Kvïµ'ðU'XU'ðUXUŒU dXUEXUzµlU,XU ÇvU:XU (2018), Assessing environmental conditions for the Gediz Delta through estimated flows at the ungauged Delta Inlet. pp. 255-261. In Gastescu, P., Bretcan, P. (edit, 2018), *Water resources and wetlands*, 4th International Conference Water resources and wetlands, 5-9 September 2018, Tulcea (Romania), p.312

4th International Conference Water resources and wetlands, 5-9 September 2018, Tulcea (Romania)

ASSESSING ENVIRONMENTAL CONDITIONS FOR THE GEDIZ DELTA THROUGH ESTIMATED FLOWS AT THE UNGAUGED DELTA INLET

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Abstract

Wetlands in Turkey, the majority of which are protected by international agreements and national legislations are subject to persistent risks in terms of water availability due to several climatic and anthropogenic factors. Gediz river flowing in a basin of ca. 17500 km2 is the major source of environmental water for sustaining the wetland ecosystem in the Gediz delta, despite the already deteriorated hydrologic conditions in this greatly modified river basin. Due to its significance for carrying water for different uses, ranging from dense settlement patterns and industries to intensive farming activities, the Gediz river has always been prompted in scientific research and managerial decision-making by targeting water management in the basin. Yet, this high competence for water among the involved sectors other than the environment itself has somehow led to disregard of the wetland as a biodiversity hot-spot at the most downstream. The flow gauging network that has been engaged in the basin for years does not fully help represent the hydrology of the wetland due to the spatially remote measurements in basin upstream and/or the limited length of the flow records captured. The presented study implements an integrated approach, through regression relationships with physical and hydro-meteorological basin characteristics, for estimating the hydrologic flow character of the wetland in its immediate vicinity and then assessing the altering requirements of the wetland area through estimated environmental flow conditions. The study unfolds the presence of any statistical trend in environmental flow series as well as providing comparative analyses between different segments of the historical time series.

Keywords: Wetlands, hydrology, environmental flow, flow monitoring, ungauged sites

1 INTRODUCTION

Turkey's wetlands hold primary significance as biological and recreational hotspots since they accommodate rich biodiversity and serve prominent ecological services. Gediz Delta, which is located with a reported surface size of 149 km^2 at the outlet of the river Gediz along the Aegean Sea coast, is a Ramsar wetland site of international importance (Figure 1). Due to water scarcity and water quality problems experienced in the river, the wetland area is subject to considerable risks, despite all governmental efforts to protect and rehabilitate the site. Wetlands in general are natural systems that depend greatly on the water input from the river systems that feed them. Any hydrologic analysis to assess the ecological sustainability of such systems in terms of water quantities requires time series data of sufficient lengths from river monitoring stations. This facility is not available in the case of Gediz wetland due to slightly remote positioning of the most downstream station from the delta inlet. To this end, the presented study aimed to estimate monthly time series of river flows from the physical, hydrologic and meteorological characteristics of the basin as well as assessing the potential of environmental flows under varying environmental management considerations.

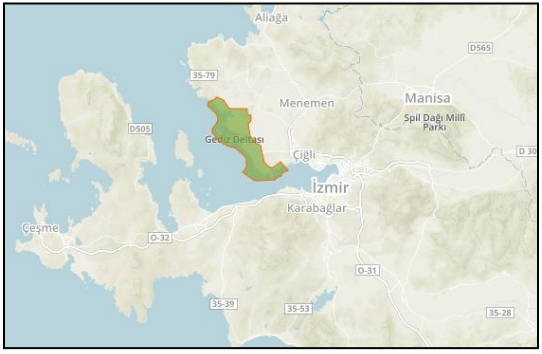
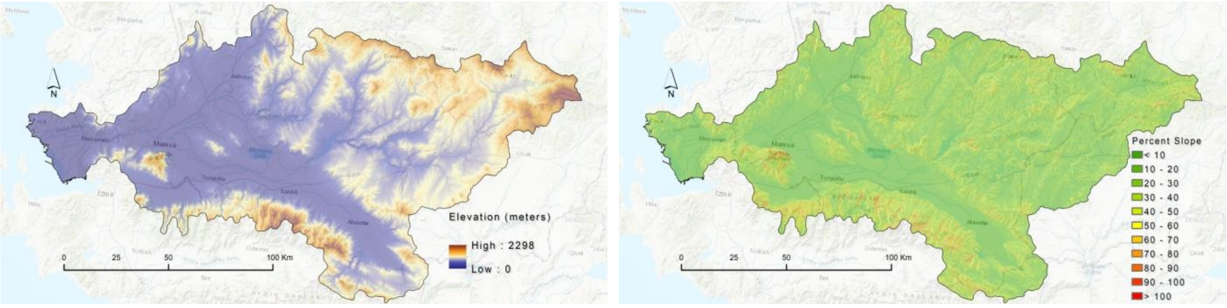


