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Research Article

The Effect of Data Granularity on Temperature Gradient Modeling in Michigan's Streams

Veri Taneselliğinin Michigan Akarsularının Sıcaklık Gradyan Modellemesi Üzerindeki Etkisi

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Abstract

Stream temperature is a critical characteristic for aquatic ecosystems. Therefore, it is crucial to understand the factors that take place in thermodynamic processes in these ecosystems. Regression models are useful tools that help us comprehend and explain the drivers of these thermal processes since they can be used for quantifying the magnitude and the type of the relationship between the independent variables (e.g., air temperature, discharge) and the response variable (e.g., stream temperature). However, selection of data granularity of data may often be a key decision for modelers. Although granularity of data is selected based on the ecological relevance of data to the question of interest in many cases, it may arbitrarily be selected by the researchers in many other cases. However, data granularity can substantially influence model coefficients, can affect the model predictions, and influence evaluation of model fitness and interpretation of model outputs. In this article, we adopted regression models and applied different data granularity scenarios to investigate the consequences of data granularity selection in modeling approaches. Our findings showed that using different data granularities resulted in considerable changes in regression coefficients in the models. Our results also revealed that overall model fitness increased with coarser-scale data granularity and model selection was influenced by the type of data granularity. This study might be helpful for modelers and environmental managers since it highlights the significance of selection of data granularity and proposes a different point of view in model design, evaluation and application from the perspective of data selection.

Keywords: *stream temperature, linear regression models, data granularity, data aggregation, temporal scale*

Öz

Akarsu sıcaklıkları sucul ekosistemlerde kritik öneme sahiptir. Dolayısıyla, akarsulardaki termodinamik süreçleri etkileyen faktörleri kavramak önem arz etmektedir. Regresyon modelleri bağımsız (örn. havanın sıcaklığı, akı) ve bağımlı (örn. akarsu su sıcaklığı) değişkenlerin birbirleriyle olan nicel ve nitel ilişkisini açıklayabildiğinden, bu ısıl süreçleri etkileyen faktörleri kavramamıza ve açıklamamamıza yardımcı olan kullanışlı araçlardır. Ancak bu modellerde kullanılan verilerin taneselliğinin ya da agregasyonun seçimi modellemeciler için zorlayıcı olabilmektedir. Çoğu durumlarda kullanılacak verinin taneselliği ekolojik uygunluğa bağlı olarak seçilse de diğer birçok durumda keyfi olarak seçilebilmektedir. Ancak veri taneselliği seçimi, model değişkenlerinin katsayılarını, model tahminlerini, model tahminlerinin değerlendirilmesini ve model sonuçlarının yorumlanmasını önemli ölçüde etkileyebilmektedir. Bu makalede, veri taneselliği seçiminin etkilerini araştırmak amacıyla regresyon modelleri farklı veri taneselliği senaryolarıyla uygulandı. Bulgular, veri taneselliği seçiminin regresyon değişken katsayılarını önemli düzeyde etkilediğini gösterdi. Ayrıca bulgular veri taneselliğindeki artışın ortalama model tahmin gücünü artırdığını ve veri taneselliğinin model seçimlerinde etkili olduğunu ortaya çıkardı. Bu çalışma veri taneselliği seçiminin önemini vurgulaması, model tasarımı, değerlendirilmesi ve uygulanması konularında farklı bir bakış açısı sunması sebebiyle, modellemecilere ve yöneticilere yararlı olabilir.

Anahtar sözcükler: *akarsu sıcaklığı, doğrusal regresyon modelleri, veri taneselliği, veri kümelenmesi, zamansal ölçek*

Introduction

Stream temperature plays a key role in the physical, chemical, and biological dynamics in freshwater ecosystems. Therefore, it is often considered as one of critical parameters in evaluation of water quality and ecosystem functioning in the literature (Neumann et. al., 2003; Ducharne, 2008; Ficklin et. al., 2013; Guo et. al., 2019; Hamid et. al., 2020). As water temperature influences the survival, reproduction and distribution of species from different taxa (e.g., primary/secondary producers, aquatic invertebrates, fish and other aquatic vertebrates), it is crucial to understand the physical determinants of water temperature in these ecosystems (Iversen, 1971; Jackson et. al., 2007; Zorn et. al., 2004; Nuhfer et. al., 2017).

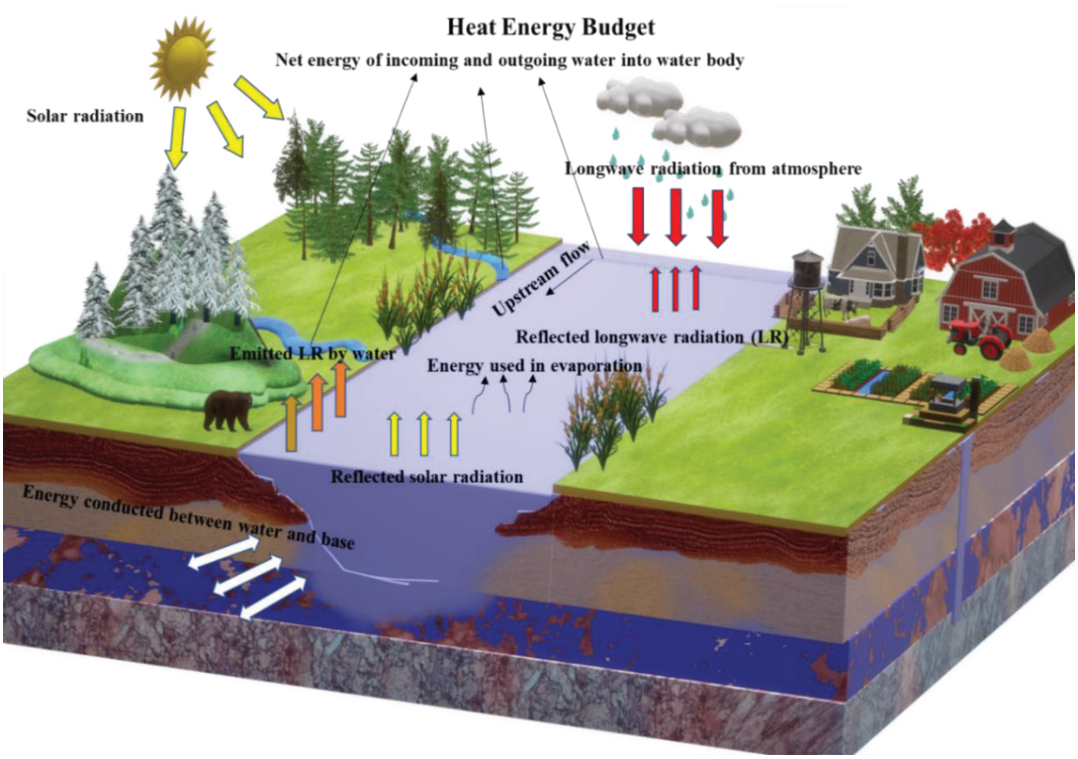
In literature, various environmental parameters are used to explain the driving factors of stream temperatures. Du et. al. (2020), for example, propose that both meteorological (e.g., air temperature) and hydrological (e.g., precipitation) processes affect stream temperatures. In other studies, these meteorological and hydrological processes are diversified into different sub-factors. For example, Cheng and Wiley (2016) describe the radiative processes such as shortwave and longwave solar radiation as explanatory meteorological factors in thermal dynamics of streams (Figure 1). Hydrological characteristics such as water depth, surface area, runoff, and groundwater contribution/withdrawal are also included as the key processes that determine the thermodynamics in a stream (Zorn et. al., 2008; Cheng, & Wiley, 2016; Du et. al., 2020; Andrews, 2019; Dertli, 2021). As the stream ecosystems are open systems, all these processes interact with each other, which makes understanding individual roles of these physical processes in stream thermodynamics hard to comprehend for researchers. At this point, statistical models help researchers explain these roles in these complex natural systems.

Statistical models are frequently used to understand the thermal dynamics in freshwater ecosystems. Regression models, for example, are able to quantify the influence of each parameter in the model on the response variable (Bender, 2009). Therefore, these models are very useful to evaluate the potential effects of different stress factors (e.g., climate change, groundwater withdrawal) on these valuable systems as they can make predictions on the trends of thermal dynamics under alternating environmental conditions (Mantua et. al., 2010; Andrews, 2019). Once successfully designed for a certain group of streams (e.g., cold streams), statistical models can reduce the need for extensive data collection, which can reduce the financial resources, time and labor that are spent in data collection procedures (Dertli, 2021). In addition, model predictions can be useful in making future projections on the population dynamics of various aquatic organisms such as fish (Chang et. al., 2018; Nuhfer et. al, 2017), and play critical roles in decision-making processes on environmental issues.

Although statistical models are useful tools for understanding the nature of thermodynamics in streams, the explanatory power of these models may depend on the structure of input data (Akossou & Palm, 2013). The type of time aggregation, or data granularity –defined as a new term in environmental studies by Dertli (2021)– is one of the important structural features of the data, since it directly influences the number of data points (e.g., sample size) and the collinearity between the model parameters (Stefan & Preud'homme, 1993; Pilgrim et. al., 1998). Because it can change the outputs of regression models, data granularity is often important. In literature, selection of data granularity is generally based on the ecological relevance of the selected data granularity to the research question of interest, and researchers often provide strong reasoning for data granularity selected in their studies. For example, Chen et. al. (1998) adopt hourly data granularity to simulate stream temperatures based on the shading dynamics of topography and vegetation throughout the day. In another study, Zorn et. al. (2004) focus on July mean temperatures as a reference temperature for Michigan streams because of it indexed conditions important to fish growth, survival, and abundance. However, in many other cases, researchers arbitrarily select the type of data granularity used in their models, even though arbitrary selection may cause misevaluations of model predictions and biases in model selection processes (Dertli, 2021).

Figure 1

Environmental Processes That are İnvolved in Stream Thermodynamics (Dertli, 2021)



So far, different studies adopt different approaches on the issue of data granularity selection, develop different perspectives and reveal various consequences of these selections (Stefan, & Preud'homme, 1993; Pilgrim et. al., 1998; Webb et. al., 2003). However, there are still only a few studies that focus on this issue, considering the substantial effects of data granularity selection on evaluation, selection, and interpretation of linear regression models. Therefore, in this paper, we focus on the response of linear regression models designed by Andrews (2019) to simulate effects of streamflow on temperature gradient (i.e., change in water temperature between upstream and downstream locations) to changes in granularity of the data used in models. Our study objectives are:

1. To evaluate and interpret the response of model coefficients to different data granularity scenarios,
2. To evaluate the fitness of the regression models under different data granularity scenarios,
3. To evaluate influence of data granularity selection on the selection of the most parsimonious (i.e., high model fitness with low model complexity) model.

Since we adopt different approaches and evaluate the models based on different characteristics (e.g., model fitness and parsimony) to observe the response of regression models to different granularity scenarios, this paper can give researchers a broad perspective on possible consequences of their data granularity selection.

Methods

Study Site, Data Collection and Data Revision

The streams were selected by Andrews (2019) for data collection throughout State of Michigan. Andrews (2019) collected data from 21 streams with various periods (e.g., between July and November) in 2015 and 2016 (Table 1). He collected water temperature and water pressure data by setting HOBO® U20 Water Level Loggers at both upstream and downstream data collection points. These data were collected in 15-minute intervals and averaged into hourly interval. Water pressure data were used to calculate upstream and downstream discharge after obtaining stream width and stream depth estimations for both upstream and downstream data collection stations. Stream velocity data were also collected for both stations by using SonTek® Flowtracker. Methods for discharge calculations are explained in the study of Andrews (2019) in details. In addition, Andrews (2019) collected air temperature and barometric pressure data from paired streams that were located in close range by using Monarch® Track-It data loggers with 15-minute time intervals. These data were also averaged into hourly interval.

In addition to air temperature, water temperature and discharge values, Andrews (2019) calculated other environmental variables, such as altitude angle, to use them as model parameters. Calculations for these environmental variables are explained in the study of Andrews (2019) in details. We obtained data for all environmental variables in hourly time interval from Andrews's (2019) study to use in our study.

We revised the data by detecting and eliminating outliers, also by trimming the data within June-October period for both 2015 and 2016. We selected this period for our study since it covers summer season, which is important for fish abundance (Zorn et. al. 2004). Another reason was that this period was the longest range of data that is found commonly for all streams. Since most of the stream's data started from late July in 2015, we only used 2016 data in this study (Dertli 2021). In addition, we used the data from 16 out of 21 streams in this study to avoid gaps in data that were detected in some streams (Figure 2).

After data revisions, we aggregated the hourly data by averaging the observations into 2-hours, 6-hours, 12-hours, daily and weekly time intervals. In the end, we obtained 1-hour (hourly), 2-hours, 6-hours, 12-hours, 24-hours (daily) and 168-hours (weekly) data granularity scenarios.

Hierarchical Model Development and Model Simulation

Andrews (2019) designed 11 linear regression models to obtain temperature gradient predictions (the difference between downstream and upstream water temperatures). He adopted hierarchical model development, in which models were formed starting from the least complex (i.e., Model 1) to the most complex (i.e., Model 10). At each step, a new parameter was included in the model, or an existing model parameter was replaced with another model parameter (Table 2). Model 11, however, was adopted from a physical model that was proposed by Magnusson et. al. (2012). In our study, these models were simulated for each stream and each data granularity scenario.

Model Fitness and Selection

We used adjusted correlation coefficient ($R^2_{adj.}$) to evaluate the amount of fit between the trends of observed and predicted temperature gradient (ΔT). Adjusted correlation coefficient was calculated based on the equation:

$$R^2_{adj.} = 1 - \frac{SSE/(n-p)}{SST/(n-1)},$$

where *n* stands for the number of observations, *p* stands for the number of parameters, *SSE* and *STT* stand for sum of squared residuals error and total sum of squares, respectively. To find the most parsimonious model under given conditions, we used model weight (*ω*) of models for each stream. To find model weights, we obtained Akaike's Information Criterion (AIC) values based on Akaike (1973). AIC values were obtained by using the equation:

$$AIC = 2k - 2\ ln\ ln\ \left(L(data)\right)\text{; and } L(data) = -\left(\frac{n}{2}\right) \cdot log_e(SSE),$$

where *L* stands for the likelihood, *k* stands for the unknown parameters and n stands for the sample size (Seber, & Wild, 1989). We used AIC values to obtain model weight as shown in the equation:

$$\omega_i = \frac{exp\left(-\frac{\Delta i}{2}\right)}{\sum_m^M exp\left(-\frac{\Delta i}{2}\right)},$$

where *M* is the total number of models, *m* is the model number, and *Δi* is the difference between AIC values of model *i* and the AIC value of the best-fitting model (Andrews, 2019). By using model weight, we compared the explanatory power of models and their model complexity based on the law of parsimony.

Table 1

List of the Streams That Are Used in This Study (Andrews, 2019)

Stream	Abbr.	Region	Upstream Latitude	Upstream Longitude	Downstream Latitude	Downstream Longitude
Pokagon Creek	PK	SLP	41.89517	-86.162632	41.915803	-86.175679
Pigeon River	PG	SLP	42.932887	-86.081828	42.91636	-86.146075
Nottawa Creek	NTW	SLP	42.192564	-85.060415	42.195998	-85.104618
Tobacco River	TB	SLP	43.909194	-84.697312	43.929905	-84.666327
Hasler Creek	HS	SLP	43.042332	-83.423206	43.083594	-83.442947
Prairie River	PR	SLP	41.801832	-85.116614	41.832568	-85.165065
Swan Creek	SW	SLP	41.90477	-85.297885	41.921249	-85.312047
Cedar Creek	CC	NLP	44.375846	-85.972647	44.369588	-85.999598
Cedar River	CR	NLP	44.956875	-85.132748	44.968664	-85.138993
Black River	BL	NLP	45.070651	-84.283728	45.089439	-84.284929
Butterfield Creek	BF	NLP	44.273249	-85.094087	44.256377	-85.03362
Morgan Creek	MG	UP	46.519698	-87.504502	46.521351	-87.494782
Spring Creek	SP	UP	46.512909	-90.156133	46.513418	-90.177011
Carp River	CP	UP	46.509131	-87.418924	46.510534	-87.388497
Escanaba River	ESC	UP	46.420206	-87.797962	46.398398	-87.770883
Squaw Creek	SQ	UP	46.057035	-87.18974	45.985396	-87.140559

Figure 1

Locations of Streams That Are Used in This Study (Dertli, 2021)

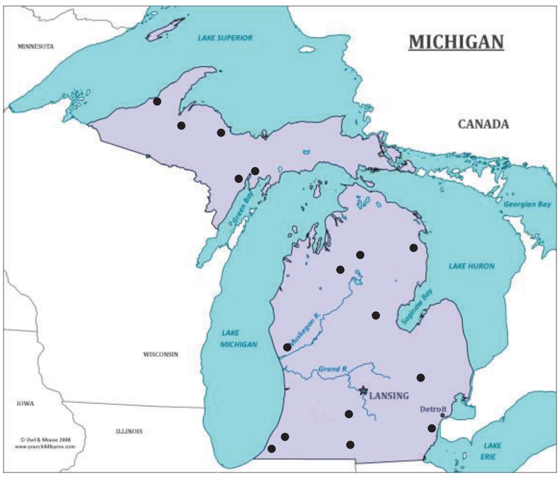


Table 2

List of Multiple Linear Regression Models (Magnusson et. al., 2012; Andrews, 2019)

Model 1	$\Delta T = \beta_0 + \beta_1(T_a - T_w)$
Model 2	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_2\left(\frac{Q_{up}}{Q_{down}}\right)$
Model 3	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_3(Q_{up}) + \beta_4(\Delta T_{flow})$
Model 4	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_3(Q_{up}) + \beta_4(\Delta T_{flow}) + \beta_5(Q_{down} - Q_{up})$
Model 5	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_3(Q_{up}) + \beta_4(\Delta T_{flow}) + \beta_5(Q_{down} - Q_{up}) + \beta_6(S)$
Model 6	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_3(Q_{up}) + \beta_4(\Delta T_{flow}) + \beta_5(Q_{down} - Q_{up}) + \beta_7(\alpha)$
Model 7	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_3(Q_{up}) + \beta_4(\Delta T_{flow}) + \beta_5(Q_{down} - Q_{up}) + \beta_6(S) + \beta_7(\alpha)$
Model 8	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_3(Q_{up}) + \beta_5(Q_{down} - Q_{up}) + \beta_6(S) + \beta_8(\Delta T_{up}) + \beta_9(\Delta T_{base}) + \beta_{10}(\Delta T_{over})$
Model 9	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_3(Q_{up}) + \beta_5(Q_{down} - Q_{up}) + \beta_7(\alpha) + \beta_8(\Delta T_{up}) + \beta_9(\Delta T_{base}) + \beta_{10}(\Delta T_{over})$
Model 10	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_3(Q_{up}) + \beta_5(Q_{down} - Q_{up}) + \beta_6(S) + \beta_7(\alpha) + \beta_8(\Delta T_{up}) + \beta_9(\Delta T_{base}) + \beta_{10}(\Delta T_{over})$
Model 11	$\Delta T = \beta_0 + \beta_1(T_a - T_w) + \beta_9(\Delta T_{base}) + \beta_{10}(\Delta T_{over}) + \beta_{11}(\frac{1}{Q_{up}} * ((T_a + 273.16)^4 + (T_w + 273.16)^4)] + \beta_{12}\left[\frac{1}{Q_{up}} * (e^{T_w} - e^{T_a})\right] + \beta_{13}(\frac{1}{Q_{up}} * \alpha)$

Note. ΔT: temperature gradient (℃), T_a: Air Temperature (℃), Tw: Upstream temperature (℃), Q_{up}: Upstream discharge (m^3/s), Q_{down}: Downstream discharge (m^3/s), ΔT_{flow}: Cumulative temperature gradient (℃), S: Day length, α: Altitude angle, ΔT_{up}: Upstream temperature gradient (℃), ΔT_{base}: Baseflow temperature gradient (℃), ΔT_{over}: Overflow temperature gradient (℃).

