Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH PAPER

Dıscrete-tıme dynamıc water qualıty ındex model ın coastal water

H. Hapoğlu[1], Ş. Camcıoğlu[1], B. Özyurt[1], P. Yıldırım2, L. Balas[2,*]

[1] *Ankara University, Engineering Faculty, Chemical Engineering Department, 06100 Tandoğan, Ankara, Turkey*

[2] *Gazi University, Sea and Aquatic Sciences Application and Research Center, 06570 Maltepe, Ankara, Turkey*

ARTICLE INFO

Article History:
Received 02 August 2020
Reviewed 25 October 2020
Revised 12 November 2020
Accepted 28 November 2020

Keywords:
Mediterranean coast
Parameters
Quality assessment
Transfer function
Water quality index (WQI)

ABSTRACT

BACKGROUND AND OBJECTIVES: It is important to develop dynamic water quality index software that reflected accurately the state of enclosed coastal water quality. This study explored water quality index model software including the third-order and daily based discrete-time transfer function in Simulink-MATLAB environment to predict the past and future water quality index changes versus discrete-time by using the data measured approximately once a month.

METHODS: A modelling software for daily based discrete-time water quality index was developed to evaluate the pollution level in enclosed coastal water bodies affected by marinas. Measurements were done at three different stations near marina entrances in Bucak, Kaş, and Fethiye Bays located at the south western Mediterranean coast of Turkey. The computed water quality index values and the sampled indicators data defined in terms of the deviation variables were used to identify the proposed third-order transfer function parameters. The proposed software is applicable for past and future estimates, where inputs may include some missing measurements. The input data are interpolated to estimate daily based inputs by using the developed model in the Simulink-MATLAB environment. For model verifications, monthly measured water quality parameters are used.

FINDINGS: The software including the daily based discrete-time transfer function and the input sources was successfully applied to predict past and future water quality index changes with 4.2 percent, 4.3 percent, and 7.1 percent of the absolute maximum errors respectively in Fethiye, Kaş, and Bucak stations. In three stations studied, seasonal comparison of the enclosed coastal water quality showed that the quality in winter (72±2) is lower than the one (82±8) in other seasons. The past and future daily predictions of water quality index changes versus discrete-time were realized successfully by using the proposed software and the data measured approximately once a month.

CONCLUSION: By determining similar transfer functions and selecting some adequate indicators, the software proposed can be adapted for quality assessment in other enclosed water bodies

DOI: 10.22034/gjesm.2021.02.04

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
36	10	2

*Corresponding Author:
Email: *lalebal@gazi.edu.tr*
Phone: +90(312) 582 32 17
Fax: +90(312) 231 92 23

Note: Discussion period for this manuscript open until July 1, 2021 on GJESM website at the “Show Article.

INTRODUCTION

The protection of natural water systems is essential due to the continuous need for water in societies (Zhang *et al*., 2012). In the long term, it is possible to protect the natural water ecosystem by reducing pollutant and nutrient inputs (Loucks and Jia, 2012; Capella *et al*., 2013). The nutritional characteristics of different coastal environments, such as estuaries or bays, can be followed comparatively with the help of a selected suitable body of water influenced by various environmental factors (Liu *et al.,* 2019; Khaton *et al*., 2017; Simboura *et al*., 2016; Campos *et al*., 2013). The coastal waters, which are affected by river discharges, aquaculture, and some other activities in nearby terrestrial and marine areas, hold an important place today (Pavlidou *et al*., 2015; Lohe *et al.,* 2015; Aydinol *et al*., 2012; Karbassi and Pazoki, 2015). Monitoring with the water quality parameters selected in terms of some life forms, and human use shows how industrial and urban wastes pollute the enclosed water bodies (Cebe and Balas, 2016; Pham Phu *et al.,* 2018). There are multiple linear regression models developed for bacterial pathogen indicators selected on two beaches on the same coastline showing similar responses to the precipitation effect. However, it is proper to use the indicators and data specific to their locations for beaches located in different areas with different characteristics (He *et al*., 2019; Rees *et al.*, 1998). As coastal waters, which are vital for ecosystems, can react very complexly due to environmental conditions, it is crucial to understand how the system in water bodies works and how the variables change those (Hapoğlu *et al.*, 2018). A proper and costly tool using satellite ocean color resolutions for marine water quality online monitoring is reported (Farrugia *et al*., 2016). The technique of mapping together the water quality index (WQI) and geographic information system(GIS) data is a simple and reliable tool for determining healthy and polluted areas in coastal water monitoring (Jha *et al*., 2015). There are some studies on the selection of appropriate water quality indices to minimize uncertainty and limiting effects that are needed to classify ecosystem-specific waters for a long time (Rangetti *et al*., 2015; Liou *et al*., 2004)). Many water parameters are monitored by considering the specific target values and mandatory values according to the water quality classes in official regulations (Regulation for the Surface Water Quality, 2016; Regulation for the Water Pollution Control, 2004). Water quality indices (WQIs) calculated using selected parameters and weighting factors provide a tool to monitor and compare the quality of the water system that changes over time (Sargaonkar and Deshpan, 2003; Boyaci et al., 2007; Karakaya and Evrendilek, 2010; Cude, 2001). The use of the area and sources of water determine mostly the parameter weights (Sutadian *et al*., 2017). A region-specific methodological approach has been developed and proposed for similar water bodies to evaluate coastal water quality in recreational areas quickly and to improve monitoring protocols and to test coastal water quality management plans. In these evaluations, a formula approach was made that expresses the sum of the relative weights of each selected variable (Azis *et al*. 2018). The probability of contamination in these ambient water bodies is very high due to the intensive social and vital activities in enclosed coastal waters. WQI approaches are used to evaluate and to compare water quality in different selected coastal water bodies (Nguyen and Sevando, 2019). In the present work, to develop dynamic WQI model using the Simulink-MATLAB environment for the coastal waters was aimed. This discrete-time model is explored for dynamic WQI estimation. The most appropriate model parameter values are calculated using the Bierman (1976) algorithm in the MATLAB environment. Experimental data-based discrete computational points have verified the dynamic model estimates. A WQI model software including the third order and daily based discrete-time transfer function was developed in the Simulink-MATLAB environment. The data obtained for the period of 20 March 2016 to 24 February 2017 were used to identify the transfer function parameters. In the previously published work, areal and temporal comparative analysis and monitoring and evaluation of coastal water quality parameters have been carried out at three stations near marina entrances in Bucak and Kaş Bays (2013-2014), and in Fethiye Bay (2016-2017) located at the south western Mediterranean coast of Turkey (Cebe and Balas, 2016; Yıldırım and Balas, 2019).