Figure 1. Gediz delta and wetland at the outlet of the river Gediz

2 MATERIALS, METHODS AND CASE-STUDY

In order to generate synthetic but representative stream flow time series at the ungauged delta inlet, the rationale behind the MA-SYE (Massachusetts Sustainable Yield Estimator) tool was basically considered. The logic here in estimating flow discharges at ungauged locations depends basically on the efforts for relating first the observed flows at streamgauges to physical and climate basin characteristics to develop quantile-based regression models and then generating synthetic flow data based on the flow-duration curve definitions for taking count of hydrologic stream flow regime through defined regression relationships for the ungauged location of interest (Archfield et al. 2010). These estimated time series for monthly flows are later used in computing monthly environmental flow potentials at the same location through desktop approaches and considering different environmental management strategies (Gül et al. 2017).

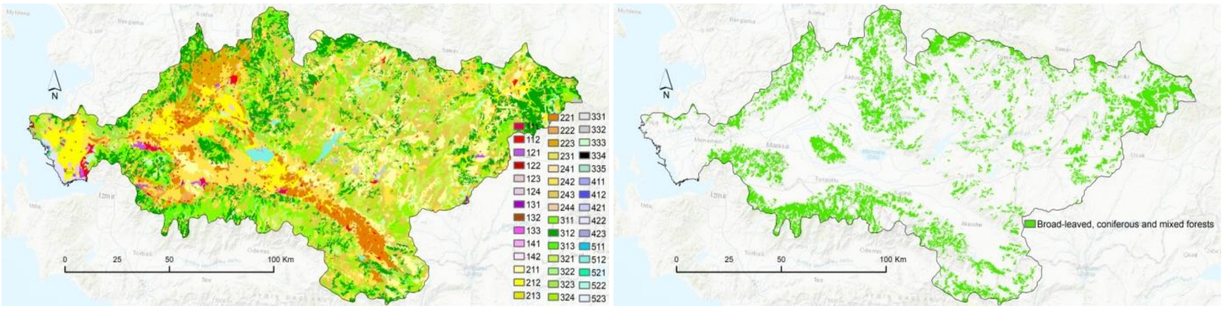
Due to the needs for spatial operations in implementing the study, geospatial data constitute the core of the datasets employed in the study. As the most fundamental dataset, digital topography model was acquired from the Aster-GDEM sources in the form of raster representation of the topographic features in 30 m. resolution (USGS 2017) (Figure 2a). Some other datasets, terrain slopes (Figure 2b) and overland flow directions for example, were derived from this data source through the use of corresponding spatial tools and operations embedded in the ArcGIS software.