Results

Regression Coefficients

Regression coefficients were obtained after model simulations for each stream. Only Model 10 coefficient values are shown in Table 3, since previous studies showed that Model 10 had the highest model fit (Andrews, 2019; Dertli, 2021). Regression coefficients of model parameters varied across streams (Table 3). For example, the air temperature-upstream temperature gradient ($T_a - T_w$) parameter coefficient had the value of 28.338 in the Carp River model, but a value of -18.751 in the Prairie River model (Table 3). Likewise, coefficient values of upstream discharge (Q_{up}) ranged between -9.301 (Carp River) and 5.079 (Pokagon Creek).

Table 3

Intercepts and Regression Coefficients in Model 10 for Each Stream by Using Hourly Data Granularity Scenario (Dertli, 2021)

Streams	Intercept (β_0)	T_a-T_w (β_1)	Q_{up} (β_3)	$Q_{down} - Q_{up}$ (β_5)	S (β_6)	α (β_7)	ΔT_{up} (β_8)	ΔT_{base} (β_9)	ΔT_{over} (β_{10})
BL	0.004	-0.380	-0.872	0.002	0.004	-0.037	-0.060	-0.013	-0.026
CR	0.982	-0.665	2.810	-0.154	0.005	-0.011	0.097	-0.029	0.015
CC	-3.800	-0.044	0.102	-0.041	-0.001	0.009	0.004	-0.012	0.001
MG	-0.258	7.516	-0.225	0.155	-0.012	-0.015	-0.231	0.186	-0.027
PK	-2.326	-1.105	-1.405	0.072	-0.014	0.027	0.043	-0.105	0.048
BF	1.690	-0.323	-0.343	0.309	0.053	-0.016	0.020	-0.006	-0.003
CP	0.500	28.338	-9.301	-0.038	0.018	-5.671	0.133	0.056	-0.004
PG	-3.953	1.841	5.079	0.009	-0.020	0.018	-0.038	0.015	0.013
SP	1.284	2.412	1.146	0.147	-0.020	0.002	0.060	-0.094	0.038
ESC	-5.148	1.626	-1.804	0.352	-0.066	0.078	-0.130	0.123	-0.033
NTW	-4.156	-0.436	-0.050	0.245	-0.060	-0.017	0.064	-0.120	0.068
TB	1.092	-1.513	-2.864	0.584	-0.077	-0.018	-0.472	0.370	-0.340
HS	2.638	0.121	-0.061	-0.037	-0.022	-0.041	0.041	0.004	0.008
PR	-5.764	-18.751	1.618	0.082	-0.038	0.019	0.244	-0.256	0.117
SQ	0.246	-1.359	-2.618	0.265	0.008	-0.019	0.140	-0.108	0.130
SW	-2.335	-2.630	0.366	0.000	0.001	-0.023	-0.088	0.008	-0.060

In addition, regression coefficients were obtained by simulating models under different data granularity scenarios. Regression coefficients of Model 10 for Tobacco River were shown (Table 4) because preliminary results showed that the predictive power of Model 10 had the highest value ($R^2_{adj} = 0.778$). Using the data with different granularities changed the regression coefficient values and signs for the same stream (Table 4). For example, regression coefficient of air temperature-upstream temperature gradient ($T_a - T_w$) had the value of 0.023 under 1-hour data granularity scenario, whereas the same coefficient had the value of -0.023 under 24-hour data granularity scenario. As another example, coefficient of discharge gradient ($Q_{down} - Q_{up}$) variable was -0.579 under 1-hour scenario, while the same coefficient had the value of 0.366 under 24-hour scenario.

Table 4

Regression Coefficient Values of Variables in Model 10 for Tobacco River (Dertli, 2021)

Data Granularity	β_0	β_1	β_3	β_5	β_6	β_7	β_8	β_9	β_{10}
1-hour	0,627	0,023	-1,166	-0,579	-0,006	0,019	-0,223	0,138	-0,144
2-hour	0,629	0,023	-1,169	-0,583	-0,006	0,019	-0,224	0,139	-0,145
6-hour	0,868	0,014	-1,43	-0,522	-0,023	0,022	-0,220	0,125	-0,137
12-hour	1,337	0,001	-2,045	0,242	-0,051	0,023	-0,055	-0,001	-0,031
24-hour	1,092	-0,023	-2,630	0,366	0,000	0,001	-0,088	0,008	-0,060
168-hour	0,780	-0,029	-1,383	-0,436	-0,056	0,000	-0,071	-0,016	-0,067

Model Fitness

Mean R^2_{adj} values of all streams for each regression model showed that Model 10 had the highest model prediction power under all data granularity scenarios (Table 5; Figure 3). When mean R^2_{adj} values of regression under all scenarios were averaged, Model 10 had the highest model fit with the average mean R^2_{adj} value of 0.548. In addition, model fitness increased with data granularity in most cases (Figure 3). For example, mean R^2_{adj} of Model 10 increased from 0.418 to 0.842 from 1-hour to 168-hour scenarios. Moreover, average mean R^2_{adj} of all models under 1-hour scenario was 0.255, whereas average mean R^2_{adj} of models under 168-hour scenario was 0.680.

Table 5

Mean Adjusted Correlation ($R^2_{adj.}$) Values of Each Model by Data Granularity across All Streams (Dertli, 2021)

	Data Granularity (h)						
Model	1	2	6	12	24	168	Average
1	0.139	0.142	0.149	0.198	0.315	0.498	0.240
2	0.094	0.098	0.108	0.133	0.202	0.415	0.175
3	0.188	0.209	0.207	0.226	0.311	0.499	0.273
4	0.205	0.209	0.225	0.253	0.340	0.571	0.301
5	0.278	0.284	0.309	0.368	0.502	0.732	0.412
6	0.253	0.257	0.279	0.360	0.485	0.737	0.395
7	0.329	0.336	0.367	0.502	0.515	0.754	0.467
8	0.258	0.375	0.391	0.453	0.591	0.812	0.480
9	0.332	0.336	0.358	0.45	0.587	0.823	0.481
10	0.418	0.423	0.447	0.563	0.598	0.842	0.548
11	0.312	0.320	0.342	0.419	0.536	0.793	0.454
Average	0.255	0.272	0.289	0.357	0.453	0.680	

Model Selection

Results showed that Model 10 had the highest model weight for most of the streams (i.e., 62.5% of all streams) under 1-hour and 2-hours scenarios (Table 6; Figure 4). Model 10 also had the highest percentage under 6-hours (50.00 %), 12-hours (43.75 %) and 168-hours (31.25 %) scenarios. However, Model 11 had the highest percentage (31.25 %) under 24-hours granularity scenario (Table 6). Moreover, as data granularity increased, number of models that had the highest model weight for at least one of the streams increased. For example, there were only 4 models (Model 8, Model 9, Model 10 and Model 11) that appeared to have the highest model weight for at least one stream under 1-hour granularity scenario, yet we observed 6 models (Model 1, Model 5, Model 7, Model 8, Model 10 and Model 11) that had the percentage value greater than zero (Figure 4) under 168-hours granularity scenario.

Figure 2

Mean Adjusted Correlation ($R^2_{adj.}$) Values of Models across Data Granularity Scenarios (Dertli, 2021)

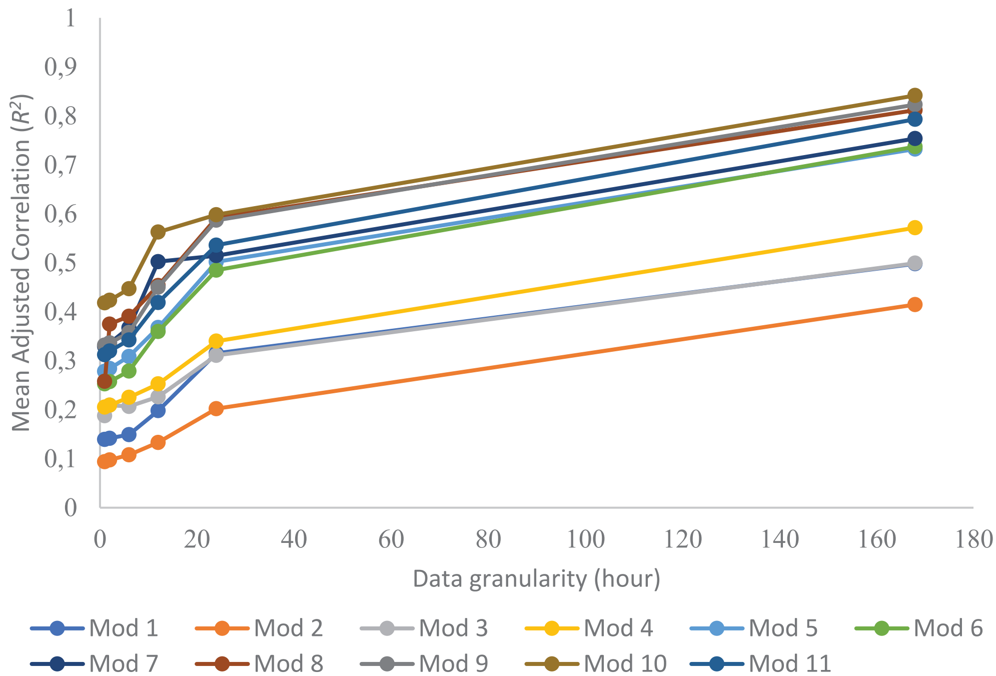


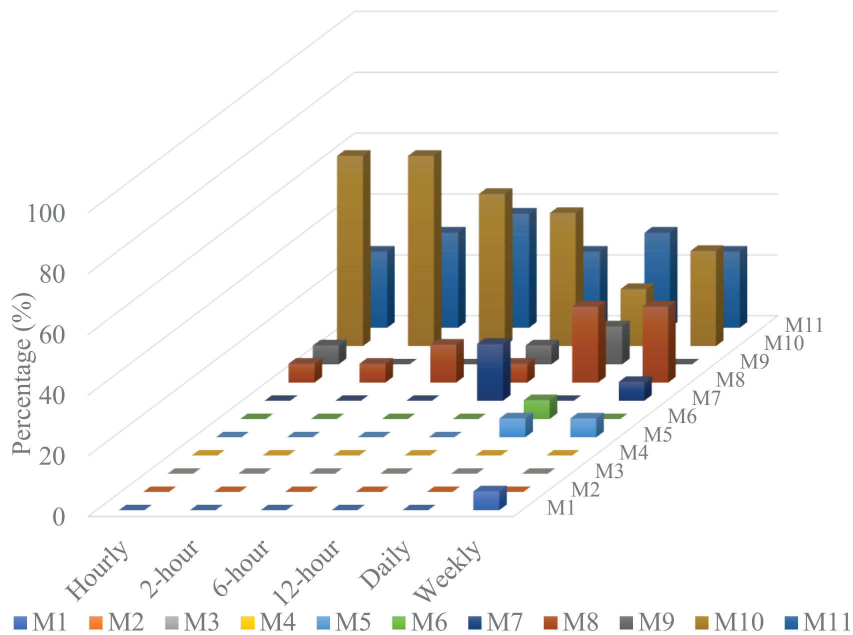
Table 6

Percentage (%) of Streams Where Each Model Had the Highest Model Weight (ω) Across Levels of Data Granularity (Dertli, 2021)

	Models											
Data granularity (hour)	1	2	3	4	5	6	7	8	9	10	11	Total
1	0	0	0	0	0	0	0	6.25	6.25	62.50	25.00	100
2	0	0	0	0	0	0	0	6.25	0	62.50	31.25	100
6	0	0	0	0	0	0	0	12.50	0	50.00	37.50	100
12	0	0	0	0	0	0	18.75	6.25	6.25	43.75	25.00	100
24	0	0	0	0	6.25	6.25	0	25.00	12.50	18.75	31.25	100
168	6.25	0	0	0	6.25	0	6.25	25.00	0	31.25	25.00	100

Figure 3

The Percentage (%) of the Models Having the Highest Model Weight at Least One Stream for Each Data Granularity with June-October 2016 Data (Dertli, 2021)



Discussion and Conclusions

Regression Coefficients across Different Streams and Data Granularity Scenarios

In this study, we used Andrews' (2019) linear regression models to predict temperature gradients in Michigan's streams. There were two main advantages of using these statistical models. First, these statistical models did not require complex mathematical calculations and extensive datasets. This is an important feature of statistical models because they make complex environmental variables (e.g., shortwave solar radiation) simpler to parameterize to be included in models (Cheng & Wiley, 2016). Moreover, less need for extensive datasets reduces the time, effort and financial resources that must be invested in data collection procedures. Second, regression coefficients clearly revealed the magnitude and type of the relationship between environmental variables and the response variable. To illustrate, if a coefficient had negative sign, then that parameter was conversely related with the response variable. This information was useful for understanding thermal dynamics in streams and most effective factors that influence the temperature gradient. Furthermore, regression coefficients could be used for testing scenarios that reflect various environmental conditions (e.g., groundwater withdrawal, air temperature) (Caldwell et. al., 2014; Andrews, 2019). Therefore, observing the response of the regression coefficients to different characteristics of streams and data granularity was important to have a better perspective on these linear regression models.

Our results revealed that the coefficient value of the same parameter varied across the streams within the same data granularity. This was an expected outcome considering different characteristics of each stream. For example, a further analysis on stream data revealed that average upstream discharge values varied substantially across streams. For example, average upstream discharge (Q_{up}) ranged between 0.035 m^3/s (Hasler Creek) and 1.618 m^3/s (Carp River) across streams between June-October 2016. Likewise, average upstream temperature (T_{up}) varied between 12.873 °C (Cedar River) and 19.346 °C (Hasler Creek) within the same time period. Therefore, we observed wide range of coefficient values across streams. In other words, each model (e.g., Model 10) was stream-specific even though all model parameters were commonly applied for all streams. Certainly, this also resulted in different model performances for each stream.

Our results also revealed that the model coefficient values in Model 10 changed across data granularity scenarios for Tobacco River. In other words, the weight of some model parameters on model predictions varied between granularity scenarios. This was a result of lower number of data points and lower variation across these data points that was caused by averaging the observations (Dertli, 2021). Consequently, the weight of each parameter changed across the granularity scenarios. In addition, the sign changes in model coefficient of the same parameter indicated parameter instability, which is an indicator of high levels of multicollinearity (Dertli, 2021). This situation has been addressed by many other studies in literature. For example, Mason & Perreault (1991) concluded that low sample size (e.g., $n = 30$) exacerbated the influence of multicollinearity in multiple regression analysis. Furthermore, Kroll & Song (2013) revealed that the effects of multicollinearity in regression models that were developed with ordinary least squares (OLS) increased with smaller sample size.

The Effect of Data Granularity on Model Fitness

As Model 10 was the most complex regression model with eight environmental parameters, Model 10 had the highest model prediction power in all data granularity scenarios (Table 5; Figure 3). Model 8 and Model 9 were other two models, which had the highest mean adjusted correlation coefficient values. One common feature of all these models was that they had day length (*S*) (i.e., Model 8) or altitude angle (α) (i.e., Model 9) or both (i.e., Model 10) as predictor variables. Another common feature was that they all had separated heat transfer variables (i.e., ΔT_{up}, ΔT_{base}, and ΔT_{base}) rather than cumulative heat transfer variable (i.e., ΔT_{flow}). Separating cumulative heat transfer variable into three different predictor variables increased the explanatory power of models since each these variables reflects different environmental processes separately. Model 1, Model 2, Model 3 and Model 4 were diverged from the rest of the models as they had significantly lower prediction power compared to other models (Figure 3). None of these models included neither day length (*S*) nor altitude angle (α). In other words, including at least one of these predictor variables substantially increased model fit. Therefore, we concluded that these variables were very important in temperature gradient predictions. This conclusion was reasonable because these variables were included in the models to reflect the influence of exposure time of streams to the solar radiation, and to illustrate the importance of solar radiation in temperature dynamics in riverine systems, which was addressed in various studies in literature (Dingman, 1972; Sinokrot & Stefan, 1993; Sridhar et. al., 2004; Dugdale et. al., 2018).

In our study, it was clearly shown that higher data granularity resulted in higher overall model fit (Table 5; Figure 3). As stated in Dertli (2021), this might be a consequence of reduced sample size (i.e., number of observations) with the aggregation of observations by taking their average. However, further observations in the same study showed that higher data granularity reduced the model fit for some streams. In other words, higher data granularity does not always result in high model fit. More legitimate reason was unique characteristics of streams that resulted in different outcomes under each data granularity scenarios. For example, the value of $R^2_{adj.}$ of Model 10 for Tobacco River under 12-hours granularity scenario was lower when compared to the same value under 6-hours data granularity scenario (Dertli, 2021). However, in the same study, it was shown that the value of $R^2_{adj.}$ of Model 10 for Carp River under 12-hours data granularity was higher than the same value under daily data granularity. To draw a better picture of the variations between stream characteristics, we obtained average downstream stream temperature and average downstream discharge values of each stream as provided in Table A1.

As mentioned before, the unique characteristics of streams were already reflected in the responses of model coefficients to changing data granularities. In addition to our findings, Dertli (2021) showed that parameter coefficients for ΔT_{up}, ΔT_{base}, and ΔT_{base} had different responses to data granularity change from hourly to weekly for each stream. This implied that different responses of model parameters caused the variations between increase or decrease patterns of model fit (i.e., $R^2_{adj.}$) across data granularity scenarios for each stream.