MATERIALS AND METHOD

Study area and water quality monitoring stations

Table 1 lists the characteristics of representative stations, namely KM (Kaş Marina), BM (Bucak Marina), and FM (Fethiye Marina), selected for

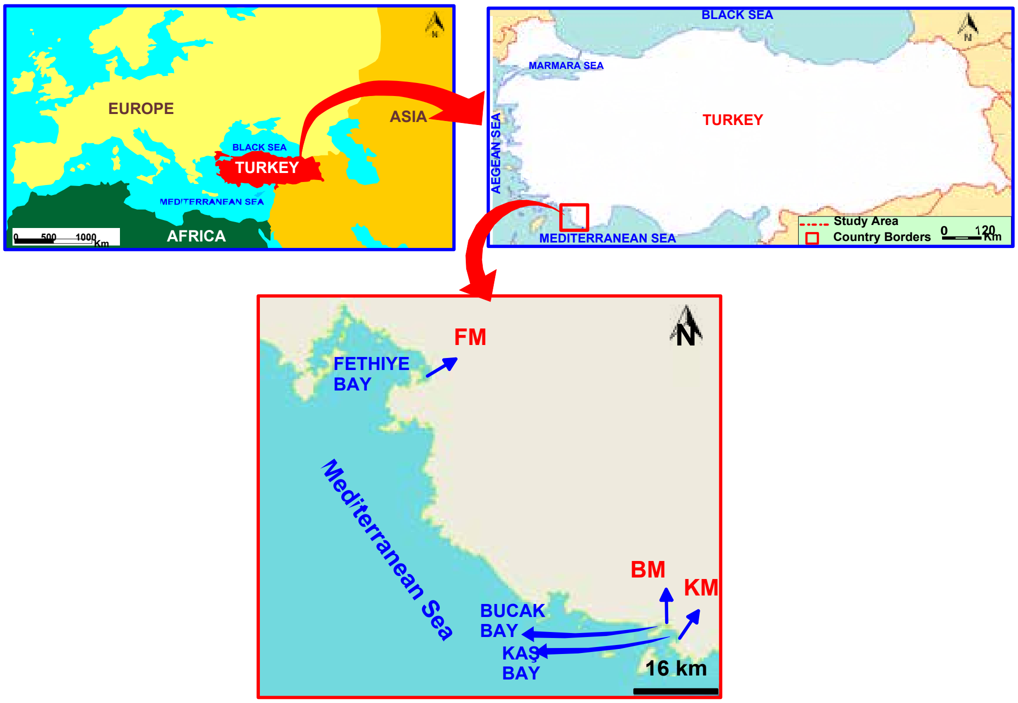

Fig. 1: Geographic location of the study area and measurement stations FM in Fethiye Bay, BM in Bucak Bay and KM in Kaş Bay at the south western Mediterranean coast of Turkey

Table 1: Water depths and coordinates of sampling points (Hapoğlu *et al.,* 2018; Yıldırım and Balas, 2019)

Station	KM	BM	FM
Latitute	36º 11.726′	36º 12.209′	36º 37.680′
Longitute	29º 38.582′	29º 37.430′	29º 6.153′
Water depth	80 m	30 m	15.3 m

the water quality assessment of the receiving environments near marina entrances shown in Fig. 1. The data obtained monthly from these stations are used for WQI calculator in MATLAB environment. The BM station in Bucak Bay, the KM station in Kaş Bay and the FM station in Fethiye Bay represent receiving coastal waters near marina entrances, and sampling from marine waters has been carried out according to TS ISO 5667-9 standard (Yıldırım and Balas, 2019). The main physical and biochemical coastal water quality parameters at the stations are measured from samples taken at -0.5 m below from the water surface. Analysis of parameters has been carried out following Turkish Standards (Yıldırım and Balas, 2019).

Water quality indices

A lot of WQIs such as National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment (CCMEWQI) etc. have been formulated (Lumb *et al.,* 2011). Among them, the merits and demerits of NSFWQI, CCMEWQI, Oregon WQI and Weight Arithmetic WQI methods are comparied (Tyagi *et al.*,2013). Search for adopted WQIs with little modifications is still going on in different countries. In this study, the known WQI formula based on three different means has been used. Weighted Mean Water Quality Index (WM - $WQI_{x = 1-n}$) is given in Eq. 1. The weight factors (Wx) of the parameters are used as constant values. Unweighted Mean Water Quality Index (UM - $WQI_{x = 1-n}$) is formulated as in Eq. 2 (Katyal, 2011) Unweighted Harmonic Square Mean Water Quality Index (UHSM - $WQI_{x = 1-n}$) is presented in Eq. 3 (Rangetti *et al.*, 2015). Here, the number of parameters chosen to calculate WQI values is n. The symbol Q_x indicates the quality values of the parameters indicated by the subscript x. By assigning ten numbers to the x symbol, total coliform (TC) (x = 0), fecal coliform (FC) (x = 1), total suspended solids (TSS) (x = 2), nitrate (NO_3) (x = 3), turbidity (x = 4), pH (x = 5), temperature difference (ΔT) (x = 6), percent saturated dissolved oxygen (%(sat)DO) (x = 7), biochemical oxygen demand (BOD) (x = 8), total phosphate (TP) (x = 9) indicators have been obtained. WQIs with high number of parameters and WQIs with only three parameters can be applied to evaluate the overall variation of water quality. In these calculations, TC can be used as bacterial indicator (Pesce *et al.,* 2000). By considering previously published work on coastal water parameters in the same locations (Cebe and Balas, 2016; Hapoğlu *et al.,* 2018; Yıldırım and Balas, 2019), the 10 parameters mentioned above were selected for this study. Hapoğlu *et al.* (2018) reported succesfull usage of WQI with x=1,6,7 in Kaş Bay by realizing statistical analysis of the water quality parameters and the indices with the different number of parameters. After checking the indices given below with the different number of parameters such as x=1-7, x=1-9, x=0,2-9, x=1,6,7, x=0,6,7. Three parameters, x=0,6,7, are chosen to developed dynamic model in this work. As a bacterial indicator, FC or TC can be chosen. Because of larger amount existance in the region, TC are prefered as a model input.

$$\text{WM-WQI}_{x=1\text{-}n} = \frac{\sum_{x=1}^{n} Q_x W_x}{\sum_{x=1}^{n} W_x} \tag{1}$$

$$\text{UM-WQI}_{x=1\text{-}n} = \frac{\left[\sum_{x=1}^{n} Q_x\right]}{n} \tag{2}$$

$$\text{UHSM-WQI}_{x=1\text{-}n} = \left[\frac{n}{\sum_{i=1}^{n} Q_x^{-2}}\right]^{0.5} \tag{3}$$

The non-dimensional quality values are provided for each parameter by using interpolation with the developed software in MATLAB environment (Hapoğlu *et al.*, 2018). From this software, BOD, TP and TC qualities are also obtained by implementing the piecewise cubic Hermite interpolation. Figs. 2 and 3 show the BOD quality and TP quality curves, respectively. The curve linking the overall bacterial quality to the TC indicator value is given in Fig. 4, considering the close relationship between the FC and TC indicators. This curve is useful, especially if the FC bacteria number is low.