(a) (b)

Figure 2. (a) Terrain elevations and (b) terrain slopes in Gediz Basin

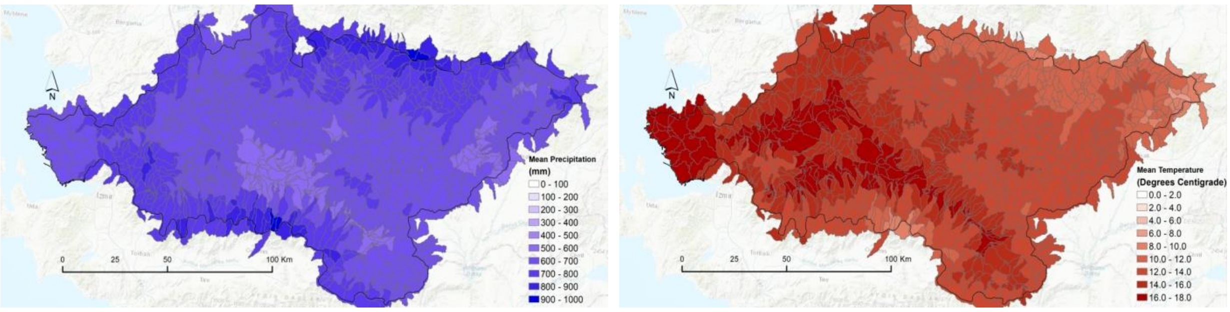
Another spatial dataset contributing to the development of physical basin characteristics was obtained from the Corine Land Cover repositories, which were constructed by the involved legal authorities in Turkey in agreement with the European Environment Agency, reported and disseminated through the Copernicus land monitoring service (European Commission 2018). From the raster dataset belonging to the data reporting year 2012 and containing the land cover data at the defined levels of Corine land cover classes (Figure 3a), a series of land use related basin characteristics, including the percent coverage of forest areas in the basin (Figure 3b), were captured for processing in further statistical analyses of the implemented study.



(a) (b)

Figure 3. (a) Corine land cover (CLC) classes as of the year 2012 and (b) forest areas in Gediz Basin

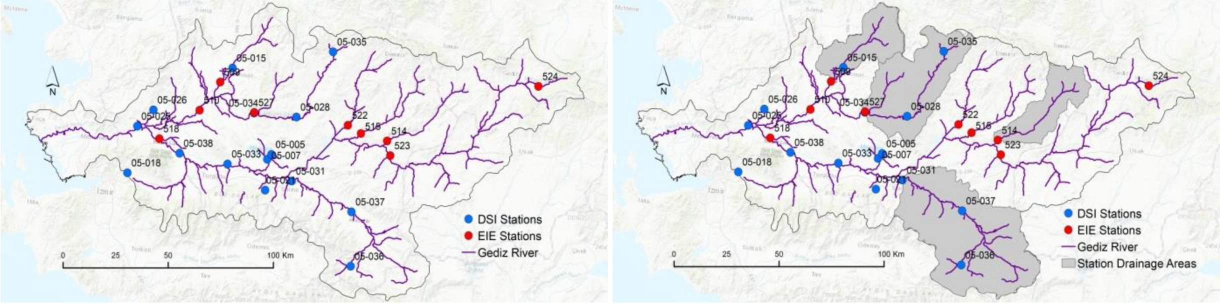
Meteorological basin characteristics were obtained from the CCM2 database that resulted from the Catchment Characterisation and Modelling (CCM) initiative by the Joint Research Center (JRC) of the European Commission and that include physical and meteorological characteristics of river basins at the micro-catchments level (De Jager and Vogt 2010). Annual average precipitation, maximum, minimum and annual average temperature data assigned to each micro-catchment in the dataset were used in performing computations for meteorological characteristics for the subbasins (i.e., drainage catchments of stream gauges) (Figure 4a and 4b).



(a) (b)

Figure 4. (a) Average rainfall (mm) and (b) average temperature in micro-catchments of Gediz Basin

For generating regression relationships to the physical and meteorological catchment characteristics to generate an initial set of stream flow quantiles on flow duration curve and then expanding the quantile estimations with additional set of data points which are associated with certain probabilities of exceedance, a series of stream gauges, which were operated in the recording period by the State Hydraulic Works (DSI) and Electrical Power Resources Survey and Development Administration (EIE) and which are available with observed stream flows in a solid recording period, were selected in the Gediz river basin (Figure 5a). The catchment characteristics that were required for employing the MA-SYE approach were computed through spatial operations in corresponding drainage catchments of the flow gauge stations (Figure 5b) and these operations provided the full list of characteristics that include drainage area, average annual precipitation, maximum and minimum temperature, mean, maximum and minimum basin elevations, percent of basin with high elevations, average basin slopes, X and Y coordinates of the stream gauge stations, X and Y coordinates of station catchments, elevation at the stream gauge and the forested shares of the catchment areas. In obtaining the drainage areas for the stations with known locations, catchment average slopes, highland shares and all elevations, the digital elevation model of the Gediz river basin was primarily utilized. For meteorological catchment characteristics, CCM2 dataset was employed for calculating areal average of precipitation and temperature characteristics for drainage areas from the level of micro-catchment polygons. Coordinate based information was taken from the georeferenced display of the station catchments as well as the stations themselves. Table 1 shows a narrowed set of these characteristics displayed with corresponding number figures for a limited set of stream flow stations.



(a) (b)

Figure 5. (a) Spatial distribution of the river flow gauges operated by DSI and EIE, (b) sample displays of drainage areas belonging to flow gauges in Gediz Basin

Table 1. Physical and meteorological drainage area characteristics computed for the gauged stream flow stations

PARAMETER / STATION	509	510	523	05-015	05-018	05-028	05-034 ...
Drainage area, in square kilometers	713.95	707.06	3222.44	502.42	31.99	789.98	1421.17
Mean basin elevation, in meters	436.03	487.11	881.5	546.92	508.03	742.27	657.16
Maximum basin elevation, in meters	1363	1479	2298	1363	803	1479	1479

Percent of basin with highlands	82 %	82 %	100 %	97 %	100 %	100 %	100 %
Elevation at the outlet of the station, in meters	80	50	352	104	284	325	134
Slope, in percent rise	18.24 %	17.34 %	17.37 %	23.17 %	18.93 %	18.02 %	19.91 %
X-coordinate at the station, in meters	459230.23	449453.53	539840.57	465081.18	415071.59	495424.41	475283.16
Percent of basin that is forested	29.12 %	25.78 %	19.27 %	37.83 %	37.61 %	22.48 %	28.86 %
...							

Flow duration curves which display stream flows with associated probabilities of exceedance help indicate flow patterns in river systems from the hydrometric and statistical perspective. The initial set of stream flow quantiles that correspond to 1%, 5%, 20%, 40% and 80% probabilities for exceeding associated flow quantities were considered through multi-variate linear regression relationships computed by using the ANOVA tool of the MS Excel software. In these operations, all physical and meteorological catchment characteristics were considered in starting operations and a statistically significant set of characteristics remained after the analysis for each quantile regression with the 95 % confidence considered. This operation resulted in the following set of four quantile relationships with corresponding catchment characteristics as independent regression variables, with the exception of Q80 quantile for low flows which did not provide a consistent and statistically significant relationship from the ANOVA analyses. This quantile value was interpolated from the neighboring quantile data points on the FDC graph.

$$Q1 = \exp(-704.16 + 0.419*A_D + 10.051*P_0 - 3.896*H_0 + 4.990*H_M + 9.026*H_{150} - 1.444*S_0 + 38.343*Y_C + 0.328*A_F) \quad (1)$$

$$Q5 = \exp(-627.61 + 0.463*A_D - 2.856*P_0 - 5.585*T_M + 3.138*H_M + 4.237*H_{150} - 12.991*X_C + 51.392*Y_S - 0.393*A_F) \quad (2)$$

$$Q20 = \exp(-1431.56 + 0.301*A_D + 0.841*P_0 + 4.463*H_M + 5.177*H_{150} - 1.378*S_0 - 7.267*X_C - 1.787*X_S + 97.093*Y_S) \quad (3)$$

$$Q40 = \exp(-697.87 + 0.639*A_D - 6.550*P_0 + 2.984*H_0 + 1.778*H_M - 11.183*X_C + 55.408*Y_S) \quad (4)$$

where A_D is drainage area (km^2), P_0 is average annual precipitation (mm), T_M is average maximum temperature (^{o}C), H_0 is mean basin elevation (m), H_M is maximum basin elevation (m), H_{150} is the percent of area above 150 m (%), S_0 is average slope (%), X_C is X-coordinate at the center of the basin (m), Y_C is Y-coordinate at the center of the basin (m), X_S is X-coordinate at the station (m), Y_S is Y-coordinate at the station (m), A_F is the percent of basin that is forested, and all variables are taken into consideration in natural logarithms.

These equations yielded the initial set of quantile data points that are to be directly estimated from regressions with catchment characteristics (Figure 6a). By using the monthly flow values of the stream gauge stations in the common period for all considered stations, eleven additional quantiles were also calculated in addition to the initial set of five quantiles, which were related to catchment characteristics. In the MA-SYE approach, each additional quantile is regressed against a neighbouring quantile value through single variate linear relationships. In this regard, all quantiles obtained from the recorded flow values were regressed correspondingly to obtain the following set of linear regression equations with associated R^2 figures as estimation measure:

$$\ln(Q15) = 0.9517 + 1.0844 * \ln(Q20) \qquad (R^2 = 0.9911) \quad (5)$$

$$\ln(Q10) = 1.0031 + 1.2535 * \ln(Q15) \qquad (R^2 = 0.9880) \quad (6)$$

$$\ln(Q30) = 0.5794 + 1.1996 * \ln(Q40) \qquad (R^2 = 0.9938) \quad (7)$$

$$\ln(Q50) = -0.3135 + 0.8288 * \ln(Q40) \qquad (R^2 = 0.9931) \quad (8)$$

$$\ln(Q60) = -0.0213 + 0.6958 * \ln(Q50) \qquad (R^2 = 0.9994) \quad (9)$$

$$\ln(Q70) = -0.0761 + 0.7736 * \ln(Q60) \qquad (R^2 = 0.9986) \quad (10)$$

$$\ln(Q85) = 0.0040 + 0.7507 * \ln(Q80) \qquad (R^2 = 0.9995) \quad (11)$$

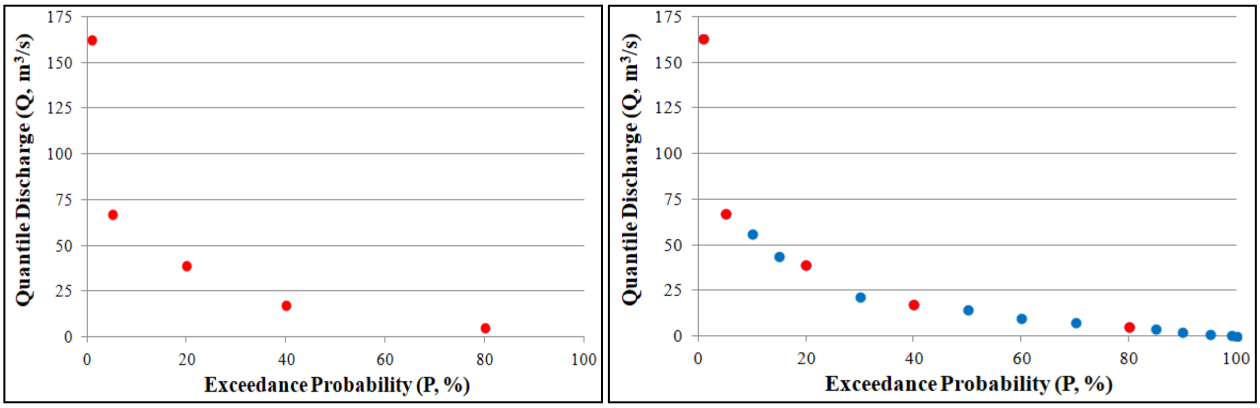
$$\ln(Q90) = 0.0116 + 0.5883 * \ln(Q85) \qquad (R^2 = 0.9143) \quad (12)$$

$$\ln(Q95) = 0.0008 + 0.5508 * \ln(Q90) \qquad (R^2 = 0.9565) \quad (13)$$

$$\ln(Q99) = -0.0027 + 0.4318 * \ln(Q95) \qquad (R^2 = 0.8497) \quad (14)$$

$$\ln(Q100) = -0.0028 + 0.7481 * \ln(Q99) \qquad (R^2 = 0.9554) \quad (15)$$

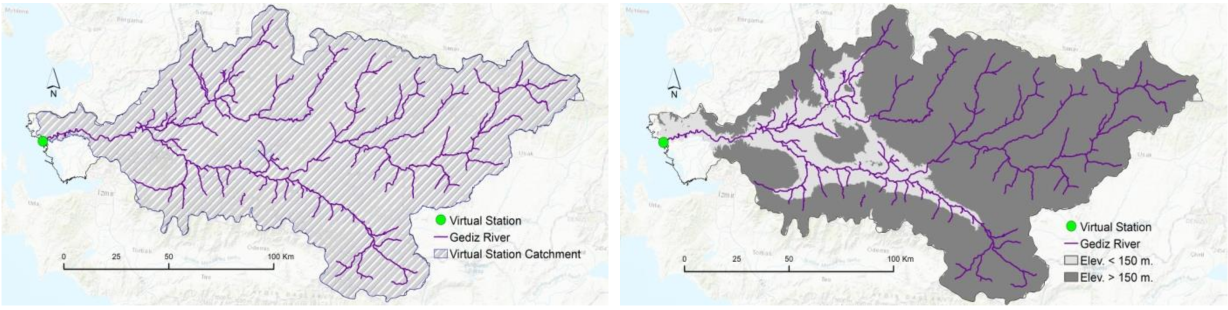
This operation resulted in a potential expansion for the data points in the FDC graph with the help of eleven new quantile data (Figure 6b).



(a) (b)

Figure 6. (a) 6 quantile data points (Q1, Q5, Q20, Q40 and Q60) and (b) additional quantile points marked on a sample FDC

After obtaining all required relationships for estimating quantile data points for the representative FDC of the ungauged location, which was selected at the delta inlet in the presented study, the next step contained efforts for first estimating the catchment characteristics for the catchment of the virtual station location to allow estimation of the initial set of five quantiles (Figure 7a), and then obtaining the expanded list of FDC quantiles from the inter-quantile regressions described above. In Figure 7b, the share of lowlands and highlands in the virtual station catchment is shown as an example to the determination of physical catchment characteristics.

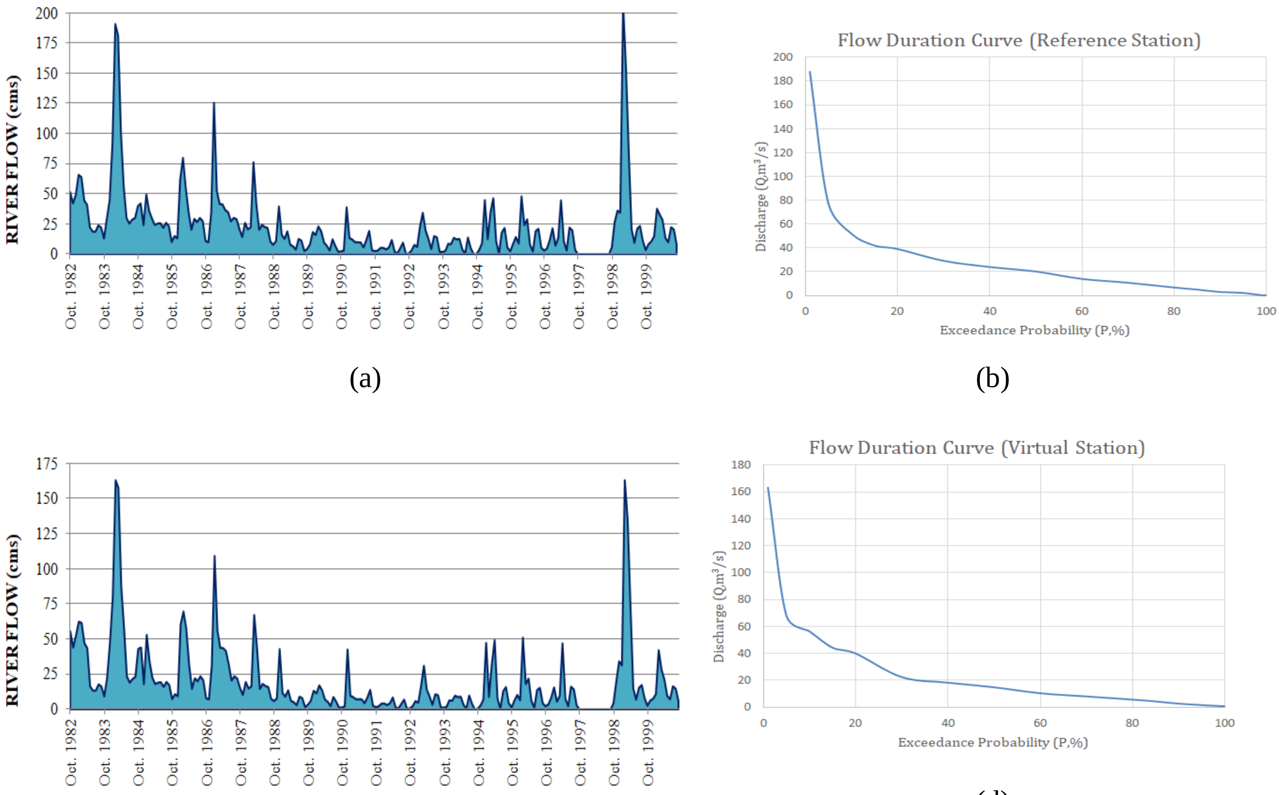


(a) (b)

Figure 7. (a) Total drainage area of the virtual station location, (b) the share of high-/low-lands in the virtual station catchment

When all data points in a total of 16 quantile values were placed on the FDC graph, a measure that is representative for the flow pattern of the virtual location was obtained for use in generating time series of the same ungauged stream location. For providing this, the selection of a reference station was required in order to apply QPPQ approach, which is based on the logic that a missing stream discharge value at a certain time in the time series data can be estimated from the measured discharge of a reference station with the same probability of exceedance/non-exceedance (Fennessey, 1994; Hughes and Smakhtin, 1996; Smakhtin, 1999; Smakhtin and Masse, 2000; Mohamoud, 2008). To this end, the stream gauge 05-025 was selected as the reference station due to spatial proximity and the interpolated highest correlation estimated in flows with the ungauged location. Considering the recorded stream flow values of the reference station (Figure 8a), the probabilities of exceedance were obtained from the FDC of the reference station (Figure 8b), and then by using the same probabilities in the FDC for ungauged location (Figure 8d), the estimated time series were modelled for the delta inlet (Figure 8c).

Following the generation of the synthetic time series for the delta wetland entrance, environmental flows were aimed to be estimated. In doing this, a desktop approach that is first based on the estimation of environmental flow FDCs through a FDC shift method and then on the generation of environmental flow time series in a similar manner with the QPPQ approach was employed. In generating FDCs for environmental flows, different environmental management strategies ranging from the management of unmodified flows to the management of poorest hydrologic conditions in the stream were considered (Figure 9).



(a)

(b)

(c)

(d)

Figure 8. Estimation of the monthly flow time series at the virtual location based on the QPPQ approach: (a) Observed monthly flows and (b) FDC of the reference station, (c) estimated flows and (d) estimated FDC of the virtual station

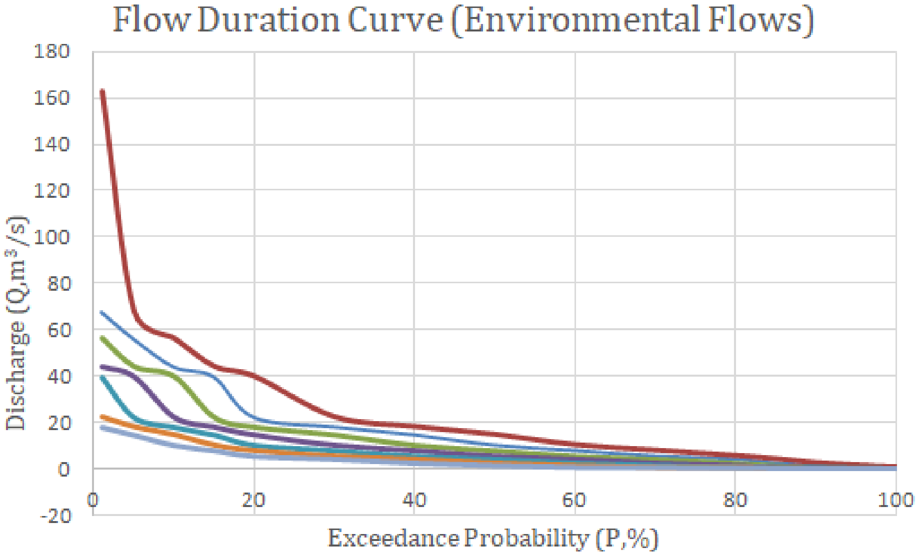
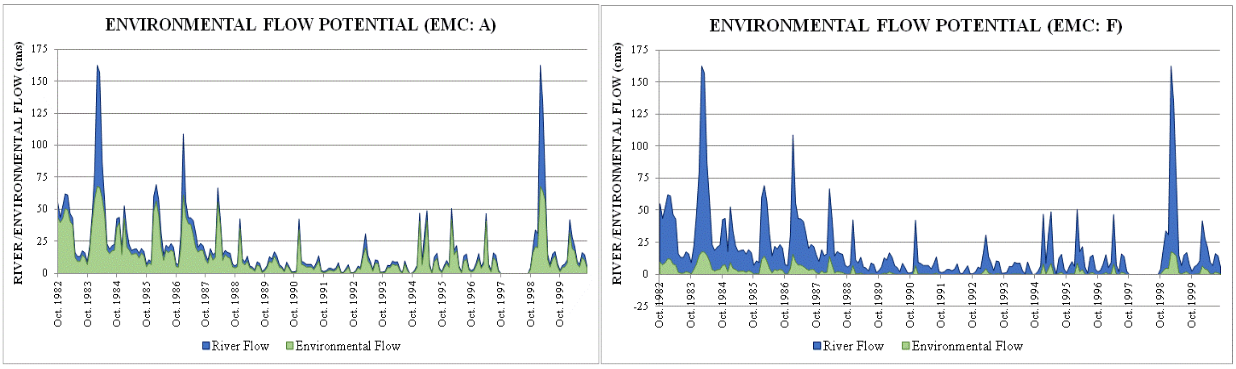


Figure 9. Estimation of FDCs for monthly environmental flows based on the FDC shift approach

By using the environmental flow FDCs for different management considerations, environmental flow time series for the ungauged site at the delta inlet were obtained accordingly. Against the estimated stream flows, Figure 10 indicates the potentials for supplying environmental flows to the delta under the best and worst management scenario conditions.



(a) (b)

Figure 10. Environmental flow potential at the virtual station location considering the environmental management based on (a) natural/near-pristine river flows and (b) critically modified river flow regime

3 CONCLUSIONS

Turkey's wetlands, especially located at the downstream ends of water scarce river systems, are under considerable risks in terms of both quantities and qualities of the stream flows released to secure/rehabilitate ecosystem functioning. There are strong needs for conducting hydrologic assessments on these vulnerable systems. This is, however, often difficult due to the lack or insufficiency of hydrometric data to support such analyses. Gediz wetland is a significant example that reflects similar risks when at the same time lacks the necessarily representative data. The presented study provides some indication about the potentials and benefits of using the given scientific framework in estimating stream flows at the delta inlet as a hydrologically ungauged location and in assessing environmental flow quantities under different management criteria for allocating environmental flows. The study serves the potential for slightly expanding the research to analyze different periods in comparison to each other as well as predicting environmental flows in future periods from the stochastic future estimates in the gauged locations.

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