All these results showed that the unique characteristics of streams are determining factor of the model fit and they influence response of the model coefficients to different data granularity scenarios. Although overall model fit increased with higher data granularity in overall, it is not possible to propose a universal rule, such as “high data granularity should be used to achieve high model performances”. Moreover, selected data granularity may not be useful for answering particular research or environmental management questions, even though the models yield robust predictions. For example, using hourly stream temperature estimates to predict seasonal fish distributions would not be appropriate (due to the temporal scale mismatch) even if model fit is higher with hourly data granularity. Therefore, it is not possible to suggest the “best” data granularity for all modeling approaches in environmental management practices. However, arbitrary selection of data granularity should be avoided because it can have consequences in model-based decision-making processes in environmental sciences. Since the ecological relevance of data granularity should be as important as the model prediction power, regression models should be designed to have the highest model fit with the most ecologically-relevant data granularity.

The Effect of Data Granularity on Model Selection

Model weight was a useful indicator of the level of model complexity-model fit balance. High model weight (i.e., maximum value of 1) of a model was an indicator of high model fit with the minimal number of explanatory variables compared to the other models that were included in the model weight analysis. The percentages that are shown in the results (Figure 4) indicated the proportion of the total number of streams (n = 16) for which a model had the highest model weight. For example, Model 10 had the highest model weight for 62.5% of all streams, while Model 11 had the highest model weight for 25% of all streams. This revealed the best possible model selection for each data granularity scenario by taking all streams into account. No model had the highest model weight for all streams in all data granularity scenarios. For example, Model 8, which did not include altitude angle (α), had the highest model weight for 6.25% of streams (n = 1) with hourly data granularity. On the other hand, Model 9, lacking day length (S) parameter, had the highest model weight for another stream within the same data granularity scenario (Table 6). In other words, a particular environmental variable (e.g., day length) may be an important determinant of model predictions for some streams, while it may not be for the other streams. This, again, highlighted the importance of the stream characteristics on model evaluation.

Despite the fact that Model 10 had the highest model weight for the majority of streams in general, increasing data granularity resulted to some changes in model selection results, such that, less complex models (e.g., Model 1, Model 5, Model 6, Model 7) appeared to have highest model weight for more streams with higher data granularity scenarios (i.e., daily and weekly). In other words, the influence of model complexity on model fit may have decreased with higher data granularity. This conclusion was congruent with the relationship between model predictive power and data granularity. Since model predictive power generally increased with higher data granularity, higher model predictive powers were achieved with a smaller number of model parameters. This conclusion implied that less complex models may be more useful and efficient to predict response variables for higher data granularities. For example, Arismendi et. al. (2014) evaluated stream temperature predictions simple linear regression model that only included regional air temperature. They averaged daily air temperatures into weekly air temperatures, and they found that their model had an average Nash–Sutcliffe efficiency (NSE) value of 0.86. Although NSE and adjusted correlation coefficient ($R^2_{adj.}$) use slightly different methods to evaluate model fit, explaining 86% of the variation between observed and predicted values can be considered a significantly high model performance for such simple model. Therefore, selection of high data granularities in data may be advantageous since it may allow modelers to adopt simple models for environmental predictions. By using such simple models, researchers may avoid dealing with complicated models, extensive data collection requirements, and possible effects of multicollinearity.

Conclusions

1. Selection of data granularity can affect the model coefficients (both magnitude and sign). This may result in biases in interpretation of environmental variables, and consequently can lead to a mismanagement of ecosystems. In addition, the chance of having multicollinearity in models can increase with higher data granularity. Multicollinearity can also cause misinterpretations of environmental variables especially when parameter instability in the model coefficients occur.

2. Model fitness may be affected by data granularity selection, which may lead to misevaluation of models. Moreover, characteristics of the streams

determine the influence of higher data granularity on model prediction power. For some streams, higher data granularity increases the model fitness while it reduces model fitness for other streams. Therefore, it is not possible to conclude that higher data granularity certainly results in higher model fitness. Although we did not address the issue in our study, selection of time period (e.g., July data) may also potentially influence the relationship between data granularity and model prediction power (Dertli, 2021).

3. Selection of best models based on the rule of parsimony may be influenced by the selection of data granularity. Since higher data granularity decreases the number of data points, it can make simpler models better predictors. In addition, selection of data granularity may change the significance of environmental variables in model parsimony. Therefore, data granularity selection is important for model designing processes.

4. Certainly, our study did not propose such data granularity type that should be used to obtain high model robustness in general sense. However, we have shown that evaluation of model fit, model selection and interpretation of the model results and environmental variables can substantially vary with data granularity selection. Therefore, we highly recommend researchers avoid arbitrary choice of data granularity and make data granularity selections based upon their relevance to their research and management purposes.

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Appendix

Table A1

Observed Average Stream Temperature and Average Discharge Values of Streams between June-October in 2016

Stream	$\overline{T_w}$	$\overline{T_{down}}$	$\overline{Q_{up}}$	$\overline{Q_{down}}$
BL	15.148	15.412	0.830	0.727
CR	17.286	17.269	1.618	1.510
CC	14.371	14.408	0.562	0.443
MG	18.232	17.780	0.136	0.150
PK	17.107	17.481	0.477	0.551
BF	16.147	15.300	0.127	0.221
CP	17.286	17.269	1.618	1.510
PG	17.223	16.837	0.503	0.667
SP	17.550	17.452	0.190	0.287
ESC	17.476	17.424	0.986	1.268
NTW	21.190	20.355	0.790	0.259
TB	16.350	16.905	0.518	0.526
HS	19.286	17.835	0.035	0.089
PR	17.477	17.813	0.287	0.323
SQ	16.247	17.207	0.036	0.122
SW	19.234	19.511	0.453	0.093

Note. $\overline{T_w}$: average upstream temperature (℃), $\overline{T_{down}}$: average downstream temperature (℃), $\overline{Q_{up}}$: average upstream discharge (m^3/s), $\overline{Q_{down}}$: average downstream discharge (m^3/s).

Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Veri Taneselliğinin Michigan Akarsularının Sıcaklık Gradyan Modellemesi Üzerindeki Etkisi

Akarsu sıcaklıklarının tatlı su ekosistemlerindeki fiziksel, kimyasal ve biyolojik süreçlerde önemli bir rolü bulunmaktadır. Bu sebeple akarsu sıcaklığının, su kalitesi ve ekosistem işlevselliğinin önemli parametrelerinden birisi olduğu düşünülmektedir (Guo ve ark., 2019; Hamid ve ark., 2020). Su sıcaklığı, birçok farklı türün (ör. birincil üreticiler, sucuk omurgalı ve omurgasızlar) hayatta kalma, üreme ve yayılma süreçlerini etkilediği için, su sıcaklıklarını belirleyen faktörlerin anlaşılması kritik bir önem arz etmektedir (Iversen, 1971; Jackson ve ark., 2007; Zorn ve ark., 2004; Nuhfer ve ark., 2017). Literatürde akarsu sıcaklıklarını belirleyen farklı meteorolojik (örn. hava sıcaklığı) ve hidrolojik (örn. yağış) süreçler ele alınmıştır (Du ve ark., 2020). Ancak bu ekosistemlerin açık sistemler olması, dolayısıyla bu süreçlerin birbiriyle de etkileşmesi akarsu sıcaklıklarına etki eden faktörlerin anlaşılmasını zorlaştırmaktadır. Bu noktada, istatistiksel modeller araştırmacılara karmaşık sistemlerin açıklanmasında yardımcı olmaktadır.

İstatiksel modeller literatürde doğal süreçlerin açıklanmasında sıkça kullanılmaktadır. Örneğin, regresyon modellerinin değişken katsayıları sayesinde bu süreçlerin birbirleriyle etkileşimi matematiksel olarak açıklanabilmektedir (Bender, 2009). Ayrıca bu sayede çevresel değişimlerin (örn. iklim değişikliği, yeraltı sularının çekilmesi) akarsu termodinamiğine etkileri tahmin edilebilmektedir (Mantua, & Tohver, 2010; Andrews, 2019). Ancak istatistiksel modeller çevresel araştırmalar için çok önemli olsa da bu modellerden alınacak çıktılar kullanılan verinin yapısına oldukça bağlı olabilmektedir (Akossou, & Palm, 2013). Örneğin, veri taneselliği verideki gözlem sayısını, çoklu doğrusal bağlantı (multicollinearity) miktarını ve model çıktılarını etkileyebildiğinden verinin önemli yapısal özelliklerinden sayılmaktadır (Dertli, 2021). Ancak birçok çalışmada, modellerde kullanılan veri taneselliği verinin ekolojik anlamına uygun olarak seçilmesine rağmen, diğer birçok çalışmada kullanılan veri taneselliği keyfi olarak seçilmektedir ya da bu seçimin sebebi açıklanmamaktadır. Bu keyfi seçim, kullanılan modellerin başarısının değerlendirilmesinde ve model çıktılarının yorumlanmasında yanılgılara sebep olabilmektedir (Stefan, & Preud'homme, 1993; Pilgrim ve ark., 1998; Webb ve ark. 2003).

Bu çalışmada, kullanılan veri taneselliğinin doğrusal regresyon modelleri ve bu modellerin yorumlanmasındaki etkisi ele alınmıştır. Bu çalışmada amaçlanan hedefler:

1. Regresyon değişken katsayılarının farklı veri taneselliği senaryolarında değerlendirilmesi ve yorumlanması,
2. Regresyon model uyumunun (fitness) değişiminin farklı veri taneselliği senaryolarında değerlendirilmesi ve yorumlanması,
3. Parsimoni ilkesine bağlı olarak model seçiminin farklı veri taneselliği senaryolarında değerlendirilmesi ve yorumlanması,

olarak belirlenmiştir. Bu hedefler doğrultusunda, veri taneselliğinin regresyon modelleri ve çıktıları üzerine ki etkilerinin ayrıntılı bir şekilde analiz edilmesi amaçlanmıştır.

Bu çalışmada, Michigan'da farklı bölgelerde bulunan 16 akarsudan elde edilen veriler, Andrews (2019) tarafından geliştirilen regresyon modelleri üzerinde, su sıcaklığı değişiminin (sıcaklık gradyan, ΔT) (℃) tahmin edilmesi amacıyla seçilmiş ve kullanılmıştır. Andrews (2019) tarafından geliştirilen bu 11 model, hiyerarşik model geliştirme yöntemi ile her adımda modele yeni parametreler eklenerek dizayn edilmiştir. Bu akarsulara ait verilerde bulunan gözlemlerin ortalaması farklı zaman dilimlerine göre alınıp, 1-saat, 2-saat, 6-saat, 12-saat, 24 saat, 168-saat olmak üzere, 6 farklı veri taneselliği senaryosu elde edilmiştir. Bu farklı senaryolara sahip veriler regresyon modellerinde yürütülerek model çıktıları elde edilmiştir. Regresyon katsayıları bu simülasyonlar neticesinde elde edilmiştir. Model uyumu modellerin çıktılarının gözlemlerle olan korelasyon miktarına bağlı olarak değerlendirilmiştir. Farklı veri taneselliği senaryolarının model seçimde neden olduğu değişiklikler Akaike Bilgi Kriteri (Akaike's Information Criterion-AIC) değerleri kullanılarak elde edilen model ağırlıklarına bağlı olarak değerlendirilmiştir (Akaike, 1973).

Regresyon katsayı analizi iki önemli bulguyu ortaya çıkarmıştır. Birincisi, Model 10 1-saat veri taneselliği senaryosunda bütün akarsular için yürütüldüğünde aynı model parametre katsayılarının değerlerinin (örn. hava-su sıcaklık farkı ($T_a - T_w$)) akarsular arasında nicelik ve nitelik olarak değişmiştir. İkincisi, aynı akarsuya ait veride farklı veri taneselliği senaryoları kullanıldığında, Model 10'a ait parameter katsayılarının nicelik ve nitelik olarak değiştigi gözlenmiştir. Örneğin, hava-su sıcaklık farkı ($T_a - T_w$) parametre katsayısının değeri 1–saat senaryosunda 0.023 olarak ölçülürken, 24-saat senaryosunda -0.023 olarak ölçülmüştür. Model uyumluluk analizleri de önemli bulgular ortaya koymuştur. Örneğin, Model 10'a hava korelasyon değerlerinin (ya da uyumluluğunun) diğer modellerden daha yüksek olduğu gözlenmiştir. Model uyumluluğu analizi ayrıca veri taneselliğinin artışının (1-saat'lik senaryodan 168-saat'lik senaryoya) genel olarak model uyumluluğunu (fitness) artırdığını göstermiştir. Parsimoni ilkesine bağlı olarak model seçimi analizleri, Model 10'un diğer modellere kıyasla daha fazla sayıda akarsu (akarsuların %62,5'i) için daha iyi çalıştığı gözlemlenmiştir. Bununla beraber, veri taneselliği bu seçimlerde değişikliğe neden olmuştur. Örneğin, 168-saat senaryosunda Model 10 sadece akarsuların %31.25'i için diğer modellere kıyasla daha iyi çalıştığı gözlemlenmiştir.

Sonuç olarak bu çalışma regresyon modelleri ve kullanılan veri yapısı açısından bazı önemli sonuçlar ortaya koymuştur. Örneğin, regresyon modellerdeki parametre katsayılarının nicelik ve niteliğinin kullanılan veri taneselliğine bağlı olarak değişebileceğinin gösterilmesi, bu modellerde bulunan parametrelerin model çıktıları üzerindeki etkisinin de taneselliğe bağlı olarak değişebileceği gösterilmiştir. Bu sonuç, modellerde kullanılan parametrelerin (ör. $T_a - T_w$) veri taneselliğine bağlı olarak akarsu sıcaklığı tahminlerine olumlu ya da olumsuz olarak etki edebileceğini göstermiştir. Bu durum, modellerde uygun olmayan bir veri taneselliği kullanıldığında akarsu sıcaklığına etki eden faktörlerin yanlış yorumlanmasına sebep olabileceğini göstermiştir. Ayrıca kullanılan veri taneselliğinin model uyumluluğuna doğrudan etki etmesi, bu modellerin uyumluluklarının değerlendirilmesinde yanlış yorumlamalara sebebiyet verebileceği ortaya koyulmuştur. Bu durum aslında uyumluluğu yüksek olan bir modelin, modele uygun olmayan bir veri taneselliği kullanıldığında uyumluluğunun düşük ölçülebileceğini göstermiştir. Bununla birlikte, kullanılan veri taneselliği, bir akarsu için kullanılması en uygun olan modelin seçimini etkileyebileceğinden, veri taneselliği seçiminin model seçimlerinde yanlış kararlara yol açabileceği sonucu ortaya çıkmıştır.

Şuna dikkat çekmek gerekir ki bu çalışma hangi veri taneselliğinin daha iyi olduğunu ortaya koymayı amaçlamamıştır. Çünkü veri taneselliğinin artması ya da azalması her model veya her durum için farklı sonuçlar ortaya çıkarmaktadır. Bu çalışmanın asıl amacı, keyfi olarak seçilen veri taneselliğinin modeller ve model yorumlamaları üzerindeki muhtemel etkilerine dikkat çekmek ve modellemecilere daha geniş bir bakış açısı sunmaktır. Modellerde kullanılan veri taneselliğinin keyfi olarak değil, araştırmanın cevap bulmaya çalıştığı sorulara uygun olarak seçilmesi, bu modellerin uygunluğunun ve başarısının objektif bir biçimde değerlendirilmesinde büyük önem teşkil edecektir.

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Review Article

Agent-Based Approach on Water Resources Management: A Modified Systematic Review

Su Kaynakları Yönetiminde Etmen Tabanlı Yaklaşım: Uyarlanmış Sistematik Derleme

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Abstract

Social, economic, and ecological dimensions of water resources make water management a highly complex domain related to many intertwined human-nature systems. Therefore, the decision and implementation of sustainable policies require following the evidence-based approach. Agent-Based Modeling and Simulation is one of the latest computer-aided modeling and simulation applications widely used to understand the phenomena associated with water-related/human-oriented engineering systems. In this study, conducting a modified systematic review approach, a field-specific review of the 128 articles on water resources management with Agent-Based Modeling was presented. Application areas of Agent-Based Modeling in water resources management and examples of its use as a decision support tool were evaluated. As an integrative systematic review of Web of Science, Science Direct, and Google Scholar, this study summarizes the leading work of Agent-Based Modeling applications on water resources management. Current trends show that water research professionals have often used Agent-Based Modeling as a social simulation tool. Due to its role in facilitating interdisciplinary research, its application area is widening. However, there is a need for a comprehensible and open share of application-oriented information to guide the scientific community.
Keywords: *agent-based modeling, simulation, water resources management, sustainability*

Öz

Sosyal, ekonomik ve ekolojik boyutları, su yönetimini insan-doğa sistemiyle ilgili iç içe geçmiş oldukça karmaşık bir alan haline getirmektedir. Bu nedenle sürdürülebilir politikaların belirlenmesi ve uygulanması konusunda kanıta dayalı yaklaşımın izlenmesine ihtiyaç duyulmaktadır. Etmen Tabanlı Modelleme ve Simülasyon (ETM), suyla ilgili/insan odaklı mühendislik sistemleriyle ilişkili olguları anlamak için yaygın olarak kullanılan en güncel bilgisayar destekli modelleme ve simülasyon yaklaşımlarından biridir. Bu çalışmada, araştırma konusunun gerekleri doğrultusunda uyarlanmış bir sistematik derleme yaklaşımıyla, Etmen Tabanlı Modelleme metodolojisi ile su kaynakları yönetimine ilişkin 128 makalenin incelemesi sunulmuş, Etmen Tabanlı Modelleme'nin su kaynakları yönetimindeki uygulama alanları ve karar destek aracı olarak kullanım örnekleri gözden geçirilmiştir.

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Web of Science, Science Direct ve Google Scholar arama motoru/veritabanı kullanılarak yürütülen bu çalışma, su kaynakları yönetimi konusundaki önde gelen Etmen Tabanlı Modelleme çalışmalarını özetlemektedir. Mevcut eğilimler, bir sosyal simülasyon aracı olarak Etmen Tabanlı Modelleme'nin akademisyenlerce sıklıkla kullanıldığını ve disiplinlerarası araştırmaları kolaylaştıran rolü nedeniyle uygulama alanının genişlemekte olduğunu göstermektedir. Ancak, uygulamaya yönelik bilgilerin açık paylaşımına ihtiyaç duyulmaktadır.