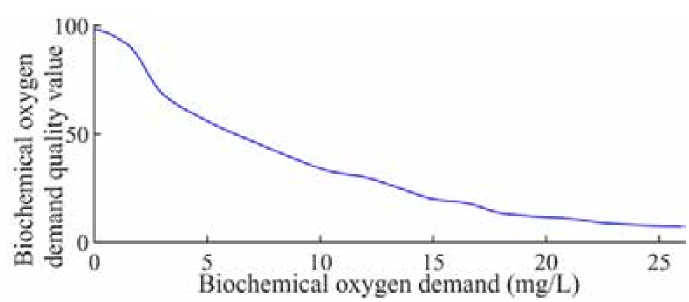

Fig. 2: The relationship between biochemical oxygen demand and its quality value

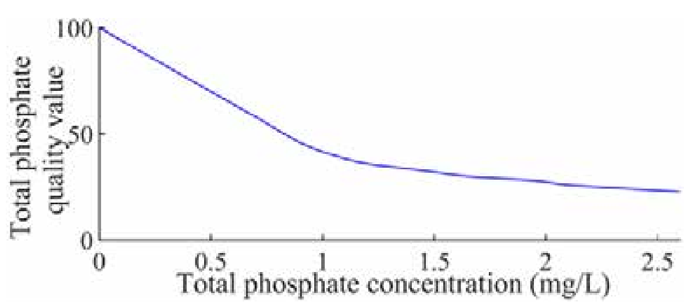

Fig. 3: The relationship between total phosphate and its quality value

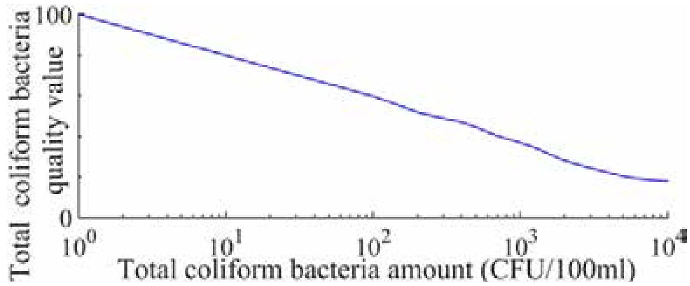

Fig. 4: The relationship between total coliform bacteria amount and its quality value

In the known WQI formulas, the selection of parameters to be used as an indicator is important since the quality value of some parameters is high so that the calculated index value can be high (Hapoğlu *et al*., 2018). Besides, an indicator with a high pollution effect can create a sensitivity difference between different WQI formulas. In this study, known WQI formulas were developed based on the minimum norm with the technique described below to increase the sensitivity between formulas. Weighted mean water quality index (WM-WQI-MN) based on minimum norm, unweighted mean water quality index based on the minimum norm (UM - WQI-MN) and unweighted harmonic square mean water quality index based on the minimum norm (UHSM-WQI-MN) are calculated with the software prepared in MATLAB environment using calculation steps in Eqs. 4-10. Binary element evaluations defined in Eq. 5 are made between two parameters, such as parameter i and parameter j for the matrix given in Eq. 4. These binary element calculations are made between two parameters, such as parameter i and parameter j for matrices (A_t, B_t, C_t) to be generated based on each WQI formula. These matrices are calculated from the following Eqs. (4-9) for each individual sampling step (t = 1,2,…, m). Formulas in Eqs. 1-3 (WM-WQI$_{x = 1-n}$, UM-WQI$_{x = 1-n}$, UHSM-WQI$_{x = 1-n}$) are developed based on the minimum norm (MN) as given in Eqs. 11 to 13 by the technique described above.

$$A_t = \begin{bmatrix} a_{11} & \cdots & a_{1j} \\ \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ij} \end{bmatrix} \quad (4)$$

$$a_{ij} = \frac{\left\{ W_{x=i}\left(\frac{Q_{x=i}}{100}\right) + W_{x=j}\left(\frac{Q_{x=j}}{100}\right) \right\}}{\left(W_{x=i} + W_{x=j}\right)} \quad (5)$$

$$B_t = \begin{bmatrix} b_{11} & \cdots & b_{1j} \\ \vdots & \ddots & \vdots \\ b_{i1} & \cdots & b_{ij} \end{bmatrix} \quad (6)$$

$$b_{ij} = \frac{\left(Q_{x=i} + Q_{x=j}\right)}{200} \quad (7)$$

$$C_t = \begin{bmatrix} c_{11} & \cdots & c_{1j} \\ \vdots & \ddots & \vdots \\ c_{i1} & \cdots & c_{ij} \end{bmatrix} \quad (8)$$

$$c_{ij} = \left(\frac{2}{\left(\frac{Q_{x=i}}{100}\right)^{-2} + \left(\frac{Q_{x=j}}{100}\right)^{-2}} \right)^{0.5} \quad (9)$$

WQI matrices (At, Bt, Ct) with different binary indicator elements were used to obtain WQI values on the basis of the MN for each t, as in the A_t example shown in Eq. 10. In MATLAB environment, the MN is calculated with the software developed as the matrix two norm ($||At||_2$) ||, which provides the smallest size measurement (Chapra, 2012). The E_{max} value in Eq. 10 is the largest eigenvalue ($[A_t]^T [A_t]$).

$$A_{t2} = \left(E_{max}\right)^{0.5} \quad (10)$$

In this study, three different WQI calculations based on the MN for each t were performed using Eqs. 11 to 13.

$$\text{WM-WQI-MN} = \left(\frac{A_{t2} * 100}{n}\right) \quad (11)$$

$$\text{UM-WQI-MN} = \left(\frac{B_{t2} * 100}{n}\right) \quad (12)$$

$$\text{UHSM-WQI-MN}=\left(\frac{C_{t2}*100}{n}\right) \quad (13)$$

To evaluate WQIs from the six formulas mentioned above, the non-dimensional quality values and weights are obtained from the previously developed software in MATLAB environment (Hapoğlu *et al.*, 2018). NSFWQI Rating (excellent (91-100), good (71-90), medium (51-70), bad (26-50), very bad (0-25) reported by Tyagi *et al.* (2013) is used to rank the six WQI formulas.

Discrete time transfer function for water quality index estimation

TC, temperature, and DO monthly sampled indicator data and WQI values calculated with the selected formula (Eq. 13) are used for daily data generation using the zero-order hold element. The proposed transfer function parameters with the daily data generated are calculated using the Bierman (1976) algorithm. Input and output variables of the proposed transfer function are defined in terms of the deviation variable. Here [(UHSM-WQI-MN)-(UHSM-WQI-MN)$_b$], [ΔT-ΔT$_b$], [%(sat)DO-%(sat) DO$_b$], and [TC-TCb] values are defined as the output variable (OV), the first input variable (IV1), the second input variable (IV2), and the third input variable (IV3), respectively. The third-order transfer function with three inputs and one output variable is given in Eq. 14. The dynamics of the stations dictates the sampling time required. The sampling time of this transfer function is chosen as one day. Thus the model requires inputs data at every sampling time. To obtain output behaviour versus time, necessary inputs are provided by using repeating sequence interpolation technique.

$$\begin{aligned}\text{OV}=&\frac{0{,}00053258z^3\text{-}0{,}0014z^2}{z^3\text{-}0{,}9990z^2+0{,}0026z\text{-}0{,}0059}\text{IV1}\\&+\frac{\text{-}0{,}0854z^3+0{,}1422z^2}{z^3\text{-}0{,}9998z^2\text{-}0{,}2787z+0{,}4726}\text{IV2}\\&+\frac{0{,}0040z^3\text{-}0{,}0079z^2}{z^3\text{-}0{,}9859z^2\text{-}0{,}1514z+0{,}2741}\text{IV3}\end{aligned} \quad (14)$$

The model (Eq. 14) calibration is achieved in MATLAB environment by using the recursive algorithm (Bierman, 1976) and a random sequence input produced based on experimental data obtained monthly from FM station with zero-order hold element. This input is utilised as a forcing function in order to determine the transfer function parameters. No previous knowledge of the model parameters was assumed so that the initial set of parameter estimates is fixed equal to zero with large initial values used for the covariance matrix diagonal elements. The parameter evaluation is performed recursively using the Bierman (1976) update algorithm in MATLAB environment. For the model verification, the experimental data obtained monthly from FM station are compared with the model output (Fig. 10). For the last stage , BM and KM are selected far from FM to illustrate model applicability. The evaluation stage is executed by comparing the simulated WQI values in different stations in the different time domain with the WQI values evaluated from experimental measurements (Fig. 11). In this study, a model for WQI, which includes daily based discrete-time transfer function given in Eq. 14 in Simulink-MATLAB environment, has been developed. In case the daily input data is missing, the developed model can generate the input data using the repeating sequence interpolation technique and perform estimates of WQI that can be defined as the past and the future according to the specified initial date indicated by sub-index b.

RESULTS AND DISCUSSION

The enclosed coastal WQI assessment has been performed at three stations near marina entrances in Bucak, Kaş, and Fethiye Bays on the Mediterranean coast of Turkey by calculations with monthly intervals using WM-WQI, UM-WQI, UHSM-WQI formulas. WQI values are calculated by using different formulas with seven indicators from x = 1 to 7 for the BM station in Bucak Bay, as shown in Fig. 5. In winter, the results of UHSM-WQI create more fluctuations than the results of WM-WQI and UM-WQI. An evaluation comes out that these fluctuations might be due to the sensitivity to load effects of fecal coliform concentration. There has been a significant relationship between the T and DO (r=-0.8480, p=8.7995E-6), DO and TC (r=0.7422, p=4.2062E-4), TC and FC (r=0.5100, p=0.0306) data pairs. However, there is no significant relationship between DO-FC data pairs (r = 0.4402, p = 0.0675). For very close Kaş Bay region, previously reported DO-FC data pairs (r=0.6980, p= 0.0001) indicates significant relation (Hapoğlu *et al*., 2018). The ratios of FC at BM station to FC at KM station are 0.459 (21.12.2013) and 1.335 (8.2.2014). The ratios of TC at BM station to TC at KM station are evaluated as 1.123 (21.12.2013) and 1.158 (8.2.2014). This result shows that there are direct FC discharges in the environment. Fig. 5 shows WM-WQI-MN, UM-WQI-MN, UHSM-WQI-MN values calculated with the same seven parameters. These WQI formulas are developed based on the MN with matrix elements based on WQI values calculated on indicator pairs quality values (Eqs.11-13). These curves, based on the MN, which change more closely with each other, show high sensitivity considering the relationship between other traditional formulas. UHSM-WQI-MN values constitute the lower limit among the curves based on the MN, while the WM-WQI results follow a path between the UM-WQI and the UHSM-WQI curves. In index formula calculations that use a large number of indicators, some quality parameters that indicate a low level of pollution may mask the emergence of problems associated with changes in other quality parameters (Hapoğlu *et al*., 2018). The evaluation to solve this problem is that it would be appropriate to use fewer significant indicator parameter groups in the light of monitoring studies with WM-WQI calculated with three parameters (x = 1, 6, 7) in Kaş enclosed coastal water body containing many station data (Hapoğlu *et al*., 2018). This selection, which is proposed over the water body without excessive pollutant input, has been compared in this study for BM, KM, and FM stations near marina entrances.

All WQI formulas calculated using seven indicators for BM station selected in Bucak Bay shown in Fig. 5 are recalculated by using only FC (x = 1), ∆T (x = 6) and %(sat)DO (x = 7) parameters and given in Fig. 6. As a result of the comparison of these index curves, UHSM-WQI-MN values calculated with a small

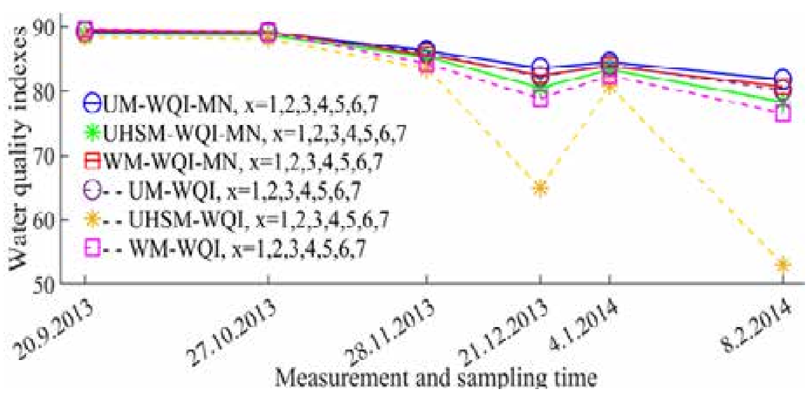

Fig. 5: Change of water quality indices with seven parameters with respect to time for station BM

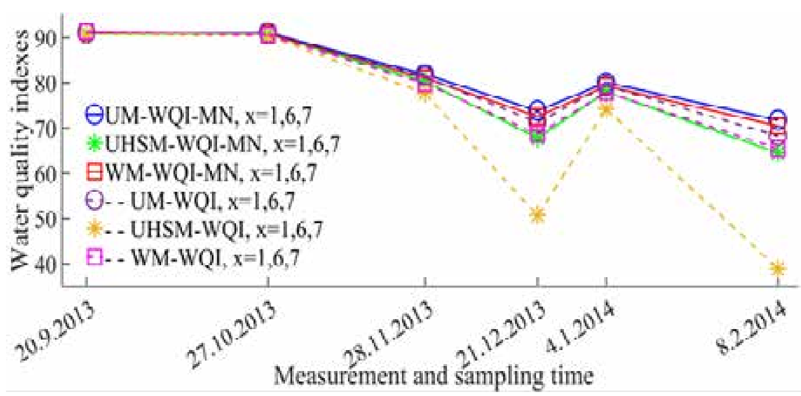

Fig. 6: Change of water quality indices with three parameters with respect to time for station BM

number of selected parameters are found suitable for monitoring.

KM station selected in Kaş Bay has shown a similar change in WQI with the BM Station compared to the FM station. It is possible to understand this similarity from the comparison of WM-WQI-MN, UM-WQI-MN, UHSM-WQI-MN values calculated with three indicators (x = 1,6,7) as shown in Fig. 7 and the changes given in Fig. 6. There is a significant seasonal decrease from WQI values, which is 80-95 in autumn to 70-80 index values in winter. At FM station in winter, UHSM-WQI-MN values monthly calculated with three indicators (x = 1,6,7) were 73.84, 78.23, and 65.82. UHSM-WQI-MN values with three indicators (x = 0,6,7) were also monthly calculated for winter as 73.25 , 68.95, and 68.38. By comparing 73.84 in December and 78.23 in January, the low amount of fecal coliforms pointed out at station FM is sufficient to cover up the seasonal index decrease at FM station in Fethiye Bay. As a result of the statistical analysis performed with the measurements taken from the station FM, a significant relationship ($p < 0.05$) has been detected between the T and DO ($r=-0.8845$, $p=0.0082$) data pair. The lack of a significant relationship between the data pairs of FC measurements with DO($r=0.6143$, $p=0.1422$), pH ($r=0.0718$, $p=0.8784$) and T ($r=-0.7022$, $p=0.0786$) supports the direct fecal coliform entries that cover up WQI. Fig. 8 shows the annual changes in WQI-MN, UM-WQI-MN, UHSM-WQI-MN values calculated monthly with three (x=1,6,7) and nine (x=1-9) parameters using FC as the bacterial indicator for the FM station. The use of FC as a bacterial indicator in the FM station with high direct input effects has been examined. It has been evaluated that these values, which are much less than TC amounts, are not sufficient for the determination of the sensitive dimensionless bacterial indicator quality value. This assessment has been supported by monitoring that the fall and

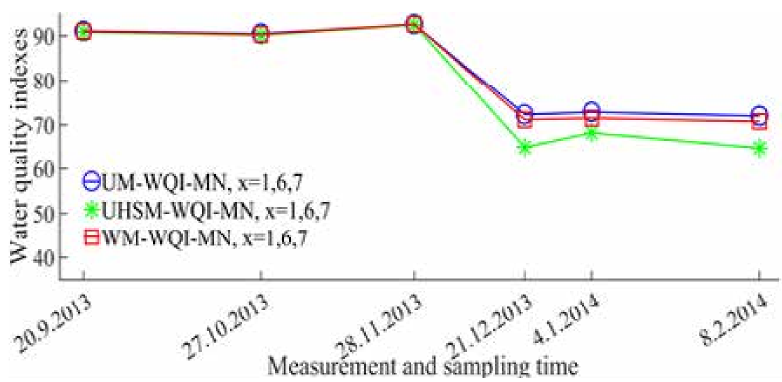

Fig. 7: Change of water quality indices with three parameters with respect to time for station KM)

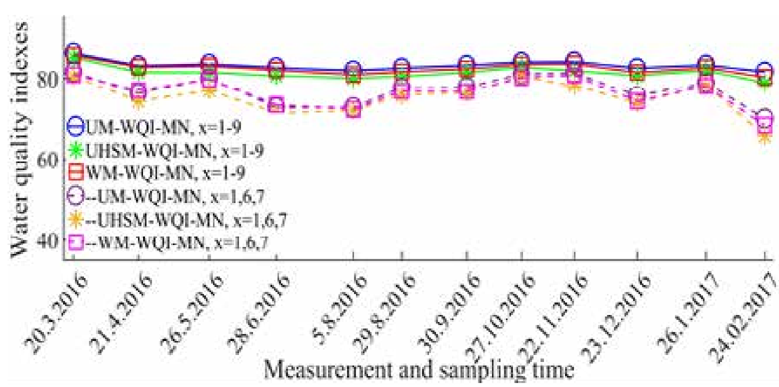

Fig. 8: Change of water quality indices with three and nine parameters with respect to time for station FM

winter seasonal changes seen in FM station did not show a significant decrease as seen in WQI in BM and KM stations (Figs 6 and 7).

The changes of WQI-MN, UM-WQI-MN, UHSM-WQI-MN values with three (x = 0,6,7), and nine (x = 0, 2-9) parameters using TC bacteria measurements in the computations of dimensionless bacterial quality value (Fig. 4) for Station FM with time is shown in Fig. 9. UHSM-WQI-MN, which generates lower limit values in quality monitoring with three parameters (x = 0,6,7), has been evaluated that quality monitoring, estimation, and comparison can be made in similar stations near marina entrances.

Dynamic WQI (UHSM-WQI-MN) has been created in the Simulink-MATLAB environment, which uses interpolation in the input data defined with a daily based discrete-time transfer function (Eq. 14) as monitoring, estimation and comparison tool. The model parameter estimation used in the software has been carried out with monthly measurements from the FM station, and daily random input values produced using the zero-order hold element. The changes in daily UHSM-WQI-MN values for FM station estimated by this software are given in Fig. 10. TC_b, DT_b, $\%(sat)DO_b$, and $(UHSM\text{-}WQI\text{-}MN)_b$ values calculated by the measurements dated 29 August 2019 were used as the initial values in obtaining output indicated by a line. The daily UHSM-WQI-MN software outputs obtained for backward and forward of the selected initial date are compared with WQI data calculated from monthly measurements (WQI-MN, UM-WQI-MN, UHSM-WQI-MN) displayed with symbols. Based on these comparisons, software predictions have been found very successful for station FM. The daily input data is provided by using the Simulink library with the repeating sequence interpolation method in the software that uses a daily discrete-time step. The applicability of this

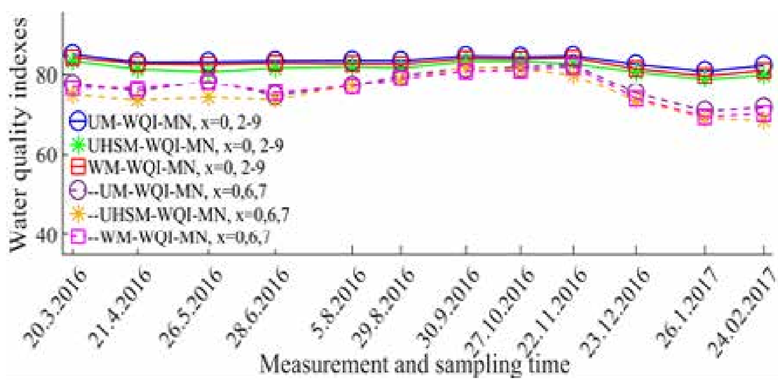

Fig. 9: Change of water quality indices using total coliform as bacterial indicator with three and nine parameters for the station FM with time.

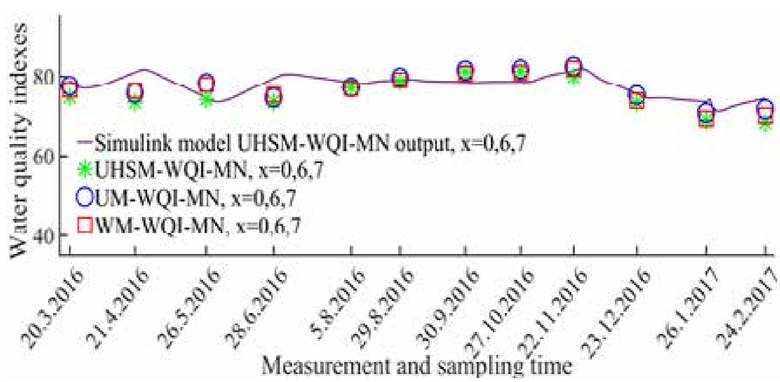

Fig. 10: Water quality index output from model with three input variables for station FM

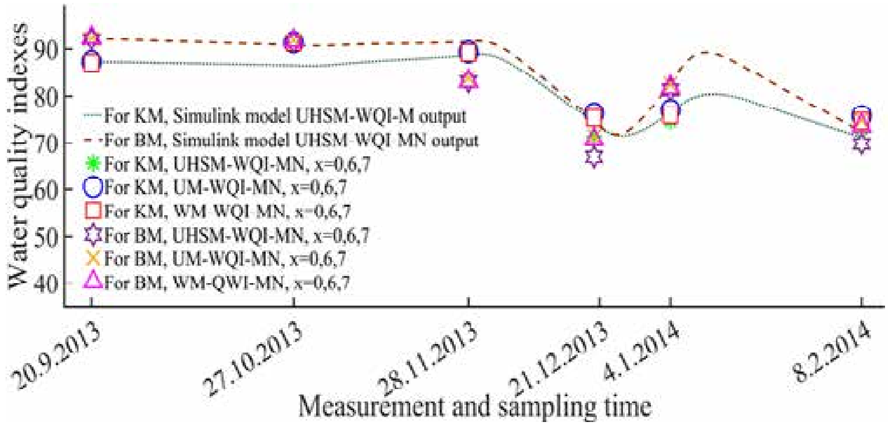

Fig. 11: Water quality index output from model with three input variables for stations KM and BM

Table 2: A comparative water quality assessment at FM, BM and KM stations

Season	Station FM Seasonal evaluation for 20.3.2016-24.2.2017 with montly UHSM-WQI-MN(x=0,6,7)	Station BM Seasonal evaluation for 20.9.2013-08.2.2014 with montly UHSM-WQI-MN(x=0,6,7)	Station KM Seasonal evaluation for 20.9.2013 -08.2.2014 with montly UHSM-WQI-MN (x=0,6,7)
Spring	Good ([75+73+74]/3=74)		
Summer	Good ([74+77+79]/3=76,7)		
Autumn	Good ([81+81+80]/3=80,7)	Good ([92+92+83]/3=89	Good ([87+91+89]/3=89)
Winter	Medium-Good ([73+69+68]/3=70)	Good ([70+81+70]/3=73,7)	Good ([71+75+71]/3=72,3)

software as a follow-up, estimation, and comparison tool has been investigated for nearby similar stations, BM, and KM (Fig. 11). Software outputs shown with different dashed lines for the station KM and BM were obtained using TC_b, DT_b, $\%(sat)DO_b$ and $(UHSM\text{-}WQI\text{-}MN)_b$ values initially calculated by the measurements dated 20 September 2013. The software results shown in Fig. 11 have been found successful in the five-month forecast and follow-up from the initial value. The software developed has been successfully applied for the comparison of the WQI changes in the same time interval for station KM and BM. UHSM-WQI-MN data calculated from monthly measurements are given in Table 2 for three similar stations in the enclosed coastal areas shown in Fig. 1. Although the general quality evaluation is good, it has been calculated that the WQI values from autumn to winter decreased by 13.2% for FM station, 17.2% for BM station, and 18.7% for KM station. When resultant curves of the software given in Figs. 10 and 11 are examined for the same three stations, the water quality has been classified as good with the observation of a slight decrease from autumn to winter.

CONCLUSION

An enclosed water quality assessment of three different stations was monthly performed to investigate the usage of the conventional and the proposed generalized formulas of WQIs. The absolute maximum discrepancy among the conventional formulas used was detected as 30 percent. The discrepancy among the proposed formulas was found as 7.1 percent. The conventional WQIs with much noisier index curves may be ill-suited with respect to constant or equal weighting factors utilization, number of parameters chosen and external disturbances availability. Accordingly the application of a generalization technique based upon MN was proposed to maintain the desired robustness and the smoothness of the index curves versus discrete sampling time. For station BM, among both three conventional WQIs with x=1-7 and three proposed WQIs based on MN with x=1-7, an absolute maximum discrepancy of 27 percent, and 3 percent were detected respectively (Fig. 5). Besides, among both three conventional WQIs with x=1, 6, 7 and three proposed WQIs based on MN with x=1, 6, 7, an absolute maximum discrepancy of 30 percent, and 7.1 percent were detected respectively (Fig. 6). For station KM, among three proposed WQIs based on MN with x=1, 6, 7, an absolute maximum discrepancy of 7.1 percent was found (Fig. 7). For station FM, among both three proposed WQIs based on MN with 1-9 and three proposed WQIs based on MN with x=1, 6, 7, an absolute maximum discrepancy of 3.1 percent, and 4.6 percent were detected respectively (Fig. 8). Besides, among both three proposed WQIs based on MN with x=0, 2-9 and three proposed WQIs based on MN with x=0, 6, 7, an absolute maximum discrepancy of 3.1 percent, and 4.6 percent were determined respectively (Fig. 9). The UHSM-WQI-MN proposed among other formulas was found sensitive enough by considering performance comparison with the usage of various numbers of indicators. The computed WQI values and the sampled indicators data of TC, T, DO in the form of deviation were used to identify the proposed third order transfer function parameters. The software including the daily based discrete time transfer function and the input sources which the daily based indicators data were determined by using interpolation technique among the monthly sampled inputs was proposed and successfully applied to predict past and future water quality index changes versus time. The maximum absolute errors between the WQI calculated from experimental measurements and the simulated WQI from the software developed are found as 4.2 percent, 4.3 percent, and 7.1 percent respectively in Fethiye, Kaş, and Bucak stations. For the quality prediction and comparison, the software proposed can be adapted to other enclosed coastal water. Thus it may provide an effective tool in the comparable enclosed coastal water bodies. In this study, the model described above has been developed in the Simulink-MATLAB environment and proposed as a reliable tool with flexible applicability for coastal water quality index follow-up, prediction, and comparisons. The model has been successfully applied to enclosed coastal water bodies of Bucak, Kaş, and Fethiye Bays having marinas. In software development, a daily discrete-time third-order three inputs, and one output transfer function were found suitable for the region studied. FM station measurements define the parameters of this model. This software has successfully provided the predictions and comparisons of daily changes in UHSM-WQI-MN at the same stations, with the application of newly selected initial dates and different date intervals for the future. This software can be applied for stations with different features in the same region by updating the model parameter identification step with the representative station measurements. This software can be applied to other enclosed coastal water bodies by using the repeatable steps of selecting the appropriate number of indicators and determining the transfer function parameters by using the regional descriptive measurements obtained.

AUTHOR CONTRIBUTIONS

H. Hapoglu developed a model in the Simulink-MATLAB environment, and provided the WQI data, prepared the manuscript text. Ş. Camcioglu provided some non-dimensional quality values in MATLAB environment. B. Ozyurt helped in the literature review and provided some of the remained non-dimensional quality values in MATLAB environment. P. Yıldırım performed the analyses on water quality parameters. L. Balas conducted field measurements and performed coastal water quality evaluations, compilation of the data and manuscript preparation.

ACKNOWLEDGEMENTS

This study has been supported financially by the Scientific and Technological Research Council of Turkey [TUBITAK, Project No:115Y468] and Ankara University Scientific Research Projects Coordination Unit [Project No:14L0443001 2016]. The authors would like to thank employees of DLTM Software Technologies Limited Company due to their support for field measurements.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

A_t	Water quality index matrix
$[A_t]^T$	Transpose of the matrix
$\|\| A_t \|\|_2$	The matrix 2 norm
BOD	Biochemical oxygen demand
BM	Bucak Marina
DO	Dissolved oxygen
E_{max}	The largest eigenvalue of $([A_t]^T[A_t])$.
FC	Fecal coliform
FM	Fethiye Marina
GIS	Geographic information system
KM	Kaş Marina
MATLAB	Software environment developed as a matrix laboratory
MN	Minimum Norm
NO_3	Nitrate
p	Significance value, significant for $p < 0.05$ condition
Qx	Quality value of the parameter indicated by the index x
r	correlation coefficient
T	Temperature -0.5 m depth below the surface
TC	Total coliform bacteria
TC_b	Accepted initial value at a specific sampling date selected for the total coliform
Tref	Reference temperature -10m depth below from the surface
TSS	Total suspended solids
TP	Total phosphate
WQI	Water Quality Index
UHSM-WQI	Unweighted Harmonic Square Mean Water Quality Index
UM-WQI	Unweighted Mean Water Quality Index
WM-WQI	Weighted Mean- Water Quality Index
W_x	Weight factor of the parameter indicated by the index x
%(sat)DO	The ratio of 100 times the DO value to the 100% saturated DO value
$\%(sat)DO_b$	Accepted initial value of % (sat) DO value on a selected sampling date
DT	Difference from reference temperature value (Tr_{ef}) and surface temperature value (T), (Tr_{ef}-T)
DT_b	Accepted initial value at a specific sampling date selected for the temperature difference

REFERENCES

Aydinol, F.I.T; Kanat, G.; Bayhan, H., (2012). Sea water quality assessment of Prince Islands' Beaches in İstanbul. Environ. Monit. Assess., 184:149-160 **(12 pages).**

Azis, P.A.; Mancera-Pineda, J.E.; Gavio, B. (2018). Rapid assesment of coastal water quality for recreational purposes: Methodological proposal. Ocean. Coastal Manage., 151: 118-126 **(9 pages).**

Bierman, G.J., (1976). Measurement updating using the U-D factorization. Automatica, 12 (4), 375-382 **(8 pages).**

Boyacioglu, H., (2007). Development of a water quality index based on a European classification scheme. Water S.A., 33(1): 101–106 **(6 pages).**

Campos, C.J.A.; Kershaw, S.R.; Lee, R.J., (2013). Environmental Influences on Faecal Indicator Organisms in coastal waters and their accumulation in bivalve shellfish. Estuaries and Coasts. 36: 838-853**(16 pages).**

Capella, J.V.; Bonastre, A.; Ors, R.; Peris, M., (2013). In line river monitoring of nitrate concentration by means of a Wireless Sensor Network with energy harvesting. Sens. Actuators, B, 177: 419-427 **(9 pages).**

Cebe, K.; Balas, L., (2016). Water quality modelling in Kaş Bay. Appl. Math. Model. 40: 1887-1913 **(27 pages).**

Chapra, S.C., (2012). Applied numerical methods with MATLAB for engineers and scientists. Matrix inverse and condition, Splines and Piecewise Interpolation. McGraw Hill, New York, 268-283: 429-461 **(33 pages).**

Cude, C.G., (2001). Oregon water quality index a tool for evaluating water quality management effectiveness. J. Am. Water Resour. Assoc., 37(1): 125-137 **(13 pages).**

Farrugia, H.; Deidun, A.; Gauci, A.; Drago, A., (2016). Defining the trophic status of Maltese (Central Mediterranean) coastal waters through the computation of water quality indices based on satellite data. J. Coastal Res., 75 (SI): 632-636 **(5 pages).**

Hapoğlu,H.; Camcıoğlu, Ş.; Özyurt, B.; Yıldırım, P.; Yılmaz, N.; Balas, L.,(2018). Enclosed coastal waters quality monitoring with bacterial indicator phase-plane analysis. J. Fac. Eng. Archit. Gaz., 33(4): 1419-1431 **(13 pages).**

He, Y.; He, Y.; Sen, B.; Li, H.; Li, J.; Zhang, Y.; Zhang, J.; Jiang, S. C.; Wang, G.,(2019). Storm runoff differentially influences the nutrient concentrations and Microbial contamination at two distinct beaches in northern China. Sci. Total Environ., 663: 400–407 **(8 pages).**

Jha, D. K.; Devi, M. P.; Vidyalakshmi, R.; Brindha, B.; Vinithkumar, N. V.; Kirubagaran, R., (2015). Water quality assessment using water quality index and geographical information system methods in the coastal waters of Andaman Sea. India. Mar. Pollut. Bull., 100 (1): 555-561 **(7 pages).**

Karakaya, N.; Evrendilek, F., (2010). Water quality time series of Big Melen stream (Turkey): its decomposition analysis and comparison to upstream. Environ. Monit. Assess., 165(1-4): 125–136 **(12 pages).**

Karbassi, A.R.; Pazoki, M., (2015). Environmental qualitative assessment of rivers sediments. Global J. Environ. Sci. Manage., 1)2): 109-116 **(8 pages).**

Katyal, D., (2011). Water quality indices used for surface water vulnerability assessment. J. Environ. Sci., 2 (1): 154-173 **(20 pages).**

Khatoon, H.; Haris, N.; Banerjee, S.; Rahman, N.A.; Begun, H.; Mian, S.; Abol-Munafi, A.B.; Endut, A., (2017), Effects of different salinities on the growth and proximate composition of Dunaliella sp. Isolated from South China Sea at different growth phases. Process. Saf. Environ. Protct., 112: 280-287 **(8 pages).**

Liou, S.M.; Lo, S.L.; Wang, S.H., (2004). A generalized water quality index for Taiwan. Environ. Monit. Assess., 96: 35–52 **(18 pages).**

Liu, X.; Sen, B.; Zhao, Y.; Bai, M.; He, Y.; Xie, Y.; Li, J.; Wang, G., (2019). Gradients of three coastal environments off the South China Sea and their impacts on the dynamics of heterotrophic microbial communities. Sci. Total Environ., 659: 499–506 **(8 pages).**

Lohe, R.N.; Tyagi, B.; Singh, V.; Tyagi, P.; Khanna, D.R.; Bhutiani, R., (2015). A comparative study for air pollution tolerance index of some terrestrial plant species. Global J. Environ. Sci. Manage., 1(4): 315-324 **(10 pages).**

Loucks, D.P.; Jia, H., (2012). Managing water for life. Front. Environ. Sci. Eng., 6(2): 255-264 **(10 pages)**.

Lumb, A.; Sharma, T.C.; Bibeault, J. F. (2011). A review of genesis and evolution of water quality index (WQI) and some future directions. Water Qual. Exposure Health, 3: 11-24 **(14 pages)**.

Nguyen, N.T.T.; Sevando, M., (2019). Assessing Coastal Water Quality through an Overall Index. Pol. J. Environ. Stud., 28 (4):2321-2330 **(10 pages).**

Pavlidou, A.; Simboura, N.; Rousselaki, E.; Tsapakis, M.; Pagou, K.; Drakopoulou, P.; Assimakopoulou, G.; Kontoyiannis, H.; Panayotidis, P., (2015). Methods of eutrophication assessment in the context of the water Framework directive: Examples from the Eastern Mediterranean coastal areas. Cont. Shelf Res., 108: 156–168 **(13 pages).**

Pesce, S. F.; Wunderlin, D.A., (2000). Use of water quality indices to verify the impact of Cordoba city (Argentina) on Suquia River. Water Res., 34(11): 2915-2926 **(12 pages).**

Pham Phu, S.T.; Hoang, M.G.; Fujiwara, T., (2018). Analyzing solid waste management practices for the hotel industry. Global J. Environ. Sci. Manage., 4(1): 19-30 (12 pages).

Rangetti, I.; Dzwairo, B.; Barratt, G. J.; Otieno, F.A.O., (2015). Ecosystem-specific water quality indices. Afr. J. Aquat. Sci., 40(3): 227–234 **(8 pages).**

Rees, G.; Pond, K.; Johal, K.; Pedley, S.; Rickards, A., (1998). Microbiological analysis of selected coastal bathing waters in the U.K., Greece, Italy and Spain. Water Res. 32(8): 2335-2340 **(6 pages).**

Regulation for the Surface Water Quality, (2016), Rebulic of Turkey Ministry of Forest and Water Management. Official Gazette date: August 10, 2016. No: 2979.

Regulation for the Water Pollution Control, (2004). Rebulic of Turkey Ministry of Environment and Forestry.Official Gazette date: December 31, 2004. No: 25687.

Sargaonkar, A.; Deshpande, V., (2003). Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. Environ. Monit. Assess., 89(1): 43-67 **(25 pages).**

Simboura, N.; Pavlidou, A.; Bald, J.; Tsapakis, M.; Pagou, K.; Zeri, Ch.; Androni, A.; Panayotidis, P., (2016). Response of ecological indices to nutrient and chemical contaminant stress factors in Eastern Mediterranean coastal waters. Ecol. Indic, 70: 89–105 **(17 pages).**

Sutadian, A.D.; Muttil, N.; Yilmaz, A.G.; Perera, B.J.C., (2017). Using the Analytic Hierarchy Process to identify parameter weights for developing a water quality index. Ecol. Indic., 75: 220–233 **(14 pages).**

Tyagi, S.; Sharma, B.; Singh, P.; Dobhal R., (2013). Water quality assessment in terms of water quality index. Am. J. Water Resour., 1(3): 34-38 **(5 pages).**

Yıldırım, P.; Balas, L., (2019). Monitoring and evaluation of coastal water quality parameters in Fethiye Bay, Turkey. Appl. Ecol. Environ. Res., 17(5): 10421-10444 **(24 pages).**

Zhang, J.; Wei, Z.; Jia, H.; Huang, X., (2017). Factors influencing water quality indices in a typical urban river originated with reclaimed water. Front. Environ. Sci. Eng., 11(4): 8 **(10 pages).**

AUTHOR (S) BIOSKETCHES

Hapoğlu, H., Professor, Ankara University, Engineering Faculty, Chemical Engineering Department, 06100 Tandoğan, Ankara, Turkey. Email: *Hale.Hapoglu@ankara.edu.tr*

Camcıoğlu, S., Ph.D., Research Assistant, Ankara University, Engineering Faculty, Chemical Engineering Department, 06100 Tandoğan, Ankara, Turkey. Email: *camcioglu@ankara.edu.tr*

Özyurt, **B.,** Ph.D., Research Assistant, Ankara University, Engineering Faculty, Chemical Engineering Department, 06100 Tandoğan, Ankara, Turkey. Email: *bozyurt@ankara.edu.tr*

Yıldırım, P., Ph.D., Instructor, Gazi University, Sea and Aquatic Research Center, Engineering Faculty, Civil Engineering Department, 06570 Maltepe, Ankara, Turkey. Email: *fpelin@gazi.edu.tr*

Balas, L., Ph.D., Professor, Gazi University, Sea and Aquatic Research Center, Engineering Faculty, Civil Engineering Department, 06570 Maltepe, Ankara, Turkey. Email: *lalebal@gazi.edu.tr*

HOW TO CITE THIS ARTICLE

Hapoğlu, H.; Camcıoğlu, S.; Özyurt, B.; Yıldırım, P.; Balas, L., (2021). Discrete-time dynamic water quality index model in coastal water. Global J. Environ. Sci. Manage., 7(2): 197-210.

DOI: 10.22034/gjesm.2021.02.04

url: https://www.gjesm.net/article_47892.html