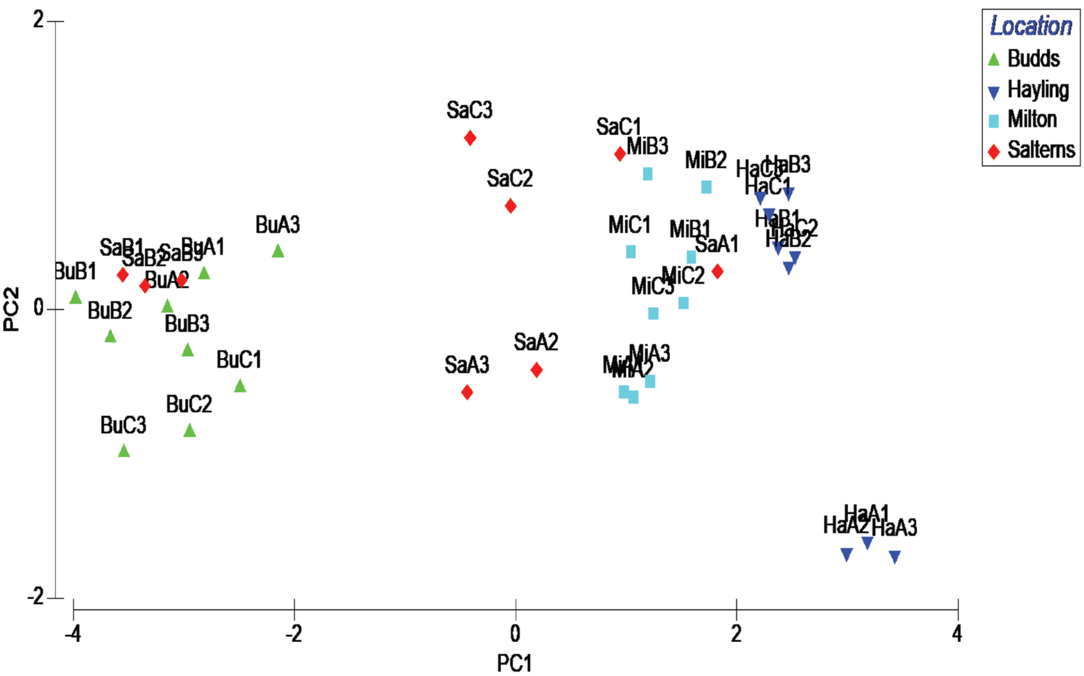


Figure 2. Two-dimensional principal component analysis (PCA) representing the ordination of normalised metals, grain size and depth data for Langstone Harbour, from each of the sediment samples of four stations, Budds (Bu), Hayling (Ha), Milton (Mi) and Salterns (Sa). (A, B, C represents the three sites for each station; 1, 2, 3 represents the replicates for each site). PC1 (x-axis) and PC2 (y-axis) jointly account for 92.1% of the total sample variability. PC1 accounts for the greater part of the variation (84.2%).

PERMANOVA test strongly suggested that there was a significant effect of the station groupings on variability in environmental factors including metals, very fine grain size and depth in Langstone Harbour (pseudo-F = 8.7575, P = 0.0012, calculated with 4255 unique permutational combination). The ordination of environmental data by PCA (Figure 2) showed the clear separation of Budds along with B site of Salterns from other stations due to changing contaminant loads and very fine sand and silt-clay fraction of sediments towards inner parts (Budds and Salterns) of the harbour. This clear separation was also confirmed by PERMANOVA pairwise tests (Table 5) strongly. The environmental grouping in Budds differed from the inner stations Hayling and Milton (p = 0.0004 for both pair) whereas not from Salterns station which may result from the consistent environmental values of Salterns-B site with Budds. Moreover, Salterns B significantly varied from site A (p = 0.0066) and site C (p = 0.0014) within the station. Budds and Salterns station had a fairly scattered pattern with its inconsistent values of environmental variables. The distant cluster of Hayling site A indicated the large change in environmental composition by contributing the within-station variability that was also confirmed statistically (A-B sites $p = 0.001$; A-C sites $p = 0.0012$). The explained variability of 92.1% by two-dimensional PCA plot demonstrated a satisfactory description of structure of environmental variables among the stations.

The further PCA analyses (Figure 3) showed that Hayling, Milton and some sites within Salterns had relatively unpolluted sediment by heavy metals comparing with Budds. The distinct grouping of Budds and C site of Salterns mainly resulted from the pattern of increasing concentrations of all the heavy metals (Zn, Ni, Cu, Cr and Pb) in company with higher percentages of very fine sand and mud towards shallow waters.

The metals contributed more to the variation of in the ordination (Figure 3). The southern stations Hayling and Milton had a close grouping indicating their relative resemblance in terms of having less contaminated larger sediment particles in deeper waters whereas the Salterns demonstrated a great variation in all environmental parameters of this study. The increasing water depth was the main reason contributing the by far separation of site A from the other sites in Hayling station.

Univariate Measures of Macroinfaunal Community Structures

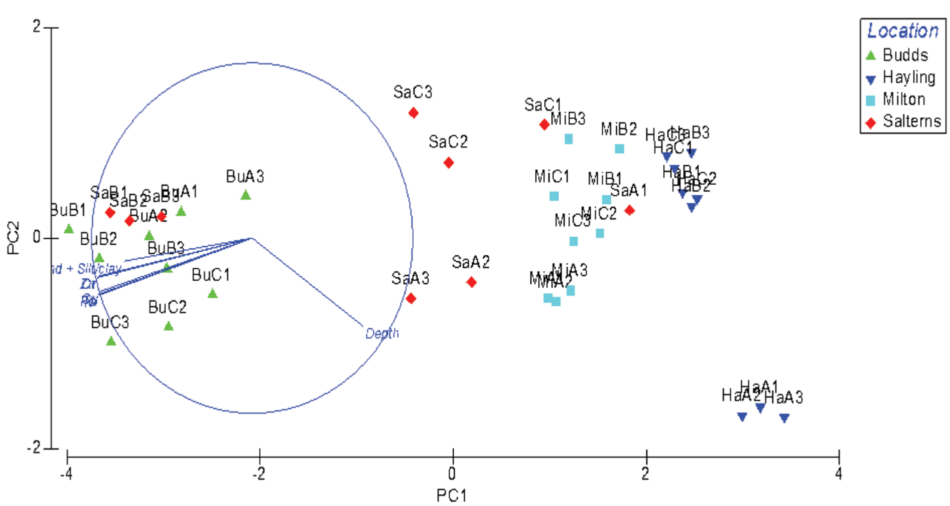


Figure 3. Two-dimensional abiotic PCA ordination on the basis of Euclidean distance measure of normalised metals, grain sizes and depth data for Langstone Harbour. The vector overlays show the variables accounting for the environmental grouping in the stations Budds, Hayling, Milton and Salterns.

The observed species of macroinfauna per sample were sparse along the harbour, with a mean number of species and individuals being 1.3 and 19.7, respectively. The dominant group of the harbour was Annelida which was completely composed of Polychaete worms and made up 57.1% of all observed species and followed by Crustaceans and fully bivalves Molluscs with 20.4% and 14.3%, respectively, constituting the 91.8% of infauna overall.

Table 3

Pairwise Comparisons of Stations from Tukey's Test for Significant Differences in Margalef's Richness (d) and Shannon-Wiener Diversity

Station pairs	Margalef's richness (d) p-values	Shannon-Wiener diversity (H') p-values
Budds-Hayling	0.9994	0.9957
Budds-Milton	**0.0460**	**0.0307**
Budds-Salterns	**0.0006**	**0.0019**
Hayling-Milton	**0.0349**	0.0520
Hayling-Salterns	**0.0004**	**0.0035**
Milton-Salterns	0.3547	0.7023

Note. Bold values indicate the significant differences where, $p < 0.05$.

Species richness (Margalef's) and diversity (Shannon Wiener) for macroinfaunal data varied significantly ($p < 0.05$) among the stations of the harbour (richness: $p = 0.0001$, $F = 9.78$; diversity: $p = 0.0004$, $F = 7.879$). The pairwise comparisons of stations (Table 3) disclosed that the richness and diversity of the infaunal communities in station pairs Budds-Hayling and Milton-Salterns varied not significantly despite the occurring substantial variation in environmental parameters in these pairs. Infaunal community structure of Budds had the lowest diversity (mean $H' = 0.34$) among the stations and fairly low species richness (mean $d = 0.4$) following the Hayling (mean $H' = 0.40$, mean $d = 0.35$), however, had the highest total assemblage in number ($n = 260$). The outer stations Hayling and Milton showed no statistically significant macroinfaunal diversity ($p = 0.052$) in comply with the statistically non-significant difference in metal concentrations, grain sizes and depth between this pair ($p = 0.1046$).

Regarding the feeding modes of infaunal organisms observed along all harbour, interface feeders, which could switch between suspension and deposit feeding, were predominant group by accounting for 52.8% and the succeeding feeding type was suspension feeding, by constituting 28.1% of all feeding modes. The analysis of feeding types based on stations (Table 4) indicated that the organisms with two feeding strategies seemed to be adapted the environmental conditions of relatively more contaminated stations Budds and Salterns whereas Hayling inversely dominated predator and deposit feeder infauna. Milton station varied from other stations with the dominant filter feeding type of the community with the ratio up to 75.9%.

Table 4

The Percentages (%) of Infaunal Species Assemblages from the Specified Stations in Langstone Harbour Based on Their Feeding Modes

Stations	Deposit feeder	Suspension feeder	Predator	Interface feeder	Omnivore	Scavenger	Parasitic
Budds	0.8	1.2	11.9	87.1	0	0	0.8
Hayling	42.9	4.8	52.4	0	0	0	0
Milton	9.4	75.9	1.3	9.9	0	1.9	1.4
Salterns	4.7	14.5	10.3	61.7	2.1	0	0.5

The observed invasive benthos from the samples across the harbour were non-native species the common slipper shell *Crepidula fornicata* (Linnaeus, 1758), the orange-tipped sea squirt *Corella eumyota* (Traustedt, 1882) and native European green crab *Carcinus maenas* (Linnaeus, 1758). *C. fornicata* was particularly aggregated in Milton station and then in Salterns and Budds with the mean individual numbers per site of 120, 47 and 33, respectively. Their presence substantially decreased in Hayling station to mean number of 4 individual. Besides, the absence of *Corella eumyota* and *Carcinus maenas* in Hayling was also worth mentioning.

Multivariate Analyses of Infaunal Species Composition with Associated Environmental Variables

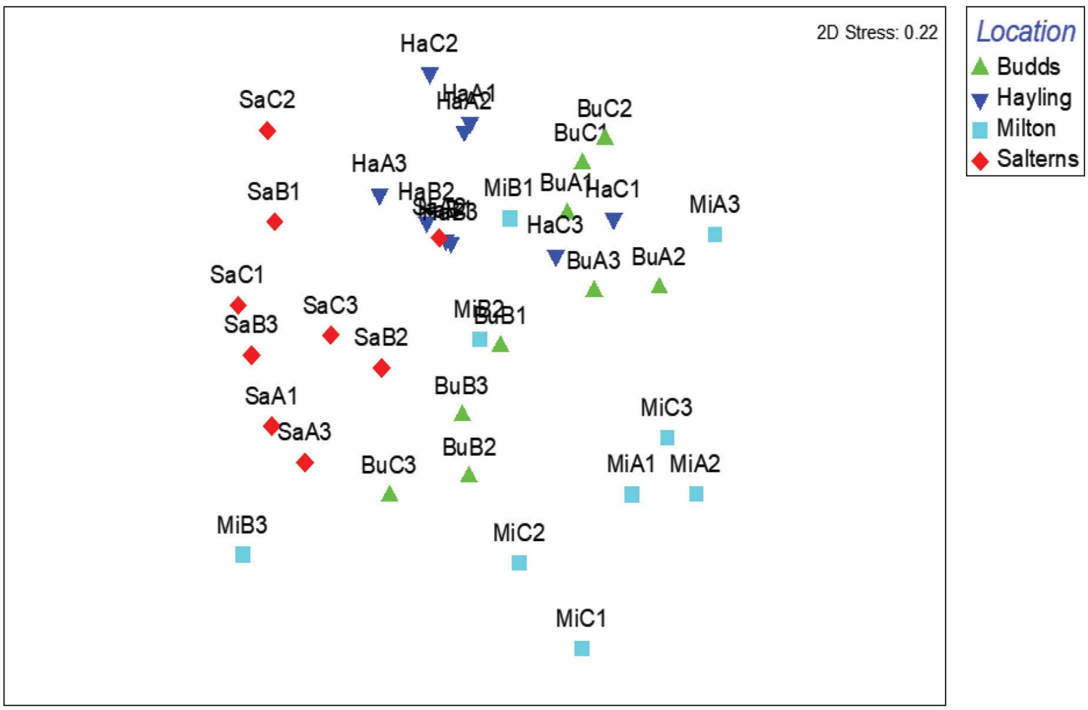


Figure 4. 2-d non-metric multidimensional scaling (nMDS) ordination (rank-based order of the similarities) for fourth root transformed species abundance data-subtidal soft-sediment infauna-from Langstone Harbour at each of the samples of four stations.

MDS ordination (Figure 4) of all samples demonstrated a relative gradation in infaunal structure. Hayling had relatively consistent species composition throughout the station despite the present two separate groups of A and B site within. One of the Northern stations, Salterns had also a separate grouping of composition however with a great variety of distributions within the station. Regarding the Budds, which had the clear separate grouping in terms of sediment contaminants, finer particle content along with water depth (Figure 3), it showed similarities in species structure with some sites from Hayling as well as from rather scattered Milton. However, Hayling and Milton stations fairly differed from Budds ($p = 0.0004$ for both comparisons) in terms of contamination level in combination with certain environmental variables. The ordination of metal contamination (Figure 3) began with the least contaminated station Hayling and was followed by Milton, A and C site of Salterns and culminated in by far higher metal concentrations of B site of Salterns and Budds station. The gradation of infaunal compositions in stations (Figure 4), therefore, showed no pattern as their ordination could not be supported with spatial trends obtained from environmental variables. Besides, the plot had no clear separation between the assemblages from inner north (Bu and Sa) and southern stations (Ha and Mi).

Table 5

Pairwise Comparisons from PERMANOVA for Significant Differences in the Composition of Environmental Factors and Species between Stations

Stations	Environmental p-values	Biota p-values
Budds, Hayling	**0.0004**	0.0872
Budds, Milton	**0.0004**	0.1988
Budds, Salterns	0.1316	**0.021**
Hayling, Milton	0.1046	**0.0384**
Hayling, Salterns	**0.0268**	**0.0216**
Milton, Salterns	**0.0366**	**0.0288**

Note. *Bold values indicate the significant differences, = $p < 0.05$.*

According to the results from PERMANOVA, the groupings of stations in MDS (Figure 4) significantly represented the changes in subtidal macroinfaunal communities (pseudo-F = 2.57, p = 0.0006, calculated with 4227 unique permutation). The pairwise tests of biota data from stations (Table 5) confirmed that Budds (i.e. the nearest station to the WWTP) differed from only Salterns station. Besides, Budds and Salterns had no significant difference (p = 0.1316) in their distributions of environmental variables although the outermost site of Budds, C site, varied significantly in infaunal distribution within the station (A-C: p = 0.0192; B-C: p = 0.014). This similarity was also supported by the statistical difference (p = 0.0166) between C and innermost A site in environmental variables. Salterns station, with a marked change in contamination and particle sizes compared to Hayling and Milton, had unsurprisingly significantly different species compositions from these stations suggesting evidence against the null hypothetical scenarios of no difference in species compositions among the stations.

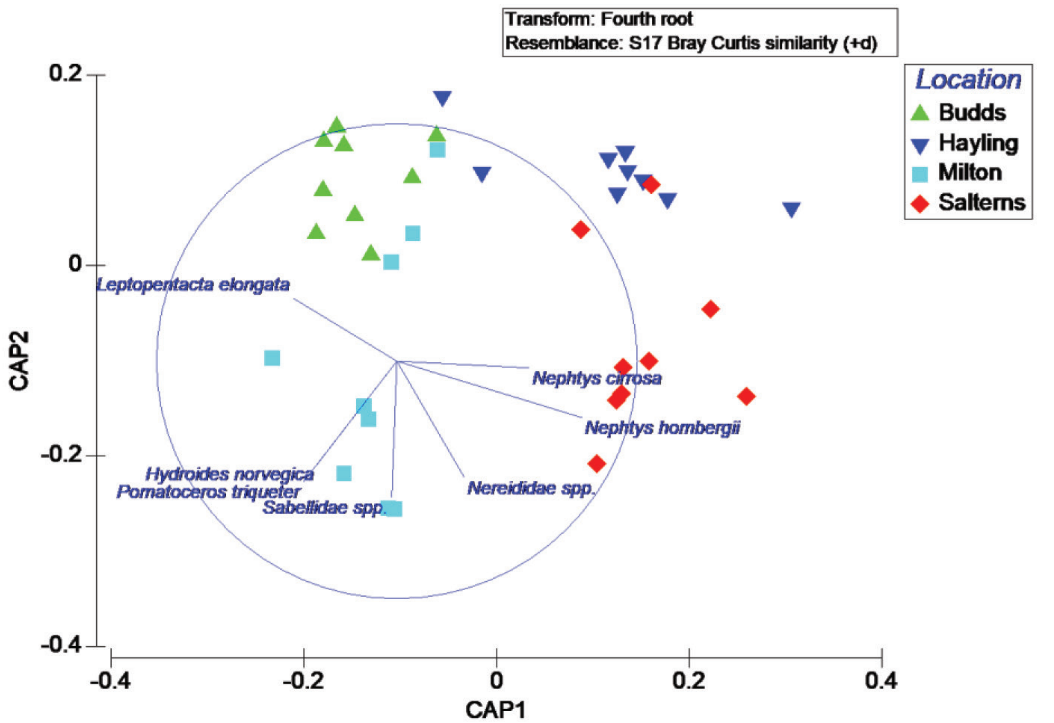


Figure 5. 2-d CAP (canonical analysis of principal coordinates) ordination (distance-based order of similarities) for fourth root transformed species abundance data from each of the samples of four stations in Langstone Harbour. The plot includes the vector overlay showing the most contributing species to dissimilarities among the stations (The adjusted Pearson's correlation for the analyses, $r > 0.5$).

Further CAP analysis including the vector overlay of species that characterise each macroinfaunal community structure of stations (Figure 5) clearly showed the contribution of an echinoderm species *Leptopentacta elongata* (Düben & Koren, 1846) to the significant separation of the community structure of Budds from the Salterns ($p = 0.021$). Two infaunal species and a ragworm family of Polychaetas, *Nephtys hombergii* (Savigny in Lamarck, 1818), *Nephtys cirrosa* (Ehlers, 1868), and Nereididae, were the typified (representing) taxa of the significantly differentiated community structure of Salterns from all the stations in the harbour. The particular presence of tube-building Polychaetas *Hydroides norvegica* (Gunnerus, 1768), *Pomatoceros triqueter* (Linnaeus, 1758) and Sabellidae family were the main contributor organisms to the dissimilarity of Milton station from Hayling and Salterns.

Table 6

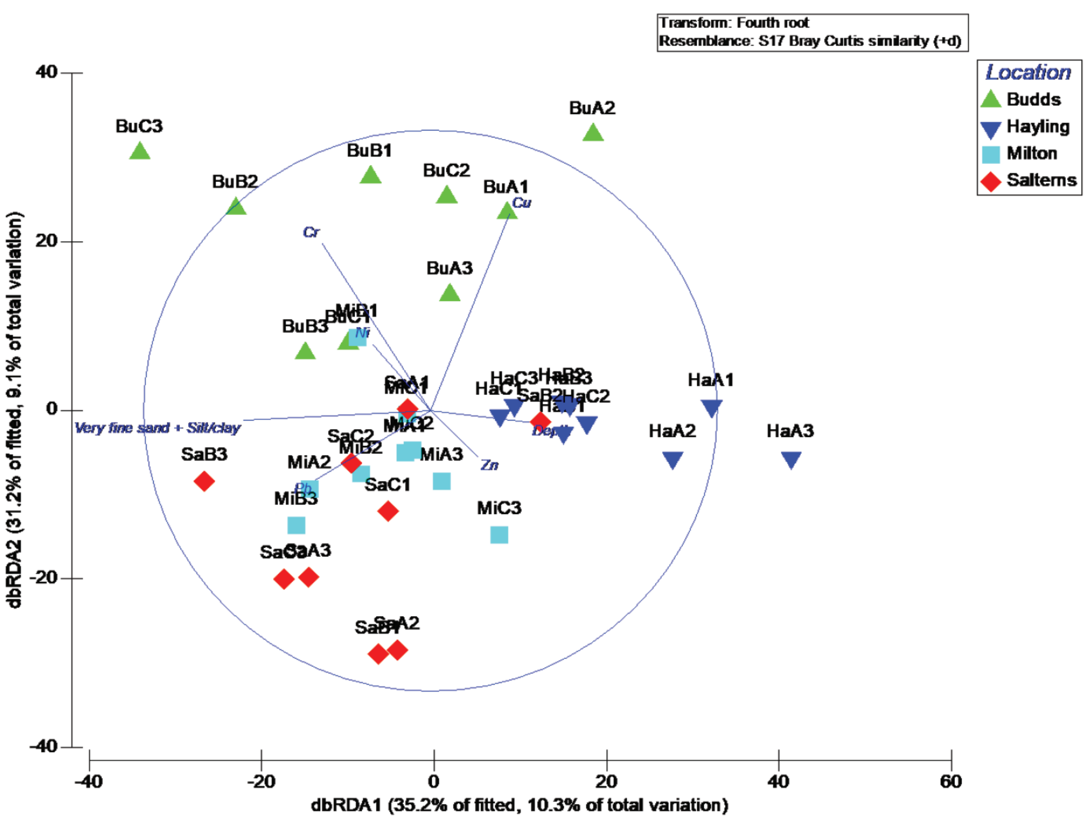
Results of Marginal Test from the Distance Based Linear Modelling (DISTLM) Indicating the Significance of Correlations between the Infaunal Structure and Each of the Environmental Data in Langstone Harbour

Environmental variables	Pseudo-F values	p-values
Depth	1.813	**0.046**
very fine sand + silt/clay	2.346	**0.007**
Cr	2.396	**0.007**
Cu	1.956	**0.033**
Ni	2.038	**0.025**
Pb	2.06	**0.021**
Zn	1.676	0.075

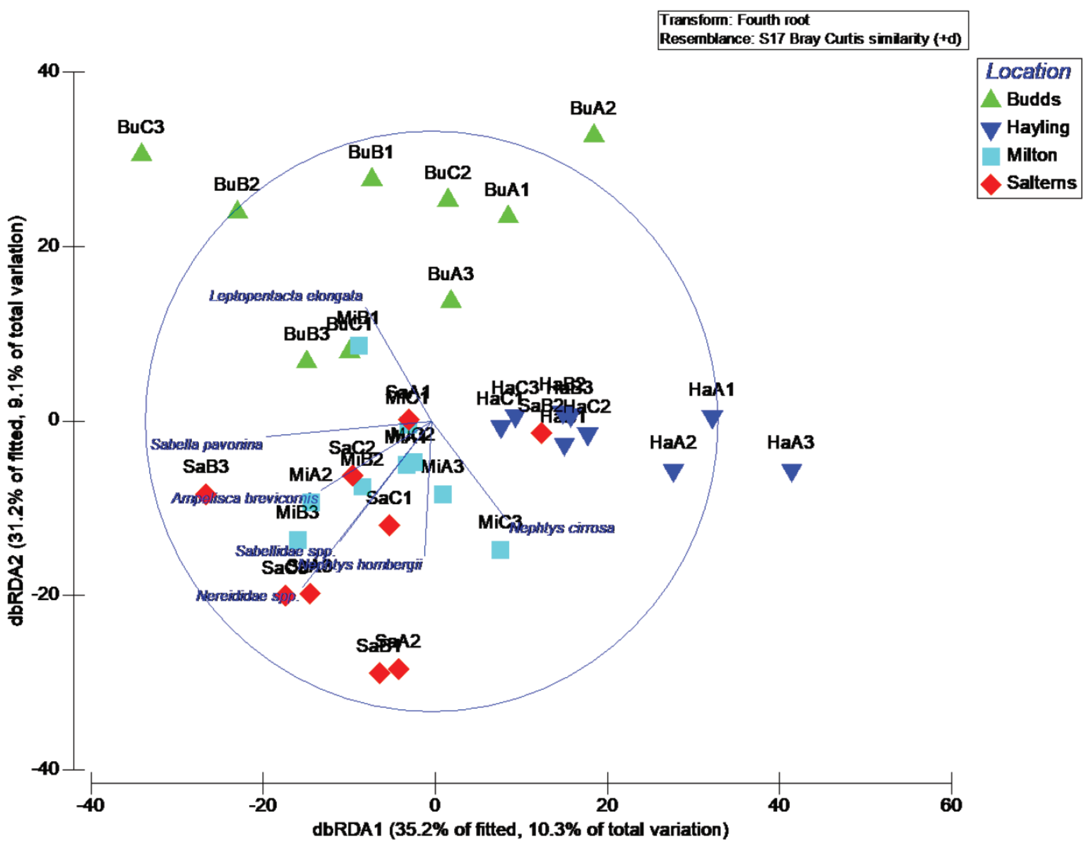
Note. Bold values indicate the significant differences, = p < 0.05, Cr=Chromium, Cu=Copper, Ni=Nickel, Pb=Lead, Zn=Zinc.

The individual impacts of fine sediment particles (p = 0.007) and Cr metal (p = 0.007) on the infaunal structure had stronger evidences comparing to other metals and depth. Considering the sequential tests, the best model of environmental variables explained the 29.4% of the spatial variation ($R^2 = 0.294$) in infaunal community of the harbour. The dbRDA plot (Figure 6a) with environmental vectors showed the particular contribution of Cr and Cu metals and depth on this model. The contamination of Budds sediment by Cr and Cu metals may affect the changes in infaunal assemblages of this station, however, with a great within-variation of community. The model also clearly showed the possible impact of depth on the infaunal separation of A site of Hayling station whereas the increase in the proportion of very fine sediment particles along with a decreasing water depth played a role in infaunal differentiation towards Budds and Salterns.

The model presented by dbRDA ordination plot (Figure 6b) showed the prominent presence of certain species in infaunal variations explained by abiotic factors. This model was greatly supported by the pattern in CAP ordination plot (Figure 5) which showed the main contributor species to dissimilarities among stations. In this model (Figure 6b), an echinoderm species, *Leptopentacta elongata* appeared in Budds station which had the highest sediment contamination by heavy metals and also the sediments with a higher proportion of very fine sand and mud in decreasing water depth. *Nephtys cirrosa* and *Nephtys hombergii*, polychaeta worms, occurred in sediments with the lowest heavy metals in deeper waters of Hayling and in moderate contaminated muddy sediments of Salterns. Polychaeta tube worms from Sabellidae family, particularly observed in Saltern and Budds stations having infaunal variations best explained by very fine particle proportion and higher metal enrichment. The model also indicated the particular occurring of ragworms from Nereididae, another polychaeta family, in muddy and relatively contaminated sediments of Salterns. All these observed prominent species of infaunal variations in the model might disclose the relative toleration of observed polychaeta worms and echinoderms for more contaminated sediments having more muddy characteristics within the harbour.



(a)



(b)

Figure 6. The dbRDA (distance-based redundancy analysis) ordination plots illustrating the correlation among the environmental variables which best explain the variation (Axis 1 = 10.3%, Axis 2 = 9.1%) in infaunal assemblages between the sites from the stations in Langstone Harbour. The first plot (a) includes the vector overlays showing the predictor variables that explain the variation. The vector overlays of second plot (b) visualize the prominent species occurring in the infaunal assemblage model under the influence of environmental variables (The adjusted Pearson's correlations for the analyses, $r > 0.3$ and $r > 0.4$, respectively).

Through the further DISTLM analysis (step-wise procedure), the model suggested that the prominent impact on the infaunal pattern of this tidal basin- among from other abiotic factors of the study- is Cr contamination ($P = 0.042$) of the sediments. Cr metal provided this impact with the contribution of 6.6% (Figure 7) to total variation among infaunal samples in this estuarine system. The model explaining the 29.4 % of infaunal variation between the stations based on the effects of abiotic factors, however, also particularly related to the depth ($p = 0.046$) and then to the proportion of very fine particles (p = 0.007) in sediments which explained the spatial infaunal variation of 5.1% and 4.2%, respectively. The metals except for Zn also had a significant impact on variation according to marginal test results (Table 6). The reason for this was that the contribution of Cr (6.6%) to the total of variation was not a value which could explain greatly the variation in community structure by surpassing the impacts of other predictor variables substantially.

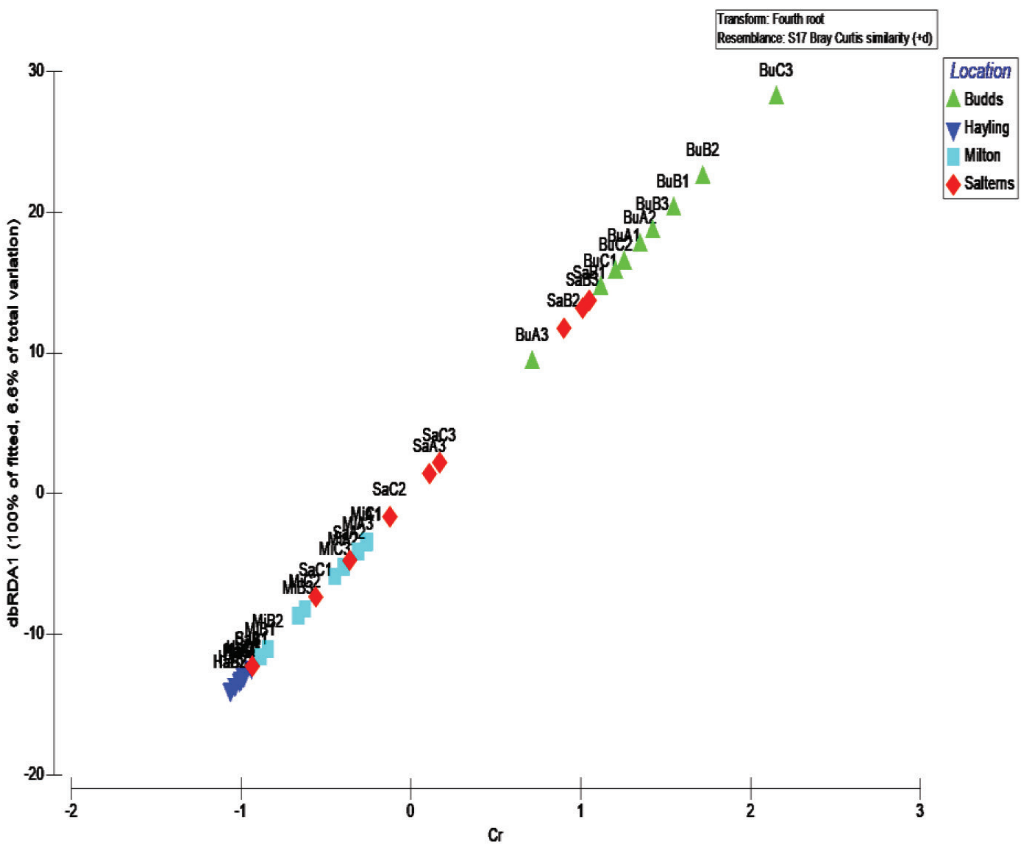


Figure 7. The dbRDA ordination plot of illustrating the contribution of the single variable Cr to the infaunal variations of 6.6% among the assemblage samples from Budds, Hayling, Milton and Salterns stations in Langstone Harbour.

Cr contamination seems taking its impact mostly on the infaunal assemblages of Budds and B site of Salterns within the harbour (Figure 7) which complies with their relative high concentrations which may due to the proximity to the wastewater discharge point. According to this model, echinoderm *Leptopentacta elongata* was the main species causing an infaunal variation in this area which explained mostly by Cr metal.

Discussion and Conclusion

In general, the composition of infaunal communities tends to remain steady by preserving their structure in undisturbed and stabilized sediment conditions (Chen & Orlob, 1972; Ritz et al., 1989). The communities of infauna may have small changes resulting from the acceptable natural variability of abiotic factors under natural conditions (Woodin, 1978; ANZECC & ARMCANZ, 2000). The present study has evidence of clear spatial differences in infaunal community structure between different stations (Table 6), which may be due to differences in metal contamination in the subtidal sediments of the harbour. As explained by Pearson and Rosenberg (1978), the reason of variation in benthic communities within a marine area is the abnormal variability of abiotic factors based on pollution loading in different sites. The present study found important variation in sediment concentrations of metals from the samples across the harbour.

The relatively by far higher concentrations of all metals analysed in the present study at near the inner eastern shore of the harbour could be arising due to Budd's Farm WWTP. The near location to this treatment plant which experiences unavoidable stormwater discharges in severe rainfalls (Southern Water, 2011) likely to cause heavy metal input to the estuary system by causing overloaded and hence overflowing local sewage works (Wittmann, 1981). The groundwater input of Bedhampton and Havant Springs with excessive chemical contaminants and the enter of rivers Hermitage and Lavant to the north east of the harbour (EA, 2016) could be attributed to comparatively higher metal load measured in north-eastern part of the harbour. Besides, lower hydrodynamics of water in inner parts of the tidal basin based on less tidal flushing is also known as a primary reason of increasing contamination of sediments (Förstner & Salomons, 1980; Knott et al., 2009).

Multivariate analyses showed an important differentiation of inner and outer basin in abiotic factors of the study (Table 5) which may also reveal the impact of station positions on the distribution of metal contaminants and grain sizes in the sediments of estuarine systems. The distinct within-station variation of site B in Salterns (Figure 2), the innermost site with greater metal content, seem supporting the estuary position effect on concentrations of pollution. The observed tendency for inner regions of estuaries to accumulate higher contaminations of heavy metals has been observed previously by Nguyen et al. (2019). Furthermore, the results of analyses in the present study demonstrated the higher potential of very fine particles to accumulate the heavy metals (Figure 3) which is parallel with the suggested results by Förstner and Salomons (1980), Groot et al. (1982) and Labianca et al. (2018). For the inner sampling locations, towards to the Budds, to the vicinity of the WWTP, metal and mud content of the sediment increase, and the within-group variability of environmental factors decrease (Figure 3). In several observational ecological surveys conducted to determine the environmental impact on biota, the models clearly indicate the more impacted areas explains a greater variation in represented biological assemblages (Warwick & Clarke, 1993). The generated model of this study coincides with this by demonstrating greater variations in inner stations Budds and Salterns which are the more impacted areas of the harbour (Figure 6a).

Although the distinct grouping of environmental factors in the eastern inner side of the harbour due to fairly higher metal load induced by increased very fine granulation of sediments, multivariate analyses showed a non-significant variation in infaunal community structure in this area. This result is contrary to expectations based upon the statement by Pearson and Rosenberg (1978) which indicate the importance of spatial variability of pollution loads on the benthic community variation within a marine environment. Besides, the absence of a clear separation between the species assemblages of northern and southern stations may disproof the position effect on the distribution of infaunal species. The inconsistency between the infaunal and environmental pattern in Langstone Harbour suggests that the metal contamination present in the harbour are not an underlying explanatory factor for the observed spatial variations in infaunal communities. Contrary to Budds, other stations with different pollution load -changing between moderate and low- and granulation in sediments differ significantly from each other with their benthic infaunal communities (Table 5). But still, the generated model which determine whether any impacts of these abiotic factors on the biotic pattern does not provide a convincing explanation for these spatial dissimilarities. Further multivariate analyses show the important individual impacts of all each abiotic factor except for Zn on infaunal pattern (Table 6). However, when all biota and abiotic factors are presumed as an interdependent whole to consider also their interrelationships which comply with the aim of the present study, the indicated best individual explanatory factor for spatial infaunal variations by the model is chromium metal (Figure 7) with its contribution of 6.6%. According to the model (Figure 6a), all abiotic factors within the research even together explain 29% of the variation in infaunal distribution and there is not any particular striking contribution by a single abiotic factor within this total explainable variation. These results may signify the presence of a different stressor or stressors in the harbour which accounts for the changes in infaunal community structures of Salterns, Milton and Hayling stations.

The absence of distributional responses of infauna to heavy metal contents of sediments across the harbour likely to be related with the concentrations which are detected below the Effect-Range Low (ERL). This specified effect (Long et al., 1995) corresponds to rarely observed biological disturbance to sediment-dwelling organisms which possibly have no necessity to be tolerated by the species with high tolerance to heavy metal pollution. Thus, the existing concentrations of heavy metals (Table 2) in this tidal basin seem to have negligible effects on the spatial differences of infaunal community structure, despite the presence of some concentrations of Cu, Ni and Zn exceeding the low effect threshold level (ERL) in samples from innermost sites in the estuary.

The extremely low and approximate diversity and richness of infaunal species in Budds and Hayling, which is the most dissimilar station pair in terms of contamination levels and other abiotic factors of the study, may also support the assumption about the presence of a different key stressor or stressors. The vicinity to WWTP may partly explain the low species diversity and richness for the surrounding marine area involving Budds station due to storm discharge-related possible pressures on the natural condition of the area. During the sampling from the present coarser substrates in Budds station sometimes resulted in the sample losses and collection of inconsistent sediment volumes due to large gravel particles that cause a half-open bucket of grab. This loss likely to affect the accuracy of the sampling process of benthic infaunal organisms, and hence the analysis results by possibly leading to collect less organisms that represent their site. For Hayling, however, it might be hard to explain based on the position of the station towards the mouth of the harbour which has good flushing conditions. The advantageous estuary position with its higher hydrodynamic in this area likely to prevent the deposition of substances causing contamination in compliance the results of this study regarding metals which considers the sediments of Hayling as the comparatively healthiest across the harbour. The heterogeneous sediments with the mixture of particles often host more species comparing with homogeneous due to having more ecological niches (Gray, 1974). Therefore, homogeneous sediment structure of Hayling consisting of only sand classes of particles could be a physical stressor for the diversity and richness of infauna for this area.

The toxicants in marine systems could directly affect the abundances of organisms by increasing the mortality or supressing the fecundity of sensitive species (Fleeger et al., 2003). Most sensitive conservative infaunal species are the first organisms fail to resist the pressure of contaminated marine sites (Ritz et al., 1989; Persaud et al., 1993). Their disappearance results in community decline and consequently the least sensitive organisms which utilize these conditions get a chance to predominate (Pearson & Rosenberg, 1978; Woodin, 1978; Warwick, 1988; Weisberg et al. 1997). Using the groupings proposed by Borja et al. (2000), there is no observation across the stations regarding a dominance of an infaunal organism known as characteristic opportunistic species of estuary systems in disturbed conditions. This could indicate the relative balanced condition in this tidal basin, thus, observed significant dissimilarities between the stations more likely to result from the natural, physical or biological stressors rather than a pollution-induced stress.

The presence or absence of infaunal species in an area depends on various natural, biological, physical and chemical environmental processes such as their competition, habitat type and dissolved oxygen level rather than just the contamination level of the sediment or water system (Persaud et al., 1993). For instance, the water depth and sediment granulometry greatly affect the benthic community structure spatially based on species (Warwick, 1988). Besides, depth also affects the distribution of grain size in sediments (Gogina et al., 2010). Environmental pattern of this study shows the homogeneous sandy sediment presence towards the mouth of the basin whereas the shallower inner stations comprised of heterogeneous very finer sediments with gravels. However, the explained spatial variability in infaunal community structure (Figure 6a) by depth is only 5.1% which is likely due to relatively small variation of depth in the study area (0.8 - 6.6 m). The model indicates that the contribution of depth more likely to affect the *Nephtys cirrosa* occurrence in homogeneous clearer sediments of Hayling.

According to structured model (Figure 6b), the predominance and specific occurrence of echinoderm *Leptopentacta elongata* in the outermost site of Budds station may indicate its success to tolerate the possible chromium-related stress despite its low impact on infaunal structuring. *L. elongata* lives buried in mud or muddy sand sediments (Picton & Morrow, 2016). The measured highest proportion of very fine particles (mean proportion: 47%) in this site support the relative preference of this burrowing species for very fine-grained sediments in keeping with the literature. Additionally, the grouping of *L. elongata* in particularly the outermost site of the area with no observation of the strong mephitis likely to be compatible with the habitat preference of this species as Larsen (1997) states the Echinoderms are generally sensitive the hypoxic water conditions and H_2S-related disturbance. The particular occurrence of the tubeworms *Sabella pavonina* in higher contaminated muddy sediments of Salterns and Budds may indicate the success of these organisms in the face of possible metal-related stress. The sediments of soft-bottom habitats could serve as a refuge for macroinfaunal organisms by enabling them to penetrate into the sediment layers below the maximum penetrating depth of the disturbant (Woodin, 1978). The organisms with tube building ability, therefore, could have the advantage to survive by becoming distant to contaminated part of the sediments (Woodin, 1978). *Ampelisca brevicornis*, an amphipod species sensitive to contaminants in estuary systems (Podlesińska & Dąbrowska, 2019), could indicate the relatively metal-related good condition of the harbour once more, by characterising Salterns and Milton stations having different contamination levels.

The contribution by multiple species to community pattern along with increasing infaunal diversity and richness gradients towards the western coast of the harbour (Figure 6b) may demonstrate the relative healthier ecological status of this side in the harbour. A disturbance that is not frequent or severe could increase the diversity due to competing species for the resources present in that marine environment (Huston, 1979) and thus, this competitive environment precludes the dominance of any single species (Ritz et al., 1989). The particular occurrence of invasive species *Crepidula fornicata*, *Corella eumyota* and native *Carcinus maenas* in high numbers at western part, moderately contaminated stations Salterns and Milton, may denote the present competitive environment in these stations. Besides the toleration to environmental stress, predation and interspecific competition are the other major determinants of the distributions of infaunal macroinvertebrates (Ryu et al., 2011). Non-native species common slipper shell, *C. fornicata,* and the orange-tipped sea squirt, *C. eumyota,* could affect these predation and competition paths by creating biological stress on infaunal communities represent these stations. American slipper limpet, *C. fornicata,* is reported in high-risk priority species lists based on its impacts on predation and trophic competition whereas there is no risk assessment concerning *C. eumyota* (Stebbing et al., 2015). The occurrence of this mollusc species in also other stations, alongside high abundances in westerns stations, differently from their reported detection in only the west side of the harbour in 2015 (Thomas et al., 2016) could be a critical signal of their over and continuing invasion. This invasion may have structuring power on spatial infaunal distribution in the harbour.

The observed polychaeta density of 57.1% across the harbour and the grain size analysis from the subtidal samples shows the fine sand dominance hosting mostly polychaeta species. They are in general the most abundant group of benthic communities and frequently used to assess the effects of stressors present in sediments and water columns on the benthic ecosystem (Dean, 2008; Pini et al., 2015). Saiz-Salinas and González-Oreja (2000) found that chemical contamination of sediments triggers the growth of polychaeta group within. Polychaetas exist with a great variety of species in estuaries and human-made harbours (Fauchald & Jumars, 1979). The occurring proportion of 57.1% in among the infaunal groups of the harbour seems reasonable considering their general abundance in benthic infaunal communities. The absence of oligochaetes and the near absence (SaA1- two individuals) of polychaeta capitellids which are known as the pollutant tolerant annelid groups (Pearson & Rosenberg, 1978) may also indicate the relative health of the harbour regarding metal contamination.

The dominance of interface feeders with the ability to switch the feeding modes seems to be adapted the environmental conditions of inner stations with more contaminated heterogeneous sediments and likely to prevent the possible competition between the deposit and filter feeder organisms in this area. Coarser-grained sediments are mostly preferred by infaunal suspension-feeders (Gray, 1974), whereas the deposit feeders dominate the finer-grained sediments with silt-clay particles (Rhoads & Young, 1970). The heterogeneous sediment structure of the inner stations Budds and Salterns could provide these two different niches for both two feeding modes. The study by Knott et al. (2009) shows the substantial decrease in numbers of filter feeder species stemming from the disturbance of contaminated sediments through the dredging, storms and tides in an estuary. The authors correlate this result with larvae mortalities due to possible back release of the toxicants into the water column. In this study, there is no observation regarding a substantial decrease of filter feeders in specified inner stations.

The present study demonstrates that heavy metal contamination in areas of the Langstone Harbour seems to have no potential to result in biological detrimental effects in local infaunal benthic organisms of the harbour. However, the behaviour of heavy metals- mobility, bioavailability and toxicity- are essential to evaluate the environmental impacts of the metal-polluted sediments and to focus on only measuring the total metal concentrations is inadequate for an environmental impact assessment (Usero et al., 1998; ANZECC & ARMCANZ, 2000; Statham, 2000) which likely to obtain solely superficial impact assessments of heavy metals on infaunal community structure in this harbour. Nevertheless, Hseu et al. (2002) state that the total concentration analysis of heavy metals in sediments could be used to assess the overall degree of contamination in a specified marine environment. This study could be extended with heavy metal analysis of the pore water to assess better the effects of these toxicants on infaunal distributions. The pore water is a crucial exposure route for infaunal species and an option to eliminate the grain size differences of the samples (Chapman et al., 2002). Warwick (1988) reports that analysing higher taxonomic groups rather than the species level in multivariate analyses provide clarity in the results to evaluate the pollution impact on fauna. Further studies, therefore, may design to analyse the distributional responses of major infaunal groups.

In reply to the hypothetical scenarios: (1) The specified stations in the harbour significantly differed in infaunal compositions and were characterised by certain species, however, could not be explained by the observed gradient of heavy metal pollution in the sediments. The multivariate models indicated the presence of other structuring pressures for these communities in these stations that were not addressed in the scope of this study, and (2) The estuary positions and grain size greatly affected the heavy metal accumulation. There was a pattern of increasing metal deposition in direct proportion to very fine and silt/clay particle percentages towards the shallower inner parts of the harbour. Because the model did not explain an important structuring impact of heavy metals or other factors on infaunal variation, to evaluate the indirect and direct effects of estuary position and the sediment grain size on distributions of infauna is unsuitable and redundant.

An attempt is made here to define and analyse the environmental conditions and biological infaunal patterns of the Langstone Harbour in company with the principles of benthic ecology in estuaries for better understanding of transitional estuarine behaviours.

The data obtained by predictive model-based studies similar to presented here could improve the predictability of environmental impact monitoring programs in transitional estuarine environments. Heavy metal contamination is a particular threat for these marine areas due to surrounding anthropogenic activities as the sediments could remain contaminated by accumulated heavy metals for years. The recovery of a marine environment with its complex nature could be the most compelling environmental process. Therefore, the biological monitoring of the estuaries periodically to assess the impacts of heavy metals on the estuarine health is crucial for the conservation of these fragile marine environments before the occurrence of undesirable effects.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Langstone Limanı (Birleşik Krallık) İçfaunal Komünitesinin Ağır Metal Değişimlerine Tepkileri

Haliçler, etraflarını çevreleyen yerleşim alanları ve endüstriyel alanlardan kaynaklı çeşitli kontaminantlara yoğun ölçüde maruz kalan oldukça kompleks ve dinamik ekosistemlerdir. Atık suların yoğun olarak karıştığı bu ortamlar, insan kaynaklı kirleticiler için nihai depolama yeri olarak görev gördüğünden, diğer denizel ortamların arasında yönetim önceliği bakımından kritik öneme sahiptir. Bu kıyısal deniz ortamlarının başlıca kirlilik kaynağı evsel ve endüstriyel atıksu deşarjlarının taşıdığı çeşitli kirletici girişleridir. Çalışmanın kapsamında yer alan kirletici, denizel çevrelerde biyolojik çeşitlilik için ana tehditlerden biri olan ağır metallerdir. Doğada doğal olarak belirli miktarlarda bulunan ve deniz organizmaları tarafından zorunlu olarak belirli oranda düşük miktarına ihtiyaç duyulan bu maddeler, kıyılarda çoğalan insan aktivitelerine bağlı olarak artan konsantrasyonları, deniz ekosistemlerinin biyolojik dengesi üzerinde büyük baskı oluşturmaktadır.

Görece uzun yaşam süresiyle kumun içerisinde kısıtlı hareket kabiliyeti veya hareketsiz şekilde yaşam sürdüren bentik içfaunal organizmalar, değiştirilmiş ve bozulmuş çevresel koşullara verdikleri tepkilerin güvenilirliği ve kuvveti ile diğer izlenebilir biyolojik gruplar arasında öne çıkmaktadırlar. Sedimanlar, su sistemlerine giren ağır metaller için lavabo görevi görürler. İçfaunal canlılar sediman ile beslenme ve yaşam alanları olması dolayısıyla sürekli etkileşim halindedir ve bu etkileşim komünite yapılarını etkilemesi için büyük bir gerekçedir. Yarı kapalı forma ve açık deniz sistemlerine kıyasla düşük tür çeşitliliğine sahip olan haliç sistemleri, makrobentik biota ve çevresel faktörler arasındaki olası interaksiyonları incelemek için uygun su kütleleri olarak değerlendirilebilir. Langstone Limanı'nda gerşekleştirilen mevcut çalışmada, stres etkenine maruz kalma karşısında oluşan infaunal tepkiler, topluluk yapılarındaki alansal değişimler baz alınarak araştırılmıştır. Geçişsel denizel çevrelerde daha gelişmiş bir anlaşılma için, çeşitli abiyotik faktörlerin etkisi altındaki yapısal bentik komünite farklılıklarına dayanarak, çok değişkenli istatistiksel analiz teknikler kullanılarak muhtemel yaklaşımlar gerçekleştirmek amaçlanmıştır.

Çalışmanın hedefleri: (1) Limanın yüzey sedimanlarındaki ağır metal yüklerindeki alansal varyasyonlara ilişkin makroiçfaunal türler paternini gözlemlemek; (2) İstasyon pozisyonu ve sediman tanecik büyüklüklerinin limandaki ağır metal konsantrasyon derecelenmeleri ve dolayısı ile makroiçfaunal komünite dağılımı üzerindeki muhtemel etkilerini değerlendirmektir. Çalışma, kıyı geçiş ekosistemlerindeki sediman içerisinde ikamet eden hassas bentik organizmaların dağılımını etkileyen faktörlerin daha iyi anlaşılması için belirlenen hedefler doğrultusunda iki hipotetik senaryo ile desteklenmektedir: (1) İstasyonlar arası farklı seviyelerde metal kontaminasyonlarına sahip sedimanlar, fizyolojik ve fonksiyonel toleranslarına bağlı olarak belirli içfaunal türler tarafından karakterize edilerek belirtilen istasyonlarda farklı içfaunal kompozisyonlara neden olabilir. (2) Alansal pozisyon ve sedimanın çok ince boyutlu partikül oranı çevresel değişkenleri, haliç ortamında istasyonlar arasındaki bentik makroiçfauna komünite varyasyonlarına, komünite yapılarını doğrudan etkileyerek ve de sediman metallerinin dağılımına etki ederek dolaylı bir şekilde katkıda bulunabilir.

Çalışmada, İngiltere'nin güney kıyısında İngiliz Kanalı'nda yer alan Langstone Limanı'nda, kirlilik girişi farklılıklarının gerçekleştiği düşünülen 4 farklı gelgit altı istasyonda, toplam 36 noktada örnekleme yapılmıştır. Bu noktalarda sırasıyla; Van Veen grab örnekleyicisi ile içfauna (>0.5 mm); Cr,

Cu, Ni, Pb ve Zn metallerinin toplam sediman konsantrasyonlarını izleme ve tanecik fraksiyon analizi için yüzeysel sediman toplanımı gerçekleştirilmiştir. Analiz proseslerinden sonra elde edilen veri seti, Primer versiyon 6 ve PERMANOVA istatistiksel yazılım paketleri kullanılarak, çok değişkenli analizler aracılığıyla incelenmiştir. Biyota ve tüm abiyotik verilerin ilişki desenleri çıkarılmış, ilişkili abiyotik verilere bağlı içfaunal komünite varyasyon oranları modellenmiş ve açıklanmıştır. Çalışma sonuçlarının daha iyi yorumlanabilmesi için belirli komunite karakteristikleri olan tür çeşitliliği ve zenginliği, ana içfaunal grup oranları, beslenme tiplerine göre sınıflandırma gibi tek değişkenli ölçümler istasyonlara uygulanmış, ilişkili olabilecek fırsatçı ve/veya istilacı yumuşak dip bentik omurgasız tür verileri de incelenmiştir.

Örneklenen makroiçfauna, Poliketler tarafından domine edilen toplam 48 takson içermiştir. İstasyonlar arasında ve bazen de istasyon içi ayırtedici varyasyonlar ve bu varyasyonlara en çok katkısı olan türler belirlenmiştir. Ekinoderm türü Leptopentacta elongata, Poliket türleri ve aileleri Nephtys cirrosa, Nephtys hombergii, Sabellidae ve Nereididae, çalışmadaki abiyotik faktörler tarafından en iyi açıklanan taksonlardır. Bazen düşük etki eşik değerini de aşan ve çalışma boyunca ölçülen en yüksek sediman ağır metal konsantrasyonlarına sahip olan havzanın kuzeydoğu iç bölge sedimanları, bölge yakınında yer alan atıksu arıtma tesisinin, halicin metal kirliliğine katkısının muhtemel işaretidir. Modelleme sonuçlarında, çalışmanın kapsamındaki abiyotik faktörler ve interaksiyonlarının, bentik içfaunal komünite yapısını %29.4 oranda açıkladığı, ve bu açıklamaya en büyük katkı yapan çevresel faktörün %6.6'lık oranı ile krom metali olduğu belirlenmiştir.

Elde edilen bulgulara dayanılarak çalışmanın hipotetik senaryolarına cevaben: (1) Limanın belirtilen istasyonları, içfaunal kompozisyonlarında anlamlı farklılıklar göstermiş ve belirli türler tarafından ifade edilmiş, fakat bu farklılıklar limanın gözlenen sediman ağır metal kontaminasyon değişimleri tarafından açıklanamamıştır. Analizlerde yapılandırılan modeller, limandaki içfaunal komüniteleri yapılandıran ve bu çalışmanın kapsamında işaret edilmeyen farklı çevresel baskıların muhtemel kontrolünü işaret etmektedir; ve (2) Haliç içi pozisyonlar ve sediman tanecik boyutları ağır metal birikimini önemli derecede etkilemiştir. Çok ince kum ve silt-kil partiküllerinin gelgit havzasının durgun sulara sahip sığlaşan iç alanlarına gidildikçe çamurlu kum karakterinde artışıyla birlikte yükselen sediman ağır metal birikimi, karakterize çevresel patern olarak dikkat çekmektedir. Modelin, ağır metallerin limandaki infaunal varyasyon üzerinde önemli bir yapılandırıcı etkisi olduğunu açıklayamaması nedeniyle, haliç içi pozisyonlar ve sediman tanecik granülometrisinin infaunal dağılım üzeri dolaylı ve doğrudan etkilerini değerlendirmek uygun olmayacaktır.

Çalışmada sunulan paternler, Langstone Limanı içfaunal komünitesinin olası stres değişimlerini anlayabilmek için gerçekleştirilebilecek gelecek çalışmalara temel oluşturarak katkıda bulunabilir. Limitli sayıda girişimden dolayı, belirli abiyotik ve biyotik faktörler arası ilişkiler bu gelgit havzası sedimanları için literatürde henüz açıklığa kavuşturulamamıştır. Burada sunulana benzer kestirimci model bazlı çalışmalardan elde edilen verilerin, kıyı denizel ortamlarında gerçekleştirilen çevresel etki izleme programlarında öngörülebilirliği geliştirebileceği düşünülmektedir.

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Collation Article

Microplastics in Environment and Effects on Biota

Çevresel Ortamlarda Mikroplastikler ve Canlılara Etkileri

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Abstract

Plastics are used in many different fields because they are light, cheap and easy to process and become one of the most important commercial materials of today. The use of plastics is increasing every year, and since most of these materials are disposable and their wastes are not managed well, it brings environmental pollution problem. Particles smaller than 5 mm and known as microplastics are formed as a result of the breakdown of plastics by different processes in nature or as a result of direct use such as microbonces, textile fibers. Microplastics are ubiquitous in nature and are of concern for ecosystems. Environmental problems related with microplastic and studies on this subject have become the focus of interest in the last decade. Microplastics into receiving water from different sources poses a threat to aquatic organisms and humans. In this study, microplastics in different environments and their effects on environment and human health were reviewed.
Keywords: *Microplastics, receiving body, health effect, pollution*

Öz

Plastikler hafif, ucuz ve kolay işlenebilir olması sebebiyle çok farklı alanlarda kullanılmakta günümüzün en önemli ticari malzemelerinden birine dönüşmektedir. Plastik kullanımı her geçen yıl artmakta, bu malzemelerin çoğunun tek kullanımlık olması ve atıklarının iyi yönetilememesi sebebiyle çevre kirliliği problemini de beraberinde getirmektedir. Plastiklerin doğada farklı süreçlerle parçalanması sonucunda veya mikroboncuk, tekstil elyafları gibi doğrudan kullanım sonucu 5 mm'den küçük olan ve mikroplastikler olarak bilinen parçacıklar oluşur. Mikroplastikler doğada her yerde bulunmakta ve çevresel ortamlar kadar canlı yaşamı için de kaygı uyandırmaktadır. Son on yılda mikroplastik kaynaklı çevre sorunları ve bu konuda yapılan çalışmalar ilgi odağı olmaya başlamıştır. Mikroplastiklerin farklı kaynaklardan su ortamlarına karışması, suda yaşayan canlılar ve insanlar için tehdit oluşturmaktadır. Bu çalışma kapsamında farklı ortamlarda bulunan mikroplastikler ile çevre ve insan sağlığına olan etkileri değerlendirilmiştir.
Anahtar kelimeler: *Mikroplastikler, alıcı ortam, sağlık etkisi, kirlilik*

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Introduction

Plastics are known as light, strong, inexpensive and corrosion resistant materials having electrical insulation and high thermal properties. (Thompson et al., 2009). Due to the continuous improvement of the durability of plastics, it has become an indispensable product of today. Plastic consumption in the world has been increasing rapidly and exponentially since the 1950s. The use of plastics is estimated to reach 540 million tons by 2020, compared to 7 million tons in the 1960s (Pardos Marketing, 2019). Rochman et al. (2013a) predicted that if consumption continues at the same trend, plastics accumulation would be approximately 33 billion tonnes on the earth by 2050. Plastics are divided into polyethylene terephthalate (PET), polyamide (PA, nylon), polyester, polyethylene (PE), polypropylene (PP), polystyrene (PS), polycarbonate (PC) and polyvinyl chloride (PVC) (Liu et al., 2019). PETs are sourced from personal care products, water bottles, food packaging films, while PAs are sourced from synthetic textile fibers and plastic bags. (Ngo et al., 2019).

Plastics are not biodegradable becuse of their high molecular weight, hydrophobicity and cross-linked chemical structure. Polymers of common use, such as polyethylene and polystyrene, are highly resistant to biological degradation (Horton et al., 2017). The most of the plastics produced are used as disposable packaging materials or short-lived products. Therefore, they are not environmental friendly materials (Hopewell et al., 2009). Plastics are commonly accumulated in the environment due to their durability, unsustainable usage and improper waste management (Barnes et al., 2009).

It is reported that approximately 4.8-12.7 million tonnes of plastics were accumulated in the oceans in 2010 which is stand for 5% of the plastic waste production (Jambeck et al., 2015). Plastic particles may float on the surface of oceans given as 5.25 trillion plastic particles equal to 268 940 tonnes in one of the recent publication (Eriksen et al., 2014). Based on World Economic Forum report the amount of plastics in the oceans will exceed the weight of fish stocks by 2050 (WEF, 2016).

Microplastic (MP) pollution levels are higher in undeveloped areas due to large quantities of plastic entering the oceans by land due to inadequate waste management. According to 2010 estimates mismanaged waste plastic waste sorting in Turkey, it ranks 14th in the world (Jambeck et al., 2015). In Europe, 70-130 thousand tons of plastics are thrown into the sea annually, and most of these plastics complete their journeys in the Mediterranean and constitute a threat to the marine ecosystem (WWF-Türkiye, 2018). Today, the plastic footprint is growing. Plastic bags known as difficult-to-decompose material, desposed to environment right after single usage since their inexpensive price results in environmental pollution for a long time (Wang et al., 2016). When plastic wastes are not disposed of safely, they accumulate in the environment and pose a threat to terrestrial and aquatic environments.

MPs are known as plastic particles smaller than 5 mm in size (Wright et al., 2013). The size classification of MPs are illustrated in Figure 1A. MPs are found everywhere in the marine environment, seawater surface and depth, from the equator to the poles, on the ocean and on the coast (Barnes et al., 2009). MPs are produced from primary and secondary sources shown in Figure 1B. Primary MPs contain PP, PE and PS particles found in personel care products (PPCPs) (Horton et al., 2017). Secondary MPs are the result of large plastics being disintegration into smaller pieces by sunlight, water, wind and other environmental factors (Sun et al., 2019). Primary sources are deliberately produced, such as washers, abrasives, and pellets, while secondary sources are caused by degradation of larger particles such as fragments and fibers (Desforges et al., 2014).

MP particles found in industry, personal care and cosmetic products are defined as micro beads (primary micro plastics). Approximately 93% of the microbeads contained in cosmetics are PE and also they can be composed of PP, PET, PMMA and nylon (Eriksen et al., 2013). The MP particles found in many personal care and cosmetic products are used daily throughout the world. MP particles and other plastic wastes generated as a result of use complete the journey after receiving wastewater treatment plants in receiving environments (Carr et al., 2016).

Due to their hydrophobic properties, MPs tend to absorb on organic materials and organic contaminants present in the aqueous medium (Carr et al., 2016). These pollutants reach humans through the food chain through MPs.

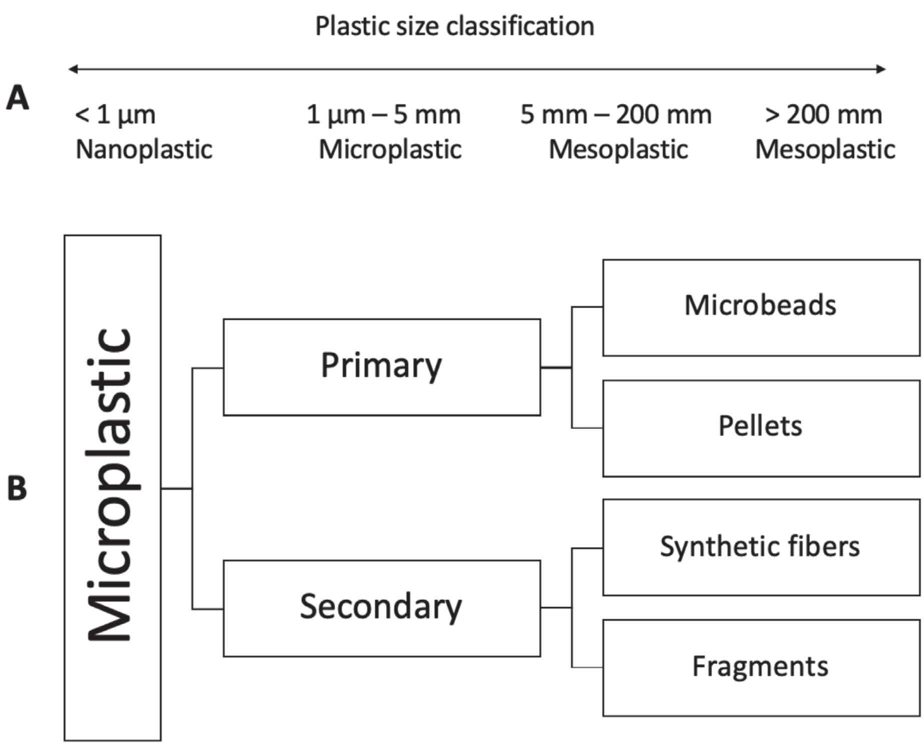

Figure 1. Classification, origins of microplastics (Germanov et al. 2018).

Microplastics in Environment

MPs can be transported for a long distance by atmosperic movements and settled down into the aquatic or terrestrial environment (Akdoğan & Güven, 2019; Dris et al., 2016). Therefore, MPs can be measured in marine (Eriksen et al., 2014), sediments (Zhang et al., 2020), lakes (Zhang et al., 2016) and rivers (Moore et al., 2011). Amount of the MPs in the different environments can be affected by wind velocity and runoff (Zhang, 2017). MPs are also released from wastewater treatment plants (WWTP) to the aquatic environments (Akarsu et al., 2020; Browne et al., 2011).

Marine environment.

MPs can be found in all the collected samples from the surface to the deep sea or ocean. MPs have been reporting in marine samples at the first time in early 1970s (Carpenter & Smith, 1972). MPs broken down into the smaller pieces due to physical, biological and chemical processes can be transffered directly or indirectly to seas and oceans (Lozano & Mouat, 2009). Ultraviolet (UV) radiation plays an important role in plastic fragmentation at marine environment. Fragmentation rate depends on the temperature, polymer type, additives and fillers (Andrady et al., 2003).

Plastics in the marine environment are of ship and terrestrial origin and a significant proportion of terrestrial plastics are transported from rivers to the sea (Lechner et al., 2014). Another important plastic input into the marine environment is through MPs that flow from the home and industrial products to the sewer systems and flow into the sea (Xu et al., 2020). The recovery rate of plastics materials is less than 5%, causing the rapid accumulation of plastics in marine environments (Sutherland et al., 2010).

The amount of primary microplastic in the marine environment is reported to be less than that of secondary microplastics (Ryan, 2015). Fibers are the most common form of MP in the marine environment (Wright et al., 2013). Fibers, an important source of MP, are caused by laundry washing. A study measuring MP concentration in 18 regions around the world has shown that a single garment can produce>1900 fibers per wash (Browne et al., 2011). Natural textile or synthetic textile fibers can be found in marine environment (Almroth et al., 2018).

Significant amounts of MP deposits accumulate in deep seas and MPs are found everywhere in sea sediments (Woodall et al., 2014). MPs abundance can be affected by distance from the coastline and the sediment depth (Xu et al., 2020). For 20 m to 80 m sediment depth, measured MPs increased from 1765 to 2771 particles/kg dry weight. The results proved that more accumulation of MPs were observed in deeper sediments (Wang et al., 2019).

Due to the nature of small particles in micron size, it can be swallowed by sea creatures as food. Starting from phytoplanktons, microplastics can be transferred through zooplanktons, sea urchins, lobsters, and ultimately to the higher tropical level via the food chain (Chatterjee & Sharma, 2019). Ingestion can upset the animals' energy balance, affect behaviour, or even block the intestinal tract resulting in severe sub-lethal effects or even death (Kühn et al., 2015). It is reported that approximately 700 marine organism species encounter marine waste and 92% of this encounter is plastic waste (Gall & Thompson, 2015).

As a result of numerous studies, it has been reported that MPs are ingested by various sea creatures such as zooplankton (Desforges et al., 2015; Sun et al., 2017), mussels (Cauwenberghe et al., 2015; Li et al., 2016), coral (Salonu et al., 2015), fish (Neves et al., 2015; Jabeen et al., 2017). MPs were found approximately 20% of

263 fish samples which are 66% of fiber and 34% of particles (Neves et al., 2015). Approximately 35% of the fish examined had plastic pieces in their guts in the North Pacific Central Gyre. A total of 1375 pieces of plastic, averaging 2.1 pieces (±5.78) per fish, were collected from fish guts. Based on another study, a total of 141 fishes from 27 species and 4 families were examined and plastic items were found inside the stomachs of 13 fishes, this is equal to 9.2% of the fishes sampled throughout the study (Davison & Asch, 2011).

Based on the previous study, conducted in Turkey's Mediterranean coast, 28 species of fish in 1337, the presence of the MP was investigated. MP was detected in 58% of the fish. 70% of ingested plastics are fiber and 20.8% are hard plastics. In addition, the amount of MP was determined by taking water and sediment samples from the same region. It was determined that 94% of MPs in water and sediment samples were between 0.1-2.5 mm in size (Güven et al., 2017).

MPs have been recognized as transport vectors for micropollutants. Rochman et al. (2013b) reported that as a result of microplastics ingested by fish, PBDE accumulation was observed in its tissues.

Plastic particles (3–9.6 µm) ingested by mussels (Mytilus edulis) accumulated in the digestive tissues and carried into the circulatory system (Browne et al., 2008). It is estimated that blue whales (Balaenoptera musculus), the largest animal in the world, received and hold MP in their body as a result of eating plankton (Yurtsever, 2014).

River basin.

MPs at the river samples in California were reported at the first time in 2011 (Moore et al., 2011). River plays an important role in the transportation of MPs. Aproximately 80% of MPs in sea was transffered by the rivers (Akdoğan & Güven, 2019). Moore et al. (2011) reported that 30 million tonnes of MPs released from the Los Angeles and San Gabriel Rivers into the marine environment in a 72 h. In another study, it was estimated that up to 2.5 million tonnes of MPs released into the ocean by the rivers each year (Lebreton et al., 2017). It is estimated that the plastic input to the Black Sea via the Danube River is 4.2 tons/day (Lechner et al., 2014).

The effects of municipal and industrial wastewater discharges on surface water and MP concentration in sediment have been investigated by various studies (Castaneda et al., 2014; Vermaire et al., 2017; Klein et al., 2015; Estahbanati &

Fahrenfeld, 2016). Based on the previous study, it was determined that WWTPs are not the only source in terms of MPs pollution in the fresh water source, but they have negative effects on the receiving environment (Estahbanati & Fahrenfeld, 2016).

MP ingestion has been confirmed for over 220 species including freshwater invertebrates and fish (Lusher et al., 2017; Peters & Bratton, 2016). Based on the previous study, MPs was found in the intestines of one third of the fish (*Rutilus rutilus* species) caught from the River Thames. The MP particle types include fibres (75%), fragments (22.7%) and films (2.3%) (Horton et al., 2018).

Lake environment.

Studies in freshwater environments have been limited compared to studies in the marine environment. Although fresh waters play an important role in carrying MPs, little is known about them. The first MP investigation in the sediment and surface waters of the West and East Dongting Lake conducted by Jiang et al. (2018). As a result of the study, the highest level of MP pollution was detected in the outlet waters of the lakes. They reported that PS and PET are commonly found in surface water and sediment samples. Faure et al. (2015) evaluated the abundance of MPs in the Swiss lakes, defined the composition of the particles, and examined the fish and birds exposed by the tendency to absorb hydrophobic organic micro-pollutants onto the MPs.

Soil environment.

Although there are terrestrial MPs, their concentrations and fate in terrestrial environments are not yet fully understood (Scheurer & Bigalke, 2018). As a result of disposal of all plastics in both terrestrial and adjacent freshwater environments can create intensive plastic pollution and annual plastic emissions to terrestrial environments may be 4-23 times larger than oceans (Horton et al., 2017). Approximately 60% of produced plastics have been reported to accumulate in landfills or natural environments (Geyer et al., 2017). The abundance, permanence and prevalence of MPs in the soil environment pose a serious environmental risk (Wang et al., 2019).

The input of primary MPs to terrestrial environments is through personal care or by applying sewage sludge containing MPs from the home products to the soil (Habib et al., 1996; Zubris & Richards, 2005). MPs separated as a result of washing the clothes are found in WWTP sludge and purified wastewater wastes since they are not biodegradable. Zubris and Richards (2005) detected MPs by polarized light microscopy on soils where organic wastewater sludge was applied. The ability to detect fibers up to 15 years after application shows the potential permanence in the soil environment. Approximately 50% of sewage sludge is used in agricultural purpose in Europe and North America, it is estimated that 850 tons of MP is added to European soil annually with sewage sludge application (Nizzetto et al., 2016). As MPs are transported by wind from land, more dense plastic materials are likely to be buried in deep layers and remain in the soil (Horton et al. 2017). Soils are considered as sinks for MPs due to the extremely slow photo-oxidative degradation for macro plastic litter and MPs buried in the soil (Duis & Coors, 2016). Zhang and Liu (2018) reported that 72% of the plastic particles in the soil were related to the soil aggregate.

Exposore to Microplastics (MPs)

The presence of MPs in environments, including consumer products, is an inevitable end to human exposure to MPs. The intake of MPs-contaminated foods, inhalation and skin contact (only nano sized particles) are among the routes of exposure (Prata et al., 2020). Figure 2 shows routes of exposure to MPs and their effects on human health.

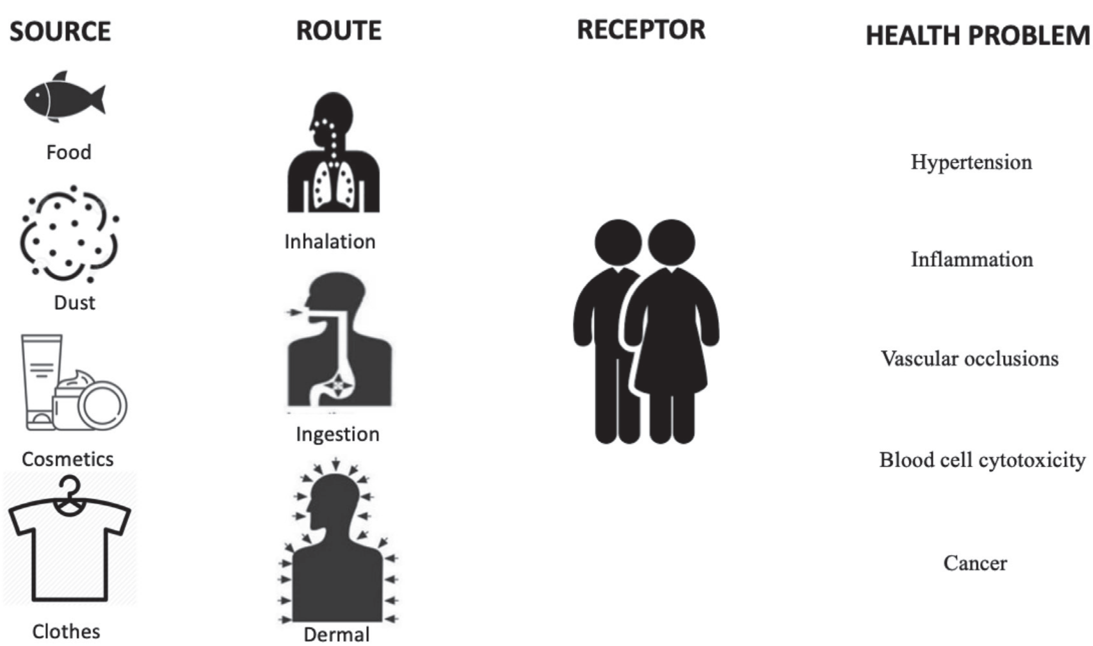

Figure 2. Effects of microplastics on human health (Prata et al., 2020).

Ingestion is probably the most common and most important route of exposure for people (Prata et al., 2020). Annual MP consumption has been reported to vary between an estimated 39000-52000 particles per person. These estimates may increase from 74000 to 121000 with inhalation (Cox et al., 2019). MPs could be detected at various samples such as mussel, fish, table salt, sugar and bottled water (Karami et al., 2017; Li et al., 2016; Liebezeit & Liebezeit, 2013; Neves et al., 2015; Oßmann et al., 2018). In a study conducted in China, MP content was found to be 550-681 particles / kg, 43-364 particles / kg, 7-204 particles / kg in sea salt, lake salt and rock / hollow salt respectively. The higher MPs abundance in sea salts is an indication that marine products are also contaminated with MPs (Yang et al., 2015).

MPs in the cirgulation could cause pulmonary hypertension, inflammation, vascular occlusions, blood cell cytotoxicity, and increased coagulability (Prata et al., 2020).

Conclusion and Recommendations

MP pollution caused by the disintegration of plastics and it has become a global environmental problem. As a result of increasing interest in recent years, studies have shown that MPs are ubiquitous. Excessive use of plastic as a material due to the low cost and functional use and inadequate recycling pose a threat for ecosystem. Preventing exposure with necessary prohibitions, raising public awareness about MPs sources and giving up disposable plastics will raise awareness on this issue. In recent years, studies on the negative effects of plastic wastes have increased. In many countries, including our country, disposable plastic bag tax was designed to decrease the use of the plastic bags. Because cosmetics also contain MPs, in some countries cosmetics containing microbeads for preventive purposes are prohibited. It is known that the pollutants of MPs in the aquatic environment are transported to the living organisms via the food chain as vectors. Consequently, studies should be carried out in order to prevent excessive plastic consumption in terms of protection of water resources, units to hold these pollutants in treatment plants should be added and measures should be taken for better management of these wastes.

According to the results of the literature review, there are many studies carried out in the marine environment. It is recommended to increase the number of studies on pollution caused by MPs in the river, lake and soil environment.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Çevresel Ortamlarda Mikroplastikler ve Canlılara Etkileri

Plastikler hafif, ucuz ve kolay işlenebilir olması sebebiyle çok farklı alanlarda (paketleme, otomotiv, inşaat, elektrik vd.) kullanılmaktadır. Yüksek ısı ve elektriksel yalıtım özelliklerine sahip, güçlü, ve korozyona dayanıklı olmaları sebebiyle çok yönlü malzemelerdir. Bu özelliklerinden dolayı günümüzün vazgeçilmez ürünü haline gelmiştir. Plastik üretimi ve buna bağlı olarak tüketimi katlanarak her geçen gün ciddi oranlarda artmaktadır. Üretilen plastiklerin tek kullanımlık ambalaj malzemelerinde ve kısa ömürlü ürünlerde kullanılması plastik kullanımının sürdürülebilir olmadığının bir kanıtıdır. Insanların bilinçsiz kullanımı, sürdürülebilir olmayan tek kullanımlık uygulamalar ve uygun olmayan atık yönetimi, alıcı ortamlarda yoğun bir plastik birikimine neden olmakta ve beraberinde çevre kirliliğini de getirmektedir.

Üretilen bu plastikler doğada ki yolculuğunu deniz ortamında tamamlarlar. Yetersiz atık yönetiminden dolayı büyük miktarlarda plastik kara ortamından okyanuslara girmektedir. Dolayısıyla gelişmemiş ülkelerde mikropastik kirliliği daha fazladır. Plastik malzemelerden geri kazanım oranının düşük olması sebebiyle deniz ortamında plastiklerin hızla birikmesine neden olmaktadır. Günümüzde plastik ayak izi giderek daha da büyümektedir. Plastik atıklar uygun ve güvenli bir şekilde bertaraf edilmediğinde çevresel ortamlarda birikerek karasal ve sucul ortamlar için ciddi bir tehdit oluşturmaktadırlar. Hatta bazı projeksiyon çalışmalarında 2050 yılına gelindiğinde plastiklerin okyanus ortamındaki balık stoklarının ağırlıklarını aşacağı öngörülmektedir.

Plastiklerin su, rüzgar ve diğer çevresel etmenler gibi farklı süreçlerle parçalanması sonucu 5 mm'den küçük boyutlu olan ve mikroplastikler olarak bilinen parçacıklar oluşur. Mikroplastikler kaynaklarına göre birincil ve ikincil olmak üzere iki sınıfa ayrılır. Birincil mikroplastikler kozmetik ve tıbbi ilaçlarda bulunan polipropilen, polietilen ve polistiren parçacıklarını içerirken, ikincil mikroplastikler daha büyük plastik parçacıkların rüzgar, su ve diğer çevresel etmenler gibi farklı süreçlerle parçalanması sonucu oluşurlar. Kısaca birincil kaynaklar yıkayıcılar, aşındırıcılar ve peletler gibi kasıtlı olarak üretilmiş olup ikincil kaynaklar ise fragmanlar ve lifler gibi daha büyük parçaların bozulması sonucu oluşurlar.

Plastik parçacıkların parçalanması sonucu oluşan mikroplastik kirliliği küresel bir çevre sorunu haline gelmiştir. Son on yılda mikroplastik kaynaklı çevre sorunları ve bu konu hakkında yapılan çalışmalar ilgi odağı olmaya başlamıştır. Bu çalışma kapsamında incelenen makalelerle mikroplastiklerle ilgili bilimsel literatürün gözden geçirilmesi ve insan sağlığına olan etkilerinin derlenmesi amaçlanmıştır.

Atmosferik serpintinin önemli bir mikroplastik kaynağı olduğu bildirilmiştir. Atmosfer ortamında bulunan bu parçacıklar rüzgarlar ile su ortamına taşınabilir veya karasal ortamlarda birikebilir. Rüzgar, sel, gelgitler ve yüzeysel akış gibi fiziksel etkenler mikroplastiklerin farklı çevresel ortamlardaki dağılımını etkilemektedir. Yapılan çalışmalar mikroplastiklerin deniz, göl sediment toprak, nehir ve atmosfer gibi çeşitli ortamlarda bulunduklarını kanıtlamıştır. Atıksu arıtma tesisleri de sucul ortamlar için önemli bir mikroplastik kaynağı olarak bildirilmiştir. Kişisel bakım ve kozmetik ürünlerinin çoğunda mikroplastik parçacıkları bulunmaktadır. Ve bu ürünler tüm dünyada günlük

olarak çok fazla kişi tarafından kullanılmaktadır. Kullanım sonucunda oluşan mikroplastik parçacıklar ve plastik atıklar yolculuğunu kentsel atıksu arıtma tesislerinden sonra alıcı ortamlarda tamamlarlar. Mikroplastiklerin farklı kaynaklardan alıcı ortamlara karışması sonucu suda yaşayan canlılar, çevre ve insanlar için tehdit oluşturmaktadır.

Nehirler plastik taşınımında önemli bir rol oynamaktadırlar ve karasal plastiğin önemli bir kısmı nehirler aracılığıyla denizlere taşınmaktadır. Lifler deniz ortamında en çok bulunan tekstil kaynaklı mikroplastik türüdür. Önemli bir mikroplastik kaynağı olan elyaf çamaşır yıkanmasından kaynaklanmaktadır. Plastiklerin yutulması sonucunda hayvanların enerji dengesini bozabilir, davranışlarını etkileyebilir ve bağırsaklarını tıkayarak ölümlerine neden olabilir. Tarımsal uygulamalarda arıtma çamurunun kullanılması ile toprak ortamına mikroplastik ilavesi yapıldığı bilinmektedir. Ayrıca mikroplastikler karadan rüzgarla taşınırken daha yoğun plastikler toprağın daha derin katmanlarına gömülerek kalması muhtemeldir.

Mikroplastiklerin hidrofobik yapıda olmaları nedeniyle sucul ortamda bulunan diğer organik kirletici maddelerle birlikte PBDE'leri, endokrin bozucu bileşikleri, kişisel bakım ürünleri ve ilaçları absorme etme eğilimi gösterirler. Mikroplastikler çevresel ortamlarda olduğu kadar canlı yaşamı için de kaygı uyandıran kirleticilerdir. Mikroplastikleri yutan canlılar tarafından bu kirleticiler besin zinciri yoluyla insanlara kadar ulaşmaktadır. Yapılan çalışmalar ile mikroplastiklerin balık, midye, sofra tuzu, şeker ve şişelenmiş sularda olduğu bildirilmiştir. Mikroplastiklerin çevresel ortamlar ve tüketici ürünler gibi her yerde olması sonucunda insanların mikroplastiklere maruz kalması kaçınılmaz bir durumdur. Mikroplastik içiren gıdaları yeme, havanın solunması ve dermal temas gibi yollarla maruz kalınmaktadır. Bu maruz kalmanın sonucu olarak parçacık toksisitesi, oksidatif stres, iltihap, translokasyon ve kanser gibi çeşitli insan sağlığına etkileri bulunmaktadır.

Plastiklerin ucuz, dayanıklı, hafif ve işlevsel olmasından dolayı gereğinden fazla kullanımı ve yetersiz geri dönüşümü sonucu önemli bir ekolojik tehdit oluşturmaktadır. Son yıllarda plastik atıkların olumsuz etkileri üzerine artan çalışmalar beraberinde gerekli tedbirleri de getirmiştir. Ülkemizin de dahil olduğu bir çok ülkede tek kullanımlık plastik poşetlerin ücretli hale getirilmesiyle aşırı plastik tüketiminin önüne geçilmeye çalışılmaktadır. Ayrıca bazı ülkelerde tedbir amaçlı mikroplastik içeren kozmetik ürünlerde yasaklanmıştır. Gerekli yasaklamalar ile aşırı tüketimin önüne geçilmesi ve halkın biliçlendirilmesi bu konuya olan farkındalığı arttıracaktır. Su kaynaklarının korunması ve sürdürülebilir bir yaşam için gereğinden fazla plastik tüketiminin önüne geçilmeli, arıtma tesislerine bu kirletici tutacak üniteler ilave edilmeli ve plastik atıkların daha iyi bir atık yönetim planı ile yönetilmesi için gerekli önlemler alınmalıdır.

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