Anahtar sözcükler: *etmen tabanlı modelleme, simülasyon, su kaynakları yönetimi, sürdürülebilirlik*

Introduction

Water research is a fundamental research domain of environmental science. One of the main reasons for this, from a systems perspective, the planet consists of sub-systems which are connected with each other in a complex way. But above all, human behavior is a complex phenomenon that is causing “coupled human-water systems” to become complicated in behavior and hard to predict. Thus, managing any nature-human system, including water resources, requires a perspective of “complex adaptive systems” (CAS).

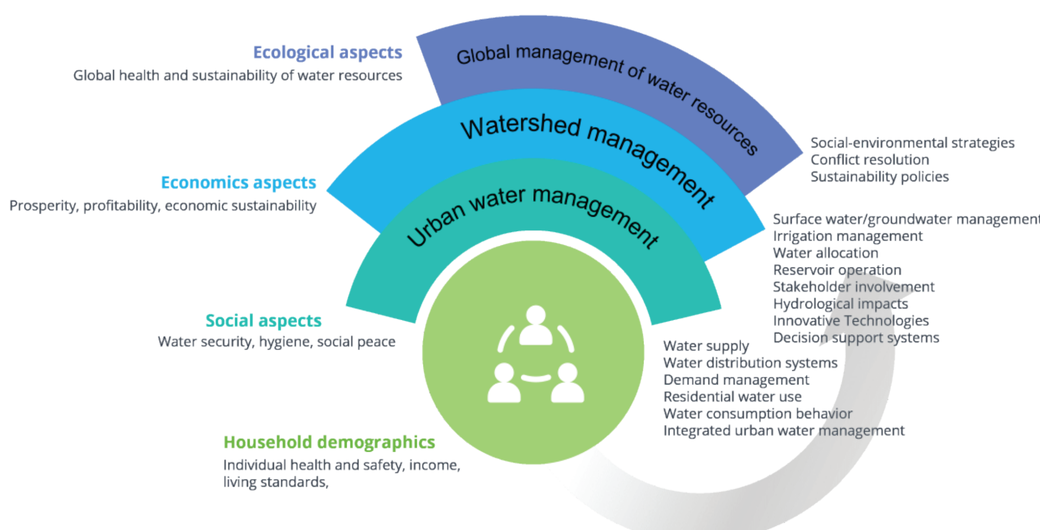
Water resources and the human systems dependent on them are so-called “socio-ecological systems” (SES) with natural and artificial features. According to this perspective, many phenomena seen at the macro scale emerge from interactions among agents at the micro-scale. However water resources are natural systems, those systems are conceptualized as SES, since humans are the foremost actors (agents) of the SES. The main reason for conceptualizing water resources as an SES is humans and their effect on these systems (Figure 1). Humans and societies have the willpower over natural systems, so those systems are rather coupled human-nature systems or socio-ecological systems.

Many phenomena that emerge on the social scale due to the choices individuals make in their daily lives affect the fate of water resources. The over-exploiting of water resources has many consequences on the households’living standards, income, and demographic characteristics. But household demographics also affect the status of water resources. In a way, demanding higher living standards means demanding more water. As a consequence of higher living standards, water resources inevitably become insufficient. Therefore, the sustainable management of water resources become an indisputable necessity today.

Water resource management consists of sustainable planning, development, distribution, and management of water resources and involves all levels of strategic, tactical, and operational enterprise/corporate management applications. Water resource management is one of the essential requirements in modern urban life, aiming to sufficiently supply and distribute fresh and clean water. Research attention to water management has grown over the years (Aydın & Keleş, 2021). However, engineering perspective of water management has come to a boundary of knowledge, unless the social aspects of water resources management (WRM) are studied. Social systems are considered as CAS in which individuals or other different social actors can change their behavior according to their level of survival and access to similar self-performance criteria. Social simulation is a sub-discipline that focuses on the processes, mechanisms and behaviors that reveal social phenomena. Computer simulations are used in research on these mechanisms and behaviors. In this approach, social processes are considered as complex (non-linear/adaptive) systems (Jager & Gotts, 2013). There are several modeling approaches to study social processes.

Figure 1

Emergent Nature of Water Resources Management from a SES Perspective



This study's main oebjective is to explore the Agent Based Modeling approach. There is a growing need and interest to investigate the complex interactions between water resources as socio-economic systems. The ABM is one of the most preferred approaches in researching these interactions in recent years. Agent-Based Modeling allows for determining individual behavior and how this behavior affects other individuals and also the environment. In ABM, systems studied are modeled as "a collection of autonomous decision-making entities", named agents. Agents make decisions, assessing their state individually, and based on a set of rules (Bonabeau, 2001). This research was carried out to present a general view of the research subject to the reader by compiling ABM-based applications in WRM.

Method

This work was conducted by a modified version of the systematic review approaches (Palmatier et al., 2018; Watson et al., 2018). Modifications include the thematic and technical aspects of the systematic review method described in related papers. The most significant modification was the construction of the search string. Instead of using a predefined search terms list, this work implemented the approach of using a simple search string and investing more time in inspecting the papers. The main objective of the research was to compose a general view of the subject, revealing the historical progress and other technical details.

Synthesis of related articles starts with the investigation by quick browse and comparison. Quick browse consists of a preliminary search of possible resources and databases related to the subject matter. Its main objective was to grasp the possible sample size for the research. Comparison of available sample sizes from different databases gives an impression about which database to follow for further analysis. Another benefit of the browsing and comparison approach is to get an intuition of the general outline of the subject matter.

The searching process consisted of querying the selected databases for the subject matter and inspecting the results for a preliminary screening. Results with high relevancy were recorded in an MS Excel-based database for further investigation. The screening step was conducted by further inspection, aiming to narrow down the number of articles until the scope of the yielded results overlapped with the one of this research. Extracting and synthesis were conducted by compiling related information from selected articles regarding keywords, WRM category, geographical and temporal coverage, software used, the title of subject-specific model development if available, and contribution to the scientific literature. As a last step of the process, the relevance of results was scored.

Searching Process

Since WRM is a term related to many social and natural sciences research topics, a comprehensive examination of scientific literature is required to get the broadest results. All possible scientific indexes, including Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), Conference Proceedings Citation Index (CPCI-S), Emerging Sources Citation Index (ESCI), Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH) were explored via Science Direct (SD) and Web of Science (WoS). The Google Scholar (GS) academic search engine was included for comparison. The specified search string was kept simple and static during all stages of research.

The search for relevant articles was implemented via an integrative approach to overcome the inconsistencies among different search engines/databases (Table 1). The search string for Science Direct was constructed as: "Agent Based Model" AND Water. And in addition, the search string for Web of Science was constructed as: "Agent Based" AND Water. After the first round of the search, the only consistent aspect of the yielded results was that the document numbers from all three databases decreased when the search string switched to "Agent Based" AND Water. Thus, instead of choosing one of the search strings, both were kept to avoid missing related articles.

Quotation marks were used to fetch the results, including "Agent" and "Based" strings. The "AND" operator concatenates previous and following strings. "Water", the only and the simplest word, was selected to represent "water world". "WRM" intentionally was not preferred to eliminate the algorithm-based differences between databases/search engines. Results are presented in Table 1.

Table 1

Selected Databases and Article Numbers

Database/Search Engine	Agent Based Model AND Water	Agent Based ANDWater	Shortlisted by Authors
GS (Articles with the exact phrase in the title of the article, Any type)	55	177	-
SD (Title, abstract, keywords)	183	345	70
WoS (Title, abstract, Keyword+)	256	735	71

Note. 13 of the selected articles were found on both WoS and SD.

After a quick browse and comparison of the results, it was clear that yielded sample coverage was too different among providers, both in numbers and context.

Especially for GS, yielded documents were far from fit to purpose by quickly browsing the results fetched on the first 50 pages. One comment on yielded documents was that the search algorithm could read most of the web page's content, bringing any result including the string "water". Besides, confusion including the term "water", which expresses the liquid form of water, rather than the term "water management", which is an administrative concept, was frequently encountered. Similarly, the terms "agent" (being a chemistry term) and "based", often appeared separately in the results, and that constituted another differentiation from the term "agent-based". Since providers have too many redundancies, the next step of the research was a one-by-one inspection, covering the WoS and the SD results, including 1080 articles found. Results from the GS engine were not advanced further since the ultimate objective of incorporating GS was already reached.

Screening

The screening process was conducted following the further inspection of the yielded results from SD and WoS. Initial screening was started by shortlisting articles throughout the criteria given in Table 2.

Initial screening of articles according to the criteria mentioned above resulted in 168 articles that were found to be essentially related to WRM. Following a cross-check of articles made by authors, results were evaluated to be included or excluded in the database. By conducting a scale of non-relevance to full relevance, the ultimate number of the shortlisted articles was obtained as 128.

Table 2

Criteria for Shortlisting and Selection

	Criteria
Study Type	Peer-reviewed empirical and theoretical/conceptual studies, journal, or conference manuscripts
Index	SCI-Expanded, SSCI, CPCI-S, ESCI, CPCI-SSH
Language	English
Date	All available history
Relevance	Not relevant; not related to WRM
	Low relevance; reference to auxiliary or technical aspects of WRM
	Moderate relevance; related to WRM with lack of application of ABM
	High relevance; complete theoretical consistency with WRM and practice of ABM
	Full relevance; main paper of the domain via scientific contribution and practice

Extraction and Synthesis

A summary of articles was compiled in an MS Excel spreadsheet, including the title, authors' names, publication year, publisher, keywords, and abstract. Articles were classified regarding WRM categories. Those categories included urban water management, irrigation management, watershed-river basin management, and global management of water resources. Issues such as conflict management, policy analysis, and socio-environmental strategies were subjected.

One other important perspective of this research was to compose technical aspects of the water-related ABM applications, including the geographical coverage of case studies, temporal coverage of simulations, software used, and supplements provided by researchers. Therefore, all available information on those parameters was collected and presented in a suitable format in the Results section.

Results

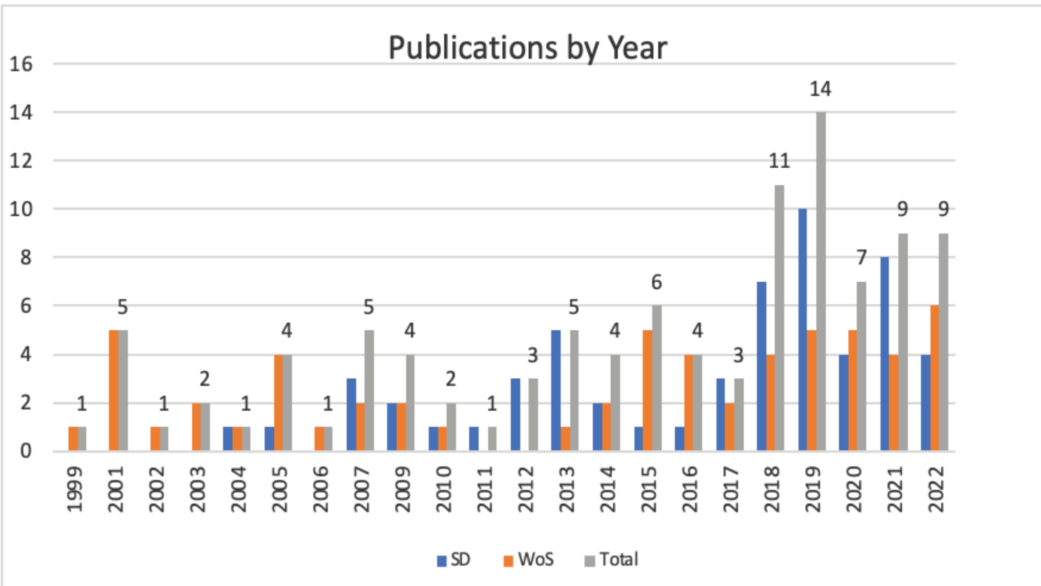
This research was carried out to present a chronological overview of agent-based methods in WRM. As expected, a broadly diverse view has emerged, both in the research discipline and the spectrum of practice. Selected articles consisted of broad coverage of articles of empirical and conceptual papers, including review articles, case studies, and perspective papers. For this reason, results were presented in a manner organized by descriptive, thematic, and methodological characteristics of articles. The descriptive analysis covers formal aspects of selected literature such as publications by years, journals with the largest collection of manuscripts, and country-based case study rankings. Thematic analysis shows the WRM aspects of the articles, such as emergent water-related terms and chronological contributions by authors. Lastly, articles were categorized by their software use as a technical part of the research. The status of the supplements provided by authors was also considered a contribution to the scientific community.

Descriptive Analysis

The use of the ABM method in research on the management of water resources has shown an increasing development since 1999. Starting from 1999, almost every year until 2022, one or more publications appeared, including journal articles, conference papers, and book chapters. However, starting from 2012, the numbers and diversity of the publications broadened (Figure 2). 2018-2019 seemed to be the densest period of the "WRM" related with ABM publications. 13 publications detected by both search engines were removed from the total.

Figure 2

Publications Shortlisted from both SD and WoS



Journals and Rankings

The distribution of publications showed the diversified and interdisciplinary nature of the research subject. Almost half of the publications appeared in 50 different journals with only one article (Table 3). For this reason, only the publishers with 2 or more manuscripts were presented in here. The top 4 publishers only provided 23% of total articles.

Case Study Country Based Rankings

Selected literature showed a wide range of geographical coverage of case studies (Table 4). AB methodology was applied to water resources management research in 29 countries worldwide. The top applications of 42 case studies came from USA, Iran, and China.

Table 3

Publications with Two or More Articles Relevant To WRM+ABM

Publication	Count
Environmental Modelling & Software	9
Sustainable Cities and Society	8
Agricultural Water Management	7
Journal of Hydrology	6
Water	4
Agricultural Systems	4
Water Resources Management	4
Journal of Environmental Management	4
Ecological Modelling	3
Journal of Water Resources Planning And Management	3
Science of the Total Environment	2
Water Resources Research	2
Simulation-Transactions of The Society For Modeling And Simulation International	2
Computers, Environment and Urban Systems	2
Physics and Chemistry of the Earth	2
Ecological Economics	2
Simulation Modelling Practice and Theory	2
International Journal of Critical Infrastructure Protection	2
Sustainability	2
JASSS-The Journal of Artificial Societies and Social Simulation	2
Water Science and Technology	2
Journal of Cleaner Production	2
Computers and Electronics in Agriculture	2
Other publications	50
	128

Table 4

Emergent Water-Related Terms under WRM

No. of Case Studies	Countries
22	USA
13	Iran
7	China
5	Australia, France
4	Greece
3	Switzerland
2	Brazil, Chile, Germany, Kenya, Morocco, Spain
1	Argentina, Cambodia, Canada, Colombia, Croatia, India, Indonesia, Israel, Italy, Mexico, New Zealand, Senegal, South Africa, Thailand

Note a. 34 publications were not case studies, or geographical coverage was not clear.

Note b. 5 of the case studies was conducted via virtual environments such as Hypothetical/Virtual.

Software Used

ABM application requires skills in advanced programming or dedicated software. However, software use was not related to all selected articles. Some articles were reviews, and some others were perspective papers offering recommendations. Thus 59 of reviewed publications did not contain software use, and the ones with software implementation were shown in Table 5.

Table 5

Emergent Water-Related Terms under WRM

Software	Articles Used
NetLogo	15
AnyLogic	7
Java / JADE	7
Python	4
MASON	4
C++	3
Repast Symphony	3
CORMAS	2
Web application	2
DynaMind	1
Envision	1
Julia	1
Others/unknown/project-based	19

Note. 58 publications were not using software, or used software was not explicit.

19 articles were related to software use, but no further information was offered via text or supplements. Software use contained broad diversity as well. Many programming languages or software packages were used to implement ABM, including software packages such as NetLogo, AnyLogic, MASON, and Repast Symphony and programming languages, especially Java, Python, and C++.

WRM Categories

From a complex adaptive systems perspective, water resources management is highly related to many human-nature coupled systems. Thus, it has social, ecological, and economic aspects. WRM categories in this study were constructed to present the transitive nature of the research domain, stemming from the associated keywords of articles provided by their authors. The objective was to show how water-related terms are sometimes used transitively, and reveal which keywords are widely subjected (Table 6). Not surprisingly, WRM was highly referred to in many articles. However, it is noteworthy that many other emerging research topics appear to be highly referred to, such as “demand management”, “irrigation management”, “groundwater management”, and “supply management”.

Table 6

Emergent Terms Related To WRM

Water-related terms	No. of Journals	Other related terms
Agricultural management	6	Agricultural economics, agricultural water management, agriculture
Conflict management	5	Conflict resolution
Demand management	13	Domestic water demand, Dynamic demand, Demand tree analysis, Water demand forecasting, Residential water demand, Water demand strategies, Water demand system
Groundwater management	10	Groundwater
Irrigation management	12	Agricultural irrigation, Irrigation system viability, Irrigation
Policy analysis	6	Policy assessment, Policy check, Water management policies, Sustainability policy
Public health hand sanitation	3	Water infrastructure safety, Contamination, Epidemics, Public health effects, Water sanitation
Public participation	2	Stakeholder engagement, Negotiation
Reservoir management	2	-
River basin management	2	-
Stakeholder behavior	6	Social learning, Participatory modeling, Participatory ABM, Role-playing games, Theory of planned behavior, Game theory
Stormwater management	1	-
Supply management	9	Water supply system, Urban water supply, Water distribution system, Water distribution system management,
Urban water management	8	Urban water resources management
Wastewater management	2	-
Water allocation	5	Water allocation optimization
Water infrastructure management	3	Coupled human-nature systems, Critical infrastructures, Water infrastructure planning, Interdependencies of critical infrastructures
Water quality management	8	Eutrophication, Risk management, Water quality, Water quality trading
Water-related innovation	3	Technology diffusion, Decentralized water technologies, Innovation adoption, Rainwater harvesting
Water resources management	16	Collaborative water management, Domestic water management, Water resources, Water resource management, Water governance
Water reuse	1	-
Water rights	1	-
Water scarcity	2	Water availability
Water security	7	-
Water trading	6	-
Watershed management	6	Wildlife support, Natural systems restoration

A Brief Chronology of ABM on Water Resources Management

Contributions to agent-based applications in water resources management were presented in Table 7, in which the title of the research and authors were contained. Contributions have consisted of summarized information that was compiled to be descriptive and as informative as possible. Abbreviations were used because of space restrictions and were written in open form in text where it was first introduced.

Table 7

Authors and Articles in Chronological Order

Author	Article
Tillman et al. (1999)	Modeling the actors in water supply systems
Berger (2001)	Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis
Tillman et al. (2001)	Interaction analysis of stakeholders in water supply systems
Le Bars & Attonaty (2001a)	A multi-agent system to the common management of a renewable resource: Application to water sharing
Mohring & Troitzsch (2001)	Lake Anderson revisited by agents
Le Bars & Attonaty (2001b)	A multi-agent system to simulate water attribution among farmers
Pahl-Wostl (2002)	Towards sustainability in the water sector - The importance of human actors and processes of social learning
Becu et al. (2003)	Agent based simulation of a small catchment water management in northern Thailand description of the CATCHSCAPE model
Barreteau et al. (2003)	Agent-based facilitation of water allocation: Case study in the Drome River Valley
Pahl-Wostl & Hare (2004)	Processes of social learning in integrated resources management
Barreteau et al. (2004)	Suitability of Multi-Agent Simulations to study irrigated system viability: application to case studies in the Senegal River Valley
Hare & Deadman (2004)	Further towards a taxonomy of agent-based simulation models in environmental management
Tillman et al. (2005)	Simulating development strategies for water supply systems
Athanasiadis et al. (2005)	A hybrid agent-based model for estimating residential water demand
Zhang et al. (2005)	Dynamic game theoretic model of multi-layer infrastructure networks
Barthel et al. (2005)	Large-scale water resources management within the framework of GLOWA-Danube. Part A: The groundwater model
Lopez-Parades et al. (2005)	Urban water management with artificial societies of agents: The FIRMABAR simulator
Nickel et al. (2005)	Large-scale water resources management within the framework of GLOWA-Danube-The water supply model
Niu & Wang (2006)	A simulation model framework of water resources multi-agent system
Schlueter & Pahl-Wostl (2007)	Mechanisms of resilience in common-pool resource management systems: an agent-based model of water use in a river basin
Barreteau et al. (2007)	Variable time scales, agent-based models, and role-playing games: The PIEPLUE river basin management game
Janssen (2007)	Coordination in irrigation systems: An analysis of the Lansing–Kremer model of Bali
Nichita & Oprea (2007)	An agent-based model for water quality control
Rixon et al. (2007)	Exploring water conservation behaviour through participatory Agent-Based Modelling
Galan et al. (2009)	An agent-based model for domestic water management in Valladolid metropolitan area
Schroeder et al. (2009)	The use of multi-agent based models to support water resources management The Moroccan case study
Smajgl et al. (2009)	Simulating impacts of water trading in an institutional perspective
Schwarz & Ernst (2009)	Agent-based modeling of the diffusion of environmental innovations –An empirical approach
Saqalli et al. (2010)	Investigating social conflicts linked to water resources through Agent-Based Modelling
Moglia et al. (2010)	Modelling an urban water system on the edge of chaos
Van Oel & Van der Veen (2011)	Using agent-based modeling to depict basin closure in the Naivasha basin, Kenya: a framework of analysis
Murphy (2012)	Exploring complexity with the Hohokam Water Management Simulation: A middle way for archaeological modeling
Isern et al. (2012)	Development of a multi-agent system simulation platform for irrigation scheduling with case studies for garden irrigation
Wise & Crooks (2012)	Agent-based modeling for community resource management: Acequia-based agriculture

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Author	Article
Akhbari & Grigg (2013)	A Framework for an Agent-Based Model to manage water resources conflicts
Belaqziz et al. (2013)	An agent based modeling for the gravity irrigation management
Nguyen et al. (2013)	Water quality trading with asymmetric information, uncertainty and transaction costs: A stochastic agent-based simulation
Zhang et al. (2013)	Trade-offs in designing water pollution trading policy with multiple objectives: A case study in the Tai Lake Basin, China
Britz et al. (2013)	Modeling water allocating institutions based on multiple optimization problems with equilibrium constraints
Iftekhar et al. (2013)	Effects of competition on environmental water buyback auctions
Zhao et al. (2013)	Comparing administered and market-based water allocation systems through a consistent agent-based modeling framework
Yuan et al. (2014)	Urban household water demand in Beijing by 2020: An Agent-Based Model
Aguirre & Nyerges (2014)	An Agent-Based Model of public participation in sustainability management
Daloğlu et al. (2014)	Development of a farmer typology of agricultural conservation behavior in the American Corn Belt
Crooks & Hailegiorgis(2014)	An agent-based modeling approach applied to the spread of cholera
Berglund (2015)	Using Agent-Based Modeling for water resources planning and management
Kanta & Berglund (2015)	Exploring tradeoffs in demand- side and supply- side management of urban water resources using Agent- Based Modeling and evolutionary computation
Ponte et al. (2015)	Real-time water demand forecasting system through an agent-based architecture
Al-Amin et al. (2015)	Agent-based modeling to simulate demand management strategies for shared groundwater resources
Murphy et al. (2015)	Simulating regional hydrology and water management: An Integrated Agent-Based Approach
Wu et al. (2015)	A scenario-based approach to integrating flow-ecology research with watershed development planning
Koutiva & Makropoulos (2016)	Modelling domestic water demand: An agent based approach
Farhadi et al. (2016)	An agent-based-nash modeling framework for sustainable groundwater management: A case study
Tomicic & Schatten (2016)	Agent-based framework for modeling and simulation of resources in self-sustainable human settlements: a case study on water management in an eco-village community in Croatia
Al-Amin et al. (2016)	Coupling Agent-Based and groundwater modeling to explore demand management strategies for shared resources
Ramsey (2016)	Use of a household survey in the development of an Agent-Based Model to support water demand management in Jaipur, India
Shafiee (2016)	Agent-based modeling and evolutionary computation for disseminating public advisories about hazardous material emergencies
Mashhadi et al. (2017)	Agent-based modeling to simulate the dynamics of urban water supply: Climate, population growth, and water shortages
Darbandsari et al.(2017)	An Agent-based behavioral simulation model for residential water demand management: The case-study of Tehran, Iran
Bakarji et al. (2017)	Agent-Based Socio-Hydrological Hybrid Modeling for water resource management
Koutiva & Makropoulos (2017)	Exploring the effects of domestic water management measures to water conservation attitudes using agent based modelling
Chen (2017)	Spatially explicit modelling of agricultural dynamics in semi-arid environments
Nandi et al. (2017)	Reduced burden of childhood diarrheal diseases through increased access to water and sanitation in India: A modeling analysis
Noel & Cai (2017)	On the role of individuals in models of coupled human and natural systems: Lessons from a case study in the Republican River Basin
Castonguay et al. (2018a)	Modelling urban water management transitions: A case of rainwater harvesting
Xiao et al. (2018a)	Agent-Based Modeling Approach to Investigating the Impact of Water Demand Management
Anthony & Birendra (2018)	Improving irrigation water management using agent technology

Table 7

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Author	Article
Xiao et al. (2018b)	Centralized and decentralized approaches to water demand management
Giri et al. (2018)	Water security assessment of current and future scenarios through an integrated modeling framework in the Neshanic River Watershed
Ohab-Yazdi et al. (2018)	Using the agent-based model to simulate and evaluate the interaction effects of agent behaviors on groundwater resources, a case study of a sub-basin in the Zayandehroud River basin
Hampf et al. (2018)	The biophysical and socio-economic dimension of yield gaps in the southern Amazon – A bio-economic modelling approach
Wang et al. (2018)	Intelligent simulation of aquatic environment economic policy coupled ABM and SD models
Castonguay et al. (2018b)	Integrated modelling of stormwater treatment systems uptake
Al-Amin et al. (2018)	Assessing the effects of water restrictions on socio-hydrologic resilience for shared groundwater systems
Monroe et al. (2018)	Allocating countermeasures to defend water distribution systems against terrorist attack
Hyun et al. (2019)	Using a coupled agent-based modeling approach to analyze the role of risk perception in water management decisions
Nouri et al. (2019)	Agent-Based Modeling for evaluation of crop pattern and water management policies
Huber et al. (2019)	Agent-Based Modelling of a coupled water demand and supply system at the catchment scale
Mewes & Schumann et al. (2019)	The potential of combined machine learning and agent-based models in water resources management
Bakhtiari et al. (2019)	A coupled agent-based risk-based optimization model for integrated urban water management
Koutiva & Makropoulos et al. (2019)	Exploring the Effects of alternative water demand management strategies using an agent-based model
Nhim et al. (2019)	The resilience of social norms of cooperation under resource scarcity and inequality-An agent-based model on sharing water over two harvesting seasons
Castilla-Rho et al. (2019)	Sustainable groundwater management: How long and what will it take?
Baeza et al. (2019)	Operationalizing the feedback between institutional decision-making, sociopolitical infrastructure, and environmental risk in urban vulnerability analysis
Thompson et al. (2019)	Interdependent Critical Infrastructure Model (ICIM): An agent-based model of power and water infrastructure
Yang et al. (2019)	Impact of dam development and climate change on hydroecological conditions and natural hazard risk in the Mekong River Basin
Bonté et al. (2019)	Building new kinds of meta-models to analyse experimentally (companion) modelling processes in the field of natural resource management
Kandiah et al. (2019)	An agent-based modeling approach to project adoption of water reuse and evaluate expansion plans within a sociotechnical water infrastructure system
Pouladi et al. (2019)	Agent-based socio-hydrological modeling for restoration of Urmia Lake: Application of theory of planned behavior
Mishra et al. (2019)	A modeling framework for critical infrastructure and its application in detecting cyber-attacks on a water distribution system
García et al. (2019)	A linked modelling framework to explore interactions among climate, soil water, and land use decisions in the Argentine Pampas
Darbandsari et al. (2020)	An agent-based conflict resolution model for urban water resources management
Bitterman & Koliba (2020)	Modeling alternative collaborative governance network designs: An Agent-Based Model of water governance in the Lake Champlain Basin, Vermont
Lin et al. (2020)	Using Agent-Based Modeling for water resources management in the Bakken Region

Table 7

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Author	Article
Tamburino et al. (2020)	Water management for irrigation, crop yield and social attitudes: a socio-agricultural agent-based model to explore a collective action problem
Kokay et al. (2020)	The application of role-playing games and agent-based modelling to the collaborative water management in peri-urban communities
Zamenian & Abraham (2020)	An Agent-Based Simulation Model for assessment of water consumption patterns during water rate ıncrease events
Yang et al. (2020)	Impact of climate change on adaptive management decisions in the face of water scarcity
Kaiser et al. (2020)	Identifying emergent agent types and effective practices for portability, scalability, and intercomparison in water resource agent-based models
Aghaie et al. (2020a)	Emergence of social norms in the cap-and-trade policy: An agent-based groundwater market
Aghaie et al. (2020b)	Agent-Based hydro-economic modelling for analysis of groundwater-based irrigation water market mechanisms
Perello-Moragues et al. (2021)	Modelling domestic water use in metropolitan areas using socio-cognitive agents
Wang et al. (2021)	An agent-based framework for high-resolution modeling of domestic water use
Aydin & Keles (2021)	A multi agent-based approach for energy efficient water resource management
Li et al. (2021)	Modeling spatial diffusion of decentralized water technologies and impacts on the urban water systems
Arasteh et al. (2021)	New hydro-economic system dynamics and agent-based modeling for sustainable urban groundwater management: A case study of Dehno, Yazd Province, Iran
Oliva-Felipe et al. (2021)	The Organisational Structure of an Agent-Based Model for the management of wastewater systems
Noori et al. (2021)	An agent-based model for water allocation optimization and comparison with the game theory approach
Jimenez et al. (2021)	Smart water management approach for resource allocation in high-scale irrigation systems
Fleming (2021)	Scale-free networks, 1/f dynamics, and nonlinear conflict size scaling from an agent-based simulation model of societal-scale bilateral conflict and cooperation
Yuan et al. (2021)	Effects of farmers' behavioral characteristics on crop choices and responses to water management policies
Ding et al. (2021)	Assessing food–energy–water resources management strategies at city scale: An agent-based modeling approach for Cape Town, South Africa
Anbari et al. (2021)	An uncertain agent-based model for socio-ecological simulation of groundwater use in irrigation: A case study of Lake Urmia Basin, Iran
Huber et al. (2021)	Agent-based modelling of water balance in a social-ecological system: A multidisciplinary approach for mountain catchments
Zolfagharipoor et al. (2021)	Agent-based modeling of participants' behaviors in an inter-sectoral groundwater market
Strickling et al. (2021)	Simulation of containment and wireless emergency alerts within targeted pressure zones for water contamination management
Granco et al. (2022)	Local environment and individuals' beliefs: The dynamics shaping public support for sustainability policy in an agricultural landscape
Du et al. (2022)	Evaluating distributed policies for conjunctive surface water-groundwater management in large river basins: Water uses versus hydrological ımpacts
Kadinski et al. (2022)	A hybrid data-driven-agent-based modelling framework for water distribution systems contamination response during COVID-19
Rojas et al. (2022)	Participatory and Integrated Modelling under Contentious Water Use in Semiarid Basins
James & Rosenberg (2022)	Agent-Based Model to manage household water use through social-environmental strategies of encouragement and peer pressure
Bahrami et al. (2022)	An agent-based framework for simulating interactions between reservoir operators and farmers for reservoir management with dynamic demands
Elhamian et al. (2022)	Quantitative and qualitative optimization of water allocation in no bandegan aquifer using an agent-based approach

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Author	Article
Nhim & Richter (2022)	Path dependencies and institutional traps in water governance – Evidence from Cambodia
Guo et al. (2022)	Modeling agricultural water-saving compensation policy: An ABM approach and application
Jimenez et al. (2022)	Intelligent IoT-multiagent precision irrigation approach for improving water use efficiency in irrigation systems at farm and district scales
Bourceret et al. (2022)	Adapting the governance of social–ecological systems to behavioural dynamics: An agent-based model for water quality management using the theory of planned behaviour

As being a computer-based simulation method, ABM was first introduced to water resources management by the work of a few pioneering researchers, including Tillman et al. (1999, 2001), Berger (2001), Le Bars & Attonaty (2001a, 2001b), and Pahl-Wostl (2002). Tillman et al. investigated the interactions among actors in water supply systems using ABM and introduced the agent-based participatory simulation term by analyzing stakeholder interactions in water utilities (Tillman et al., 1999; 2001). Berger (2001) introduced the "cellular automata" phenomenon to agricultural economic models. Pahl-Wostl (2002) described ABM as promising new developments to explore changes toward sustainability by pointing out that ABM does not disregard "complexity", "indeterminacy", and the "human dimensions".

As a main contribution of ABM, social aspects of water resources management were studied by many researchers, including Lopez-Parades et al. (2005), Rixon et al. (2007), Schroeder et al. (2009), and Smajgl et al. (2009).

The domain-specific modeling frameworks for water resources management also came into existence in the early 2000s. Becu et al. (2003) introduced CATCHSCAPE as a multi-agent system that simulates catchment features and farmers' decisions. Athanasiadis et al. (2005) presented DAWN as a hybrid model for evaluating water-pricing policies. Barthel et al. (2005) introduced the decision support tool DANUBIA for investigating the effects of climate change on the water cycle of a river basin. Barreteau et al. (2007) focused on the similarity of role-playing games (RPG) and ABM, testing their synergy via their PIEPLUE tool. Janssen (2007) argued the possibility of generalizing the success of "The Lansing-Kremer Model" in explaining the emergent interactions of a Balinese self-governing irrigation system. Saqalli et al. (2010) proposed a decision support tool named MAELIA. Jimenez et al. (2021) presented an Irrigation Agent-Based Model (IABM) for water distribution in an irrigation district. Noel & Cai (2017), Ding et al. (2021) developed ABM models of coupled human nature and nature systems (CHANS).

The conservation of water resources was also subjected to research at early stages. Mohring & Troitzsch (2001) replicated the experiments of Jay M. Anderson on a hypothetical lake, in which eutrophication by the discharge of fertilizers was studied. The idea of multi-agent simulation for water quality monitoring and control was introduced by Nichita & Oprea (2007).

Galan et al. (2009) combined social models, urban dynamics, and technological opinion diffusion with geographical information systems (GIS). Wise & Crooks (2012) implemented another GIS on complex irrigation systems called "acequia", in which ABM was used to represent interactions among actors. Akhbari & Grigg (2013) implemented an ABM that simulates the interactions among parties in a conflict scenario.

The 2010s were a period in which the economic aspects of the use of ABM in WRM were explored. Nguyen et al. (2013) examined the efficiency of water quality trading scenarios by ABM. Zhang et al. (2013) proposed a zonal-based trading ratios system to improve the cost-efficiency of the water quality trading system via an application of ABM. Iftekhar et al. (2013) studied the role of "market competition" in water buyback auctions using ABM. Zhao et al. (2013) compared the market-based water allocation systems to administered ones via ABM.

Water demand management was another research subject that emerged as a consequence of research on the human aspects of water supply management. Yuan et al. (2014) developed an ABM, "household water demand prediction model" to predict household water demand. Ponte et al. (2015) developed an ABM based prediction system for water demand forecasting. Al-Amin et al. (2015) analyzed the interactions of changing water demands and limited groundwater resources, Al-Amin et al. (2016) coupled an ABM and a groundwater model to simulate water demands under uncertainties, and Al-Amin et al. (2018) developed an ABM framework to capture the interactions of consumers and policy-makers. Murphy et al. (2015) presented a simulation framework in which the hydrological Water Balance Model (WBM) was linked to an ABM. Koutiva & Makropoulos (2016) studied the domestic water users' behavior in response to water demand management measures, using ABM, and they used an ABM tool named "Urban Water Agents' Behavior" tool (Koutiva & Makropoulos, 2019). Xiao et al. (2018a) proposed ABM approach to assess water demand management in a river basin, and they explored the centralized and decentralized procedures to assess the impact of water demand on a water supply system (2018b). Bakhtiari et al. (2019) developed a coupled risk-based ABM optimization model, which could account for water resources capacity and water demand uncertainties to determine the annual water allocation. Huber et al. (2021) applied the ABM of water supply and demand model Aqua.MORE.

Agriculture and irrigation management are among the most prominent topics of ABM applications in every period. Many scholars such as Barreteau et al., Janssen, Isern et al., Belaqziz et al., Noel & Cai, Anthony & Birendra, Mewes & Schumann, Jimenez et al., and Bahrami et al. studied the use of ABM for agriculture or irrigation management. Barreteau et al. (2004) studied the longevity of irrigation systems by describing them as a multi-agent system (MAS) virtual laboratory. Isern et al. (2012) presented a knowledge-based and distributed framework that simulates the behavior of an irrigation system. Anthony & Birendra (2018) proposed an ABM that could be used to prioritize irrigation allocation for different crops on a farm. Mewes & Schumann (2019) enhanced an ABM irrigation planning model with a machine learning-based training component. Bahrami et al. (2022) simulated the farmers' behavior toward changing cropping patterns and adaptation to new irrigation technology using the ABM framework. Jimenez et al. (2022) presented an internet of things (IoT) multi-agent irrigation approach for improving water use efficiency in irrigation systems.

The up-to-date research context on the use of the ABM method in WRM consists of interdisciplinary applications, both technically and thematically. In a technical manner, coupling ABM with another modeling or analysis approach offers many opportunities to discover and explain coupled human-nature systems. The ABM was coupled with many other methodologies such as "evolutionary computation based multi-objective methodology" (Kanta & Berglund, 2015), and "Urban Water Optioneering Tool" (Koutiva & Makropoulos, 2016), a groundwater model (Al-Amin et al., 2016; Noel & Cai, 2017; Al-Amin et al., 2018), a variable-length genetic algorithm (Shafiee, 2016), a hydrologic model (Giri et al., 2018), a Model of Nitrogen and Carbon Dynamics in Agro-ecosystems (MONICA) (Hampf et al., 2018), system dynamics models (Wang et al., 2018), a river-routing and reservoir management model (RiverWare) (Hyun et al., 2019), land use and phosphorus load accumulation models (Bitterman & Koliba, 2020), social, economic, and hydrological sub-models (Zolfagharipoor et al., 2021), a hydraulic model of a pipe network (Strickling et al., 2021), and a physically-based hydrological model (Du et al., 2022).

Discussion and Conclusion

This research composed the general view of ABM practices in WRM. We followed a modified version of the systematic review approach, adapting the method to the requirements of the research subject.

Our results suggested that the use of ABM approach in WRM has increased and expanded since 1999. Contributions came from a broad coverage of scientific research, including social and natural sciences. One or more publications appear almost every year, including journal articles, conference papers, and book chapters. However, starting from 2012, the numbers and diversity of the scientific publications have been broadened. The related publications were mostly published in between 2018 and 2019. In line with the historical development of the subject, we might say that the initial status of papers was composed of perspective papers, which the probability of using ABM in WRM was suggested. We observed that the researchs with case studies have steadily increased since the 2010s. The current trend shows that the numbers of interdisciplinary and systems approach-based research are increasing along with field studies. For instance, the interdependency of critical infrastructures such as logistics, water supply, and energy distribution systems are among the current research topics.

As a reflection of the field's interdisciplinary nature, publications appeared to come from a wide variety of publishers. Most of the publications belonged to research areas such as "environmental sciences", "ecology", "water resources", "engineering", "computer science", "geology", "mathematics", "agriculture", and "social sciences". The distribution of publications also showed the diversified and interdisciplinary nature of the research subject. Almost half of the publications appeared in 50 different journals with only one article. The top journals including "Environmental Modelling & Software", "Sustainable Cities and Society", "Agricultural Water Management", "Journal of Hydrology", "Water", "Agricultural Systems", "Water Resources Management", "Journal of Environmental Management", "Ecological Modelling", "Journal of Water Resources Planning and Management", "Science of Total Environment", and "Water Resources Research" published less than half of the related papers.

The broad geographical distribution of field studies shows that ABM methodology was applied to WRM researchs worldwide. The application scale of the studies was also diversified, ranging from water supply and distribution systems to irrigation regions, lakes, groundwaters, watersheds, and river basins. The top applications of 42 case studies came from USA, Iran, and China. Another notable point is that 10 of the proposed methodologies were examined in hypothetical or virtual environments, resulting from the flexibility of the ABM approach.

Technical aspects of the ABM approach were evaluated by software use of articles and supplements provided. Among 128 papers, 50 were related to software use, but no further information was offered via text or supplements. Since various computer programming languages or software packages are used to implement ABM, the diversity of used software was also broadened. Used software packages include NetLogo, AnyLogic, MASON, Repast Symphony, CORMAS, DynaMind, and Envision. And programming languages include Java, Python, web programming languages, Julia, and C++. 19 of the papers offered project-based software implementation or did not explicitly state the name of the software or programming language. 42 of the articles provided supplements, including “Overview, Design concepts, and Details” (ODD) documents, an explanation of methodology, or similar documents. Some of the articles systematically noted the software availability resulting from the publisher’s obligation. However, a few articles offered the software to replicate the results via working download links. That means there is still a significant gap in providing the required information to replicate results or any other scientific benefit.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Su Kaynakları Yönetiminde Etmen Tabanlı Yaklaşım; Uyarlanmış Sistematik Derleme

Bu araştırmada, su kaynakları yönetiminde Etmen Tabanlı Modelleme (ETM) uygulamalarının genel görünümü oluşturulmuştur. Araştırma yöntemi, sistematik derleme yaklaşımının araştırma konusunun gereklilikleri doğrultusunda uyarlanmış bir versiyonudur. Sonuçlar, su kaynakları yönetiminde ABM yaklaşımının 1999'dan günümüze genişleyen bir kapsama sahip olduğunu göstermektedir. Yayınlar, fen bilimleri ve sosyal bilimleri kapsayan geniş bir bilimsel literatürden derlenmiştir. Literatürde 1999 yılından günümüze hemen hemen her yıl su kaynaklarının yönetiminde ABM yaklaşımının araştırıldığı dergi makaleleri, konferans bildirileri ve kitap bölümleri ile karşılaşılabilmektedir. Ancak 2012 yılından itibaren yayınların sayısı ve çeşitliliği artmıştır. 2018 ve 2019 yılları ise ilgili yayınlara yönelik en yoğun dönemi teşkil etmektedir. Konunun tarihsel gelişimine paralel olarak, yayınların başlangıçta su kaynakları yönetiminde ABM kullanımına yönelik perspektif görüş bildiren makalelerden ibaretken, uygulamayı içeren çalışmaların 2010'lu yıllardan itibaren arttığı gözlemlenmiştir. Mevcut eğilim, saha çalışmalarıyla birlikte sistem yaklaşımı esaslı disiplinlerarası araştırmaların arttığını göstermektedir. Örneğin lojistik, su temini ve enerji dağıtım sistemleri gibi kritik altyapıların birbirine bağımlılığı güncel araştırma konuları arasındadır.

Bir bilgisayar temelli simülasyon yöntemi olarak ETM'nin su kaynakları yönetimi araştırmalarında kullanılması Tillman ve ark. (1999, 2001), Berger (2001), Le Bars ve Attonaty (2001a, 2001b), ve Pahl-Wostl (2002) gibi araştırmacılar tarafından gerçekleştirilen öncü nitelikteki araştırma ile gerçekleşmiştir. Tillman ve ark. geliştirdikleri etmen tabanlı katılımcı simülasyon uygulamasıyla su şebekeleri ve temin sistemlerindeki aktörlerin etkileşimlerini araştırmışlardır (Tillman ve ark., 1999; 2001). Berger (2001) tarafından "hücresel otomatlar" tarımsal ekonomik modellere uygulanmıştır. Pahl-Wostl (2002) ETM'nin su kaynaklarının "karmaşıklık", "belirsizlik" ve "insanla ilişkili boyutlarını" ihmal etmeyen bir yöntem olduğuna işaret ederek, sürdürülebilirlik araştırmalarında ETM'nin gelecek vaad eden bir yöntem olarak tanımlamıştır. ETM yönteminin temel bir özelliği olarak su kaynakları yönetiminin "toplumsal boyutları" Lopez-Parades ve ark. (2005), Rixon ve ark. (2007), Schroeder ve ark. (2009), ve Smajgl ve ark. (2009) gibi bir çok araştırmacı tarafından araştırılmıştır. 2000'li yılların başlarından itibaren, su kaynakları yönetimi araştırmalarına özgü pek çok modelleme çerçevesinin de oluşturulduğu görülmektedir. Becu ve ark. (2013) tarımsal su havzalarının özellikleri ve çiftçi davranışının modellendiği CATCHSCAPE isimli çoklu etmen modelini geliştirmişlerdir. Athanasiadis ve ark. (2005) su fiyatlandırma politikalarının değerlendirildiği DAWN hibrit modelini geliştirmişlerdir. Barthel ve ark. (2005) nehir havzalarındaki iklim değişikliği etkilerinin araştırılması konusunda DANUBIA isimli karar destek sistemini geliştirmişlerdir. Barreteau ve ark. (2007) bilgisayar oyunları ile ETM arasındaki benzerliklere odaklanarak, PIEPLUE isimli araçla ikisi arasındaki sinerjiyi test etmişlerdir. Janssen (2007) "Lansing-Kremer" modelinin, Bali adasındaki öz-yönetimli sulama sisteminin etkileşimlerini açıklamadaki başarısının genelleştirilmesini ele almıştır. Saqalli ve ark. (2010) MAELIA isimli bir karar destek sistemi, Jimenez ve ark. (2021) bir sulama bölgesindeki su dağıtımı için etmen tabanlı bir sulama modeli (IABM) geliştirmiştir. Noel ve Cai (2017) ile Ding ve ark. (2021) insan-doğa sistemleri için etmen tabanlı modeller geliştirmişlerdir.

Su kaynaklarının korunması da erken dönem uygulamaları arasında yer almaktadır. Mohring ve Troitzsch (2001) Jay M. Anderson'un göllerdeki ötrofikasyon durumuna ilişkin araştırmasının bir replikasyonunu ABM kullanarak gerçekleştirmişlerdir. Nichita ve Oprea (2007) su kalitesi kontrolünde çoklu etmen tabanlı simülasyon uygulaması gerçekleştirmişlerdir. Galan ve ark. (2009) sosyal modeller, kent dinamikleri ve teknolojik yeniliklerin yayılması konusunu, coğrafi bilgi sistemleri ile bir araya getirmişlerdir. Wise ve Crooks (2012) "acequia" isimli kompleks sulama sistemlerindeki aktörler arasındaki etkileşimleri temsil eden bir ETM geliştirmişlerdir. Akhbari ve Grigg (2013) su havzalarındaki farklı aktörler arasındaki etkileşimleri ETM yöntemiyle modellemişlerdir.

Su talebinin yönetimi, ETM'nin su kaynakları yönetimindeki uygulamalarından bir diğerine örnek teşkil etmektedir. Yuan ve ark. (2014), Ponte ve ark. (2015) hane halkı su talebinin tahminine ilişkin bir ETM geliştirmiştir. Al-Amin ve ark. kısıtlı yeraltı suyu rezervleri ve değişen su talepleri arasındaki etkileşimleri analiz etmiş, belirsizlik durumlarındaki su taleplerinin simülasyonuna yönelik bir eşlenik ETM ve yeraltı suyu modeli geliştirmiş ve politika geliştiriciler ve tüketiciler arasındaki etkileşimleri konu edinen ETM geliştirmiştir (Al-Amin ve ark., 2015; Al-Amin ve ark., 2016; Al-Amin ve ark., 2018). Murphy ve ark. (2015) hidrolojik su dengesi modeli (WBM) ile ETM'nin ilişkilendirildiği bir simülasyon çerçevesi oluşturmuşlardır. Koutiva ve Makropoulos (2016) evsel su kullanıcılarının yönetimsel tedbirler karşısındaki davranışlarının incelendiği "Urban Water Agents' Behavior" isimli bir ETM geliştirmişlerdir. Xiao ve ark. bir nehir havzasındaki su talebinin değerlendirilmesi konusunda ETM yaklaşımını önererek, dağıtık ve merkezi süreçlerin su talebi üzerindeki etkilerini değerlendirmişlerdir (Xiao ve ark. 2018a; 2018b).

Bakhtiari ve ark. (2019) su kaynaklarının kapasitesi ve su talebindeki belirsizliklerin göz önünde bulundurulduğu bir "yıllık su tahsis modeli" geliştirmişlerdir. Huber ve ark. (2021) su temini ve talep modeli olarak Aqua.MORE isimli modeli geliştirmiştir.

Tarımsal sulama yönetimi, ETM metodunun su kaynakları araştırmalarına uygulanması konusundaki en yaygın konuların başında gelmektedir. Barreteau ve ark. (2004), Janssen (2007), Isern ve ark. (2012), Belaqziz ve ark. , Noel ve Cai, Anthony ve Birendra (2018), Mewes ve Schumann, Jimenez ve ark., ve Bahrami ve ark. gibi pek çok araştırmacı, ETM'nin tarımsal sulama alanına uygulanması konusunda araştırmalar gerçekleştirmiştir.

Alanın disiplinlerarası doğasının bir yansıması olarak, makalelerin yarısından fazla bir bölümünün birbirinden farklı 50 dergide yayımlandığı görülmektedir. Geriye kalan kısmının "Environmental Modeling & Software", "Sustainable Cities & Society", "Agricultural Water Management", "Journal of Hydrology", "Water", "Agricultural Systems", "Water Resources Management", "Journal of Environmental Management", "Ecologic Modelling", "Journal of Water Resources Planning and Management", "Total Environment" ve "Water Resource Research" gibi önde gelen dergilerde yayımlandığı görülmektedir.

Saha çalışmalarının geniş coğrafi dağılımı, ABM metodolojisinin dünya çapında su kaynakları yönetimi araştırmalarına uygulandığını göstermektedir. Çalışmaların uygulama ölçeği de su temin ve dağıtım sistemlerinden sulama bölgelerine, göllere, yeraltı sularına, tarımsal havzalar ve nehir havzalarına uzanan bir kapsamda değişim göstermektedir. Öncü nitelikteki 42 vaka çalışması ABD, İran ve Çin'de gerçekleştirilmiştir. Dikkat çeken bir diğer nokta ise 10'dan fazla vaka çalışmasının, ABM yaklaşımının bir esnekliği olan varsayımsal veya sanal (hypothetical/virtual) ortamlar kullanılarak gerçekleştirilmiş olmasıdır.

ABM uygulaması için bir çok bilgisayar programlama dili ve paket yazılımlar kullanılabilmektedir. Bu nedenle literatürdeki uygulamaların da bu anlamda çeşitlendiği görülmektedir. NetLogo, AnyLogic, MASON, Repast Symphony, CORMAS, DynaMind ve Envision önde gelen paket yazılımlardır. Java, Python, web programlama dilleri, Julia ve C++ ise bu konuda kullanılan bilgisayar programlama dilleri arasında yer almaktadır. Bildirilerin 19'u proje tabanlı yazılım uygulaması sunmuş veya yazılımın veya programlama dilinin adını açıkça belirtmemiştir. 42 makalede, “Overview, Design concepts, and Details” (ODD) belgeleri, metodoloji açıklaması veya benzer belgeleri kapsayan ekler sunulmuştur. Bazı makalelerde sistematik biçimde araştırmada kullanılan yazılım bilgilerine yer verildiği görülmektedir. Bununla birlikte, sadece birkaç makalede, bulguların replikasyonu konusunda kullanılabilecek şekilde açık kaynak paylaşım siteleri üzerinden yazılımların okuyucuya sunulduğu görülmektedir. Bu durum, araştırmaların replikasyonu veya diğer herhangi bir bilimsel katkının sunulması için gerekli verilerin/bilgilerin eser sahiplerince açık biçimde paylaşılması konusunda hala önemli eksiklikler olduğu şeklinde değerlendirilmektedir.

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Research Article

Flood Social Vulnerability Assessment: A Case Study of Türkiye

Türkiye Örneği Özelinde Taşkın Sosyal Etkilenebilirlik Analizi

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Abstract

Among all natural disasters, floods are the most frequent and destructive one by far. Assessment of drivers and quantification of flood risk are crucial for humanity preventing its massive consequences. It is required to combine social and biophysical components of the flood risk so that it is comprehensively evaluated. In this study, Social Vulnerability Index, which assesses the adaptability and sensitivity of population to any hazard, were applied in Türkiye. 9 different parameters were used as a vulnerability indicator based on literature review and data availability. 13 cities were identified as highly and very highly vulnerable. Flood frequencies were determined by numbers of flood events occurred among 1960-2021 in each city. Only 3 of 13 cities (Ordu, Kütahya and Sinop) had the highest Flood Social Vulnerability levels as a result of the combination with Flood Frequency Index. The Flood Social Vulnerability Index analysis showed that only the social dimension of the risk is not enough to evaluate risk itself since the biophysical dimension defines the probability of any disaster to happen. The method utilized in this study can be an effective tool for decision-makers to allocate aids to improve flood preparedness over the country.

Keywords: *flood vulnerability, social vulnerability, flood frequency, flood social vulnerability index*

Öz

Doğal afetler düşünüldüğünde, taşkınlar en sık karşılaşılan ve de en fazla hasara sebep olanlar arasında yer almaktadır. Taşkın riskini oluşturan bileşenlerin değerlendirilmesi ve riskin sayısallaştırılması, bu risk gerçekleştiğinde karşılaşılması beklenen büyük boyutlu etkilerden korunmak için önemlidir. Taşkın riskini kapsamlı bir şekilde değerlendirebilmek için riskin sosyal ve biyofiziksel katmanlarının birlikte ele alınması gerekmektedir. Bu çalışmada, toplumun herhangi bir dış baskı faktörüne karşı adaptasyon yeteneğini ve duyarlılığını ölçen Sosyal Etkilenebilirlik Endeksi, tüm Türkiye genelinde il bazında değerlendirilmiştir. Literatür taraması ve veri ulaşılabilirliği göz önüne alınarak 9 farklı etkilenebilirlik parametresi belirlenmiştir. Sosyal Etkilenebilirlik Endeksi analizi sonucunda 13 şehir yüksek ve çok yüksek derecede etkilenebilir olarak nitelendirilmiştir. 1960 ve 2021 yılları arasındaki tarihi taşkınlar il bazında analiz edilmiştir. Sosyal Etkilenebilirlik Analizi ve tarihi taşkınların değerlendirilmesi sonucunda bu 13 şehirden yalnızca 3'ü (Ordu, Kütahya ve Sinop) Taşkın Sosyal Etkilenebilirlik Endeksi'nde en yüksek dereceyi almıştır. Bu Taşkın Sosyal Etkilenebilirlik Endeksi

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analizi sonuçları yalnızca riskin sosyal veya biyofiziksel katmanlarının yeterli olmadığı, riskin kapsamlı şekilde ifade edilebilmesi için bu iki katmanın birlikte değerlendirilmesi gerektiğini ortaya koymuştur. Bu çalışmada uygulanan ve önerilen yöntem karar vericiler için kullanışlı bir metod olmakla beraber tüm Türkiye'deki taşkın hazırlık yetkinliğini arttırmada rol oynayabilecektir.

Anahtar sözcükler: *taşkın etkilenebilirlik, sosyal etkilenebilirlik, taşkın sıklığı, taşkın sosyal etkilenebilirlik analizi*

Introduction

Floods are one of the most frequent and destructive type of natural disaster (Hirabayashi et al., 2013; Tanir et al., 2021). Population increase and economic growth in flood-prone areas are considered the main reasons for the destruction (Rufat & Botzen, 2022). It is estimated that flood frequency and population exposure to flood events are going to increase because of rapid urbanization, deforestation, and climate change (Hirabayashi et al., 2013; Nasiri et al., 2016). The quantification of flood risk is one of the challenges in the process of flood management for decision-makers (Ranger et al., 2011). Therefore, flood risk assessment, which is defined as a methodology to quantitatively assess flood risk, becomes very crucial in managing mitigation and adaptation efforts (Díez-Herrero & Garrote, 2020). Two main components of flood risk have been identified as flood hazard and flood vulnerability (Lugeri et al., 2010; Mohanty et al., 2020; Tascón-González et al., 2020; Tate et. al, 2021). The magnitude of the flood hazard depends on several characteristics of events such as intensity, duration, and timing phase (United Nations International Strategy for Disaster Reduction [UNISDR], 2017). Additionally, the characteristics of the basin such as slope, vegetation, and soil type also determine the severity of flood hazards (Taghavi et al., 2011).

Vulnerability is defined as a "measure of how a system is sensitive, susceptive, and adaptive to any hazard" (Munyai et al., 2019). Flood vulnerability is a quantification of how people, societies, or any kind of system will be affected by any flood events (Munyai et al., 2019; Tanir et al., 2021a; Zahran et al., 2008). By comparing the vulnerability levels of different societies, sensitivity and adaptive capacity of a society to flood hazards are also evaluated (Munyai et al., 2019). According to the literature on vulnerability assessment, the higher socially vulnerable populations leads lower levels of disaster preparedness (Zahran et al., 2008). Knowing the location of the vulnerable population, which are considered as the people that will be affected more than the rest of the population, enable that decision-makers allocate resources more efficiently in flood mitigation efforts and improve the overall flood preparedness level of the society (Chen et al., 2019).

There are numerous studies evaluating the spatial distribution of social vulnerability of people over regions. The most important studies are conducted in United States (Cutter et al., 2003), Southern Italy (Masia et al., 2018), Norway (Holand et al., 2011), and Zimbabwe (Mavhura et al., 2017). In addition, some researchers have studied the combined risk by merging social vulnerability with flood hazard/exposure in Greece (Karagiorgos et al., 2016), Germany (Fekete, 2009), Bangladesh (Hoque et al., 2019), Vila Nova de Gaia/ Portugal (Fernandez et al., 2016), and Hainan Region of China (Yang et al., 2018). To the best of our knowledge, there is no study assessing social vulnerability to floods, by considering both physical and social dimensions of flood risk, over the entire Türkiye. However, Social Vulnerability Index (SOVI) are used in various studies such as fisheries (Gómez Murciano et al., 2021). Also, the vulnerabilities for specific natural hazards in smaller areas are studied in the literature. Duzgun et al. (2011) assessed integrated earthquake vulnerability in Odunpazarı district (Eskişehir), while Yücel and Arun (2010) investigated social vulnerability to earthquake over Avcilar Region in Istanbul. In addition, urban flash flood vulnerability is conducted in Ayamama River, İstanbul to identify adaptation strategies (Reyes-Acevedo et al., 2011).

Therefore, our study aims to quantify both SOVI and Flood Frequency Index (FFI) over Türkiye and combine them to evaluate Flood Socio-Economic Vulnerability Index (FSOVI). By comparing all indexes, locations with higher vulnerability, flood frequency and combination of both of them are highlighted. Identification of those highlighted areas may help decision-makers to allocate resources for improving flood preparedness.

Material and Method

Study Area

Türkiye which covers an area of approximately 780,580 km^2 is located between 36-42 north latitude and 26-45 east longitude. 107 main rivers which have an area of nearly 1500 km^2, drain to Türkiye. The rivers of Kızılırmak, Yeşilırmak, Fırat, Dicle, Aras, Ceyhan, Seyhan, and Çoruh are some of the longest rivers (Akbulut et al., 2022). Total 3973 flood events with different drivers have been recorded in Türkiye since 1960 (General Directorate of State Hydraulic Works [DSİ], 2022). The spatial distribution of those flood events is demonstrated in Figure 7.

Türkiye is divided into 81 cities and 7 geographical regions which contains cities with similar demographics, economic activities, and geographic features. According to the survey of Address Based Population Registration System, 2021, 84,6 million people are living in Türkiye (Turkish Statistical Institute [TUIK], 2022). İstanbul, Ankara, and İzmir are the most populated cities in Türkiye.

Flood impacts are observed almost everywhere in Türkiye. The spatial characteristics of population distribution, socio-economic status, and demographics are non-homogenous over the country. Thus, it is required to assess the vulnerability to flood hazards in the cities.

Methods

Flood socioeconomic vulnerability was assessed by combining the SOVI and FFI (Tanir et al., 2021; Tanir et al., 2021b). While combining them, new index values are determined by considering the value of SOVI and FFI. Both SOVI and FFI were quantified at the city scale in Türkiye. Therefore, combined FSOVI was also evaluated at the city scale.

In our study, SOVI was performed with the hazard of place approach (Cutter et al., 2003; Cutter et al., 2012) which enables researchers to combine biophysical, social, and socioeconomic parameters to evaluate vulnerability levels of geographic locations (Fernandez et al., 2016; Khajehei et al., 2020; Tanir et al., 2021a). A variety of vulnerability parameters have been used on the characteristics of the studied area (Roder et al., 2017).

The parameters used for the definition of overall social vulnerability and their correlations with overall vulnerability are listed in Table 1. The representativeness of vulnerability parameters to the study area, accessibility of data should be considered while defining vulnerability variables for vulnerability assessments (Roder et al., 2017). Therefore, parameter selection for vulnerability definition was made by considering the accessibility of the data for each province and the frequency of appearance of those parameters in the relevant literature for this study. All data were obtained from dataset 2020 of TUIK.

Populations with a higher portion of females, elder people, and illiterate people are more likely to be affected by any hazard (Bolin & Bolton, 1986; Chakraborty et al., 2020; Cutter et al., 2003; Fernandez et al., 2016; Khajehei et al., 2020; Medina et al., 2020; Roncancio & Nardocci, 2016; St. Cyr, 2005; Tanir et al., 2021a). In addition, the less accessible health service reduces the adaptive capacity of a population to any hazard (Santos et al., 2018; Zhang & Huang, 2013). Also, more densely populated regions tend to have higher vulnerability levels (Mansur et al., 2016; Zahran et al., 2008)

Table 1

Social Vulnerability Parameters and Correlation with Vulnerability

Parameters	Correlation with Vulnerability
Number of doctors per thousand People	Negative
Percentage of Female	Positive
Percentage of Elder Dependency	Positive
Percentage of Illiterate People	Positive
Average Household Size	Positive
Numbers of Hospital	Negative
Gross Domestic Product (GSYH)	Negative
Population Density	Positive
Flood Protection	Negative

Principal Component Analysis (PCA), which is a well-known factor analysis method to aim reduce the number of parameters by optimizing the storage of information in the dataset (Absonet al., 2012; Chakraborty et al., 2020; Cutter & Finch, 2018; Khajehei et al., 2020; Mohanty et al., 2020; Tanir et al., 2021a), was applied in this study. As the PCA procedure was used to decrease the number of parameters and combine them with weights without losing too much information (Kong et al., 2017).

Before using PCA procedure, correlation and their trends depending on overall vulnerability were analyzed. The normalization procedure was applied so that the data with different units could be used in the analysis. The incommensurability problem of using data with different units has been solved by that linear transformation which maintains the correlation structure of original data (Abson et al., 2012; Kong et al., 2017). There are several normalization methods such as maximum-minimum normalization, z-score normalization, distance to target, and ranking-based normalization (Moreira et al., 2021). However, according to Moreira et al. (2021), there is a low sensitivity regarding the normalization methods in flood vulnerability assessments. One of the most widely used method: Maximum-minimum normalization method (Chakraborty et al., 2020; Tanir et al., 2021a) was applied in this study. This method compresses the data between the maximum and minimum values by following the equation below (Eqn.1).

$$P_{normalized} = (P_{actual} - P_{min})/(P_{maximum} - P_{minimum}) \quad \text{(Eqn. 1)}$$

After the application of this method, the highest value in the dataset was represented as 1 while the lowest was 0.

There are some statistical tests, such as Bartlett's Test of Sphericity and Kaiser-Meyer Olkin's (KMO) measure of sampling adequacy, that are prior to PCA procedure to check whether data is appropriate for PCA or not (Chakraborty et al., 2020; Gu et al., 2018; Monterroso et al., 2014). After conducting normalization procedure, both of the tests were applied to the dataset and these tests were successful. Then, the PCA procedure was applied. The positively and negatively correlated parameters with social vulnerability were combined individually (Eqn. 2, Eqn. 3, and Eqn. 4). Visual assessment method by the scree plot was utilized to determine the number of principal components (Chakraborty et al., 2020). The number of components is needed to be optimized to explain maximum information by using fewer principal components (Tanir et al., 2021a).

$$SOVI_{(+)} = (\text{Weight of } PCA_{1+} * PCA_{1+}) + \ldots (\text{Weight of } PCA_{5+} * PCA5_{+}) \quad \text{(Eqn. 2)}$$

$$SOVI_{(-)} = (\text{Weight of } PCA_{1-} * PCA_{1-}) + \ldots (\text{Weight of } PCA_{5-} * PCA_{5-}) \quad \text{(Eqn. 3)}$$

$$\text{Overall } SOVI = SOVI_{(+)} - SOVI_{(-)} \quad \text{(Eqn. 4)}$$

After calculating all negative and positive SOVI values, the maximum-minimum normalization process was reapplied for being able to compare all results. As a result, all cities had a vulnerability index value between 0 and 1. The breakdown and distribution of those vulnerability values are demonstrated with the Natural Jenks method by using ArcGIS.

Historical flood data from the General Directorate of State Hydraulic Works (DSI) were used for the flood frequency analysis. The number of historical floods experienced among 1960-2021 were subjected to a normalization procedure so that the results of SOVI and FFI could be combined. Similar to SOVI, the Natural Jenks method was utilized in order to demonstrate spatial distribution of flood hazards on a map. Therefore, each city had a vulnerability value as well as a flood frequency value which defines the likelihood of flood hazard to happen.

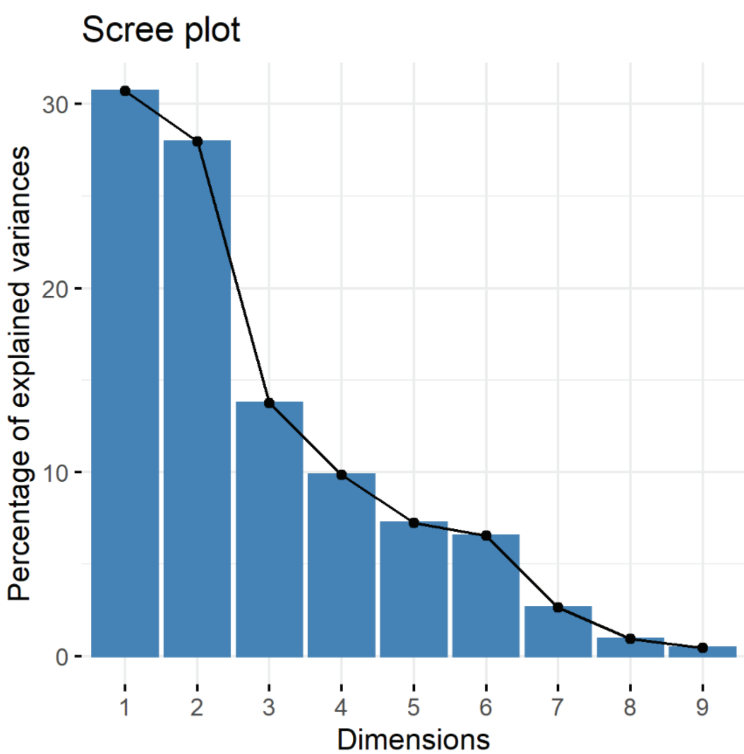
Then, normalized SOVI and FFI values were merged together to define Flood Social Vulnerability Index (FSOVI). Very low and low SOVI and FFI values were expressed as low FSOVI values. The ones at medium level in both indexes were also indicated as a medium in FSOVI while high and very high ones were considered as high value for FSOVI. Finally, all results were interpreted spatially.

Results

89% of the total information of the database was explained with 5 principal components by using visual assessment of the scree plot after PCA. It is stated that saving at least 70% of total information is acceptable in studies that use PCA as factor analysis (Fekete, 2009; Ganguly et al., 2019; Roder et al., 2017; Tanir et al., 2021a). Thus, amount of information stored in principal components is consistent with the literature. As seen in Figure 1, the percentage of explained variances is significantly higher in the first two dimensions. The percentage of explained variances falls below 10% after the 4th dimension.

Figure 1

Scree Plot (Percentage of Explained Variances)



Correlation analyses were conducted before PCA. Figure 2 illustrates that which parameters are correlated with each other and how they are correlated. The color states relation of those parameters with each other. For instance, household size and elder dependency are negatively and highly correlated (Figure 2). In addition, Gross

Domestic Product (GDP) and population density are positively correlated. Highly correlated parameters were reviewed separately in order to observe a relation between each other in Figure 3 and Figure 4.

As two of the highly correlated parameters, the relationship between household size and elder dependency is demonstrated in Figure 3. A major negative correlation is found between those variables.

Figure 2

Correlation of Vulnerability Parameters with Each Other

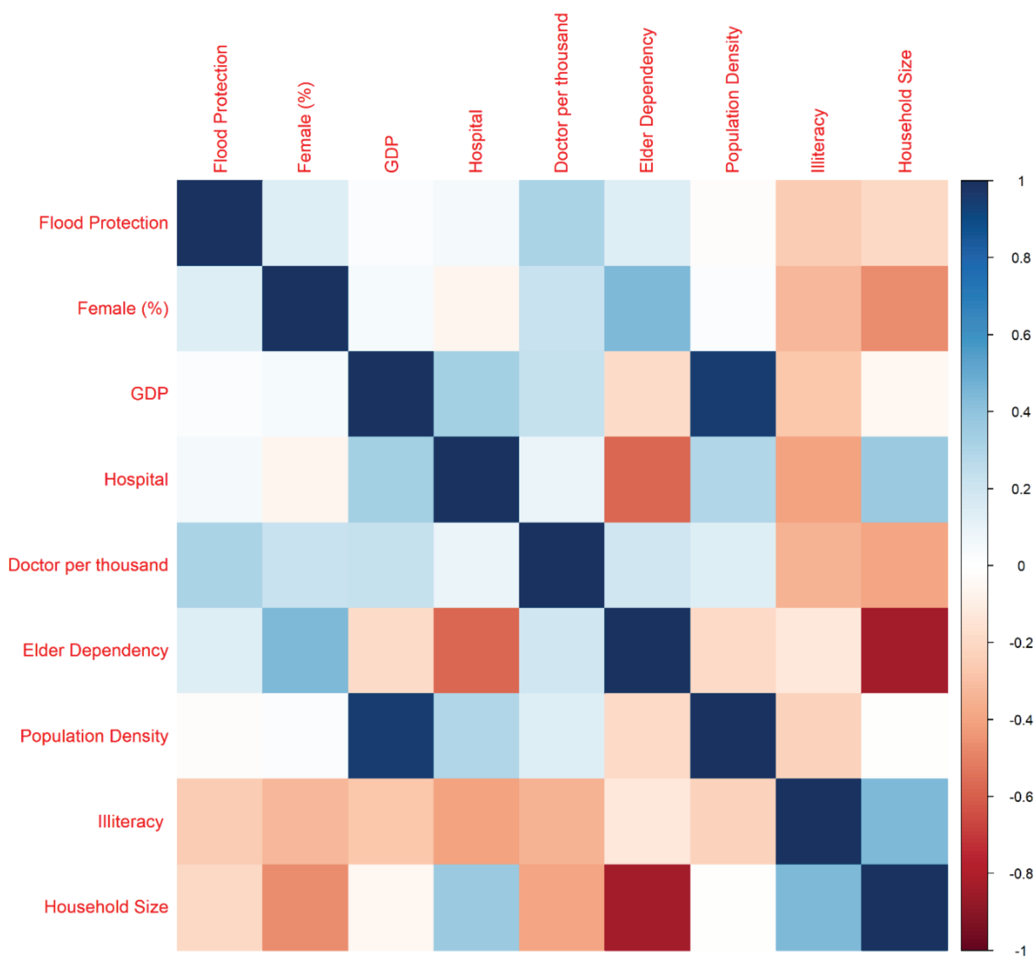


Figure 3

Correlation between Household Size and Elder Dependency

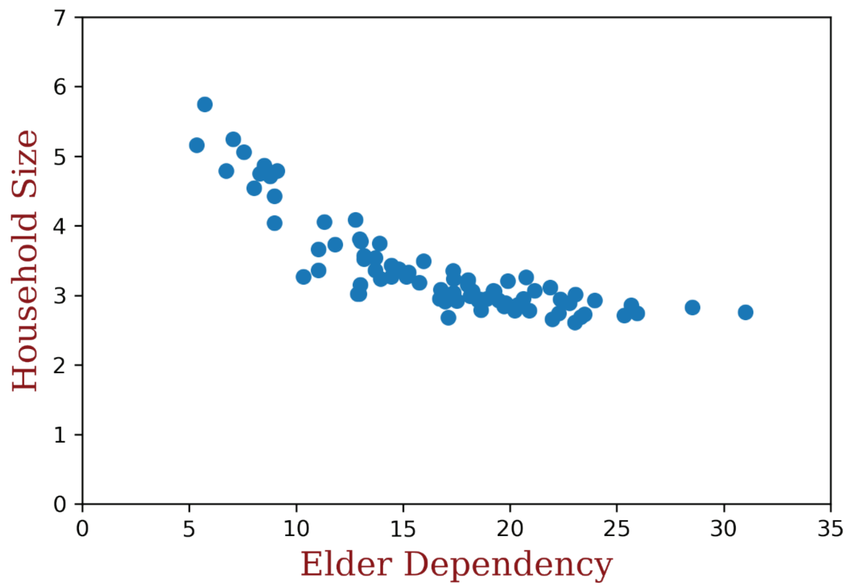
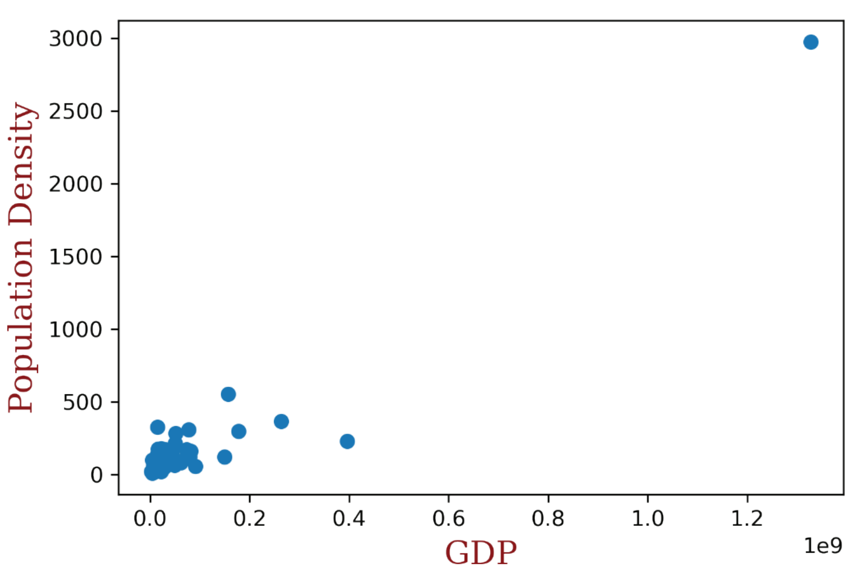


Figure 4

Correlation between Population Density and GDP



Unlike the correlation between household size and elder dependency, the correlation between the population density and GDP is strongly positive (Figure 4). It can be seen that one data point is separated from the rest of the distribution. That data point indicates Istanbul, which is the most crowded city with the highest GDP by far, was not considered as an outlier.

Figure 5 indicates that which parameters have more contribution to the expression of which dimension. The size of the circle shows how each parameter correlated are, while the color states relation of those parameters with each other. For instance, elder dependency, percentage of female population, and household size are the main parameters that explain dimension 1, while GDP and population density contribute more for dimension 2. For the rest of the dimensions, the contribution of parameters to them is distributed more homogeneously.

Figure 5

Correlation of Parameters for Dimensions

Each city was numbered based on the car number plates to facilitate interpretation of the spatial distribution of the SOVI results (Table 2).

Table 2

Car Number Plates of Cities in Türkiye

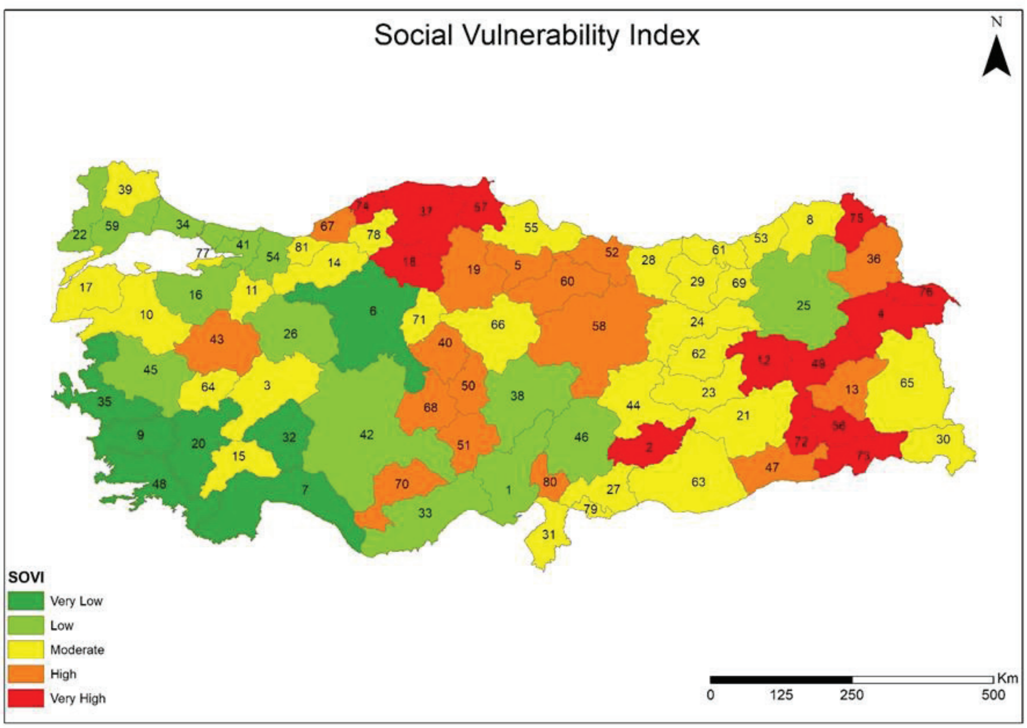
City	No:	City	No	City	No	City	No
Adana	1	Diyarbakır	21	Kocaeli	41	Trabzon	61
Adıyaman	2	Edirne	22	Konya	42	Tunceli	62
Afyon	3	Elazığ	23	Kütahya	43	Urfa	63
Ağrı	4	Erzincan	24	Malatya	44	Uşak	64
Amasya	5	Erzurum	25	Manisa	45	Van	65
Ankara	6	Eskişehir	26	Maraş	46	Yozgat	66
Antalya	7	Gaziantep	27	Mardin	47	Zonguldak	67
Artvin	8	Giresun	28	Muğla	48	Aksaray	68
Aydın	9	Gümüşhane	29	Muş	49	Bayburt	69
Balıkesir	10	Hakkari	30	Nevşehir	50	Karaman	70
Bilecik	11	Hatay	31	Niğde	51	Kırıkkale	71
Bingöl	12	Isparta	32	Ordu	52	Batman	72
Bitlis	13	Mersin	33	Rize	53	Şırnak	73
Bolu	14	İstanbul	34	Sakarya	54	Bartın	74
Burdur	15	İzmir	35	Samsun	55	Ardahan	75
Bursa	16	Kars	36	Siirt	56	Iğdır	76
Çanakkale	17	Kastamonu	37	Sinop	57	Yalova	77
Çankırı	18	Kayseri	38	Sivas	58	Karabük	78
Çorum	19	Kırklareli	39	Tekirdağ	59	Kilis	79
Denizli	20	Kırşehir	40	Tokat	60	Osmaniye	80
						Düzce	81

The spatial distribution of SOVI (Figure 6) demonstrated that 13 cities have a very high vulnerability level among all cities in Türkiye. It was determined that Ağrı (4), Adıyaman (2), Ardahan (75), Bartın (74), Batman (72), Bingöl (12), Çankırı (18), Iğdır (76), Kastamonu (37), Muş (49), Siirt (56), Sinop (57), and Şırnak (73) have the most vulnerable population in Türkiye. Bartın (74), Kastamonu (37), and Sinop (57) are socially more vulnerable due to having high proportion of elder dependency and female in their population, while high percentage of illiteracy and low health service quality are the main reasons for high vulnerability in Ağrı (4), Ardahan (75), Çankırı (18), Iğdır (76) and Muş (49). Batman (72) and Bingöl (12) are two cities with the lowest GDP among all cities.

The cities in the western part have less vulnerable population than the other cities in the middle, northern, and eastern parts of the country. It is determined that İzmir (35) was the least vulnerable city while Sinop (57) was the most vulnerable city in the country.

Figure 6

Spatial Distribution of Social Vulnerability Index in Türkiye



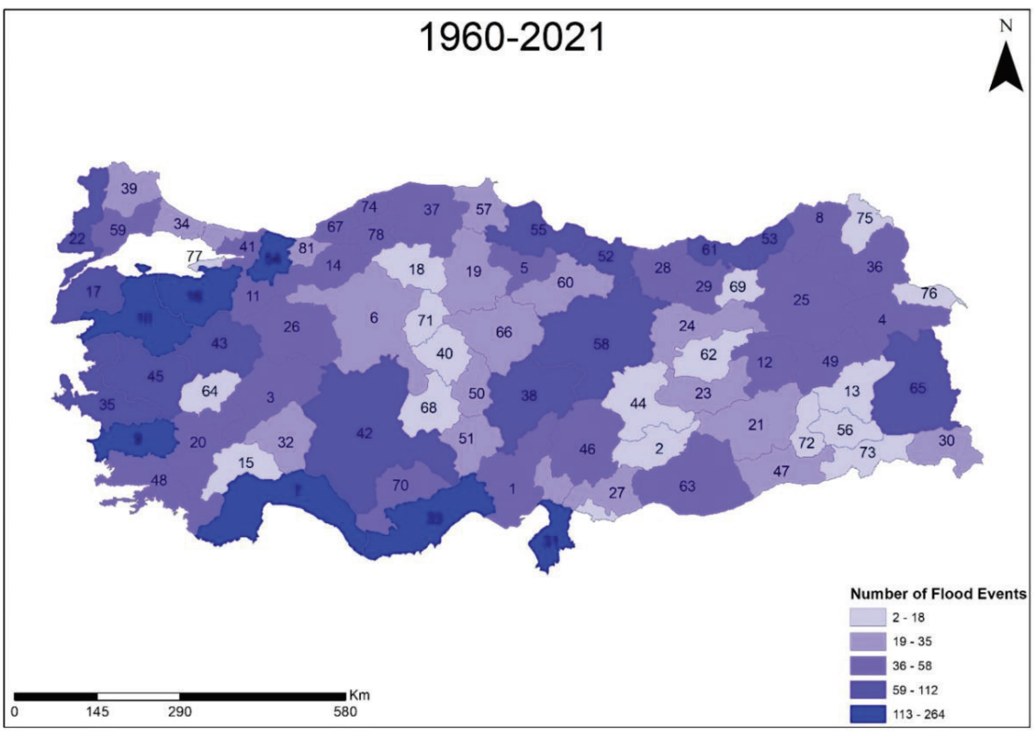
Flood Frequency Analysis

The spatial distribution of flood disasters in Turkey in 61 years from 1960 to 2021 was represented in Figure 7. Natural Jenks method was applied to dataset to identify distribution of flood disasters in Türkiye. As a result, the cities with recorded among 113-264 historical flood events were characterized as high flood frequency while 2-18 events were low flood frequency. Antalya (7), Aydın (9), Balıkesir (10), Bursa (16), Hatay (31), Mersin (33), and Sakarya (54) have experienced more flood events than the other cities in Türkiye. The numbers of flood events in these cities were between the numbers of 113-264. The highest number of flood events was observed in Balıkesir with 264 events.

The spatial distribution of flood disasters indicated that the cities located in west and south side of the country have experienced more floods than its middle, eastern and north-western parts.

Figure 7

Spatial Distribution of Flood Disasters in Türkiye



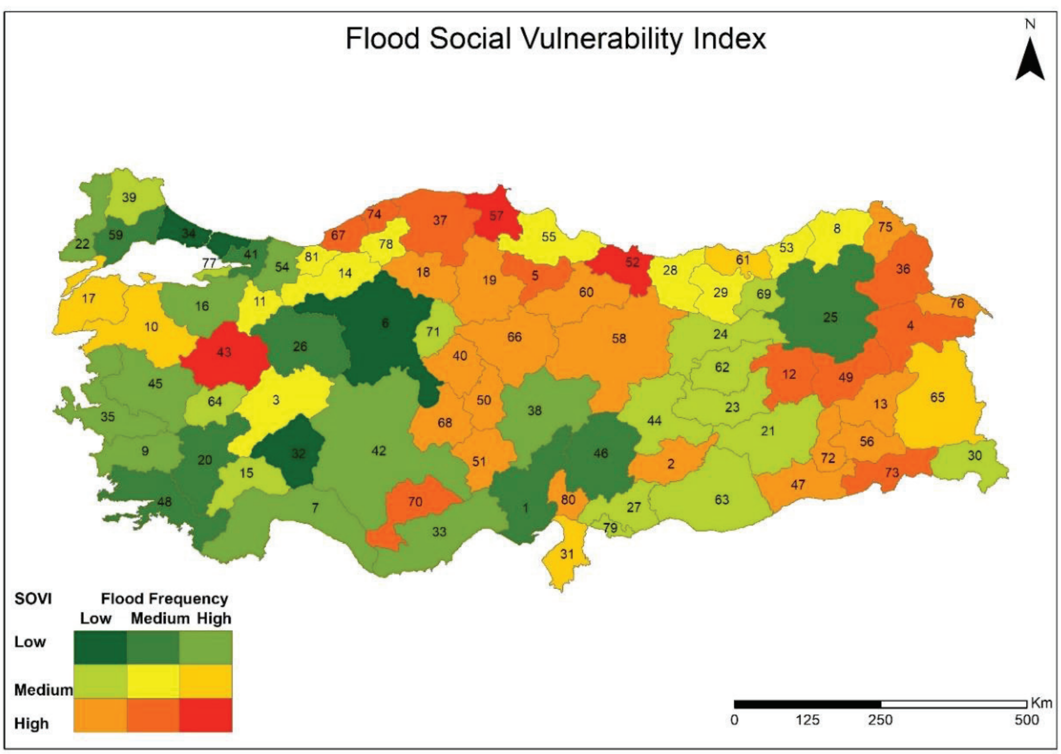
Flood Social Vulnerability Index (FSOVI)

Figure 8 displays the spatial distribution of the FSOVI. Kütahya (43), Ordu (52), and Sinop (57) have the highest FSOVI value among all cities. The cities in the western part of the country are generally less flood socially vulnerable compared to the eastern and middle part of the country since their social vulnerability levels are very low, low, and medium mostly. In addition, the cities located in the northern part of the country were more vulnerable than the southern part of Türkiye. There were highly vulnerable cities [Aksaray (68), Çankırı (18), Çorum (19), Kırşehir (40), Nevşehir (50), Sivas (58), Tokat (60), and Yozgat (66)] in the middle part of the country due to high SOVI values. Ankara (6), Isparta (32), and İstanbul (34) had the lowest FSOVI values due to their low SOVI and FFI values.

Some cities had high flood frequency but low SOVI values such as Antalya (7), Aydın (9), Balıkesir (10), Bursa (16), Hatay (31), Mersin (33), Sakarya (54), and Samsun (55). In contrast to those cities, Adıyaman (2), Ardahan (75), Çankırı (18), Iğdır (76), and Siirt (56) had low flood frequency and high SOVI values due to low GDP and higher female population. As a result, among those with high SOVI and flood frequency, the total FSOVI values are lower for the cases which one of the index is identified as low.

Figure 8

Spatial Distribution of Flood Social Vulnerability Index



Discussion and Conclusion

In the similar study conducted in entire Türkiye for assessing drought vulnerability, the spatial distribution of social vulnerability of its population indicated that Adana (1), Adıyaman (2), Ağrı (4), Ankara (6), Antalya (7), Batman (72), Diyarbakır (21), Gaziantep (27), Hakkari (30), Hatay (31), İstanbul (34), Konya (41), Kahramanmaraş (46), Mardin (47), Muş (49), Niğde (51), Şanlıurfa (63), Şırnak (73), and Van (65) are the cities with the highest social vulnerability (Türkeş, 2017). The results on the spatial distribution of SOVI in the research are partially consistent with our study. Adıyaman (2), Batman (72), Muş (49), and Şırnak (73) were determined as highly socially vulnerable cities in both studies. However, there are some inconsistencies between the results. For instance, Ankara (6) and İzmir (35) were evaluated as having a highly vulnerable population in the study of Türkeş (2017), while they were identified as the least vulnerable cities in this study. This difference between the two studies may be due to the utilization of different vulnerability parameters. In addition, the most recent available data was used in this study compared to of the data in his study (Türkeş, 2017).

This study aimed to assess flood social vulnerability over Türkiye by combining flood frequency and social vulnerability indexes. There are plenty of vulnerability parameters in the literature, but only 9 of them were used in this study due to data availability. Historical flood records among 1960-2021 were examined to assess flood frequency. Both social vulnerability and flood frequency indexes were normalized by the maximum-minimum standardization procedure to solve the incommensurability problem. Then, all indexes were displayed spatially so that highly vulnerable areas to flood disasters were mapped out. This study enabled decision-makers to identify vulnerable populations to flood in Türkiye. The resources may be allocated to improve flood preparedness of vulnerable population with the light of this information. The methodology implemented in this study can be a reference tool for other countries as well. However, specific data assessment needs to be conducted to identify most suitable vulnerability parameters for SOVI.

The spatial distribution of SOVI indicated that Adıyaman (2), Ağrı (4), Ardahan (75), Bartın (74), Batman (72), Bingöl (12), Çankırı (18), Iğdır (76), Kastamonu (37), Muş (49), Siirt (56), Sinop (57), and Şırnak (73) provinces were evaluated as having very highly vulnerable population. In addition, the western part of the country was claimed as less vulnerable compared to other parts of Türkiye. According to the flood frequency analysis, Antalya (7), Aydın (9), Balıkesir (10), Bursa (16), Hatay (31), Mersin (33), and Sakarya (54) had the highest flood frequency. When both of two indexes: FSOVI and SOVI were combined, we recorded that Kütahya (43), Ordu (52), and Sinop (57) were three of cities having the highest value on FSOVI.

Information on spatial distribution of flood is crucial for flood management and emergency response. It will also be a reference tool for decision-makers to allocate resources for flood preparedness. This reference tool can be used to prioritize local disaster response strategies as well. In addition, the methodology can be applied to any other country or Türkiye for watershed-scale as well.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Türkiye Örneği Özelinde Taşkın Sosyal Etkilenebilirlik Analizi

Doğal afetler düşünüldüğünde, taşkınlar en sık karşılaşılan ve de en fazla hasara sebep olanlar arasında yer almaktadır. Taşkın riskini oluşturan bileşenlerin değerlendirilmesi ve riskin sayısallaştırılması, bu risk gerçekleştiğinde karşılaşılması beklenen büyük boyutlu etkilerden korunmak için önemlidir. Taşkın riskini kapsamlı bir şekilde değerlendirebilmek için riskin sosyal ve biyofiziksel katmanlarının birlikte ele alınması gerekmektedir. Bu noktada iki farklı katmanı birlikte inceleyip mekânsal bir değerlendirme yoluyla riski ifade edebilen Sosyal Etkilenebilirlik Analizleri kullanılmaktadır.

Bu çalışmada, toplumun herhangi bir dış baskı faktörüne karşı adaptasyon yeteneğini ve duyarlılığını ölçen Sosyal Etkilenebilirlik Endeksi, tüm Türkiye özelinde il bazında değerlendirilmiştir. Sosyal Etkilenebilirlik Analizi dünya literatüründe deprem, kuraklık, taşkın, iklim değişikliği gibi afetlere karşı toplumun kırılganlıklarını ölçmek için yaygın bir şekilde kullanılmaktadır. Daha öncesinde Amerika, Norveç, Güney İtalya, Bangladeş gibi ülkelerde yapılan çalışmalar incelenmiş, veri ulaşılabilirliği de göz önüne alınarak 9 farklı etkilenebilirlik parametresi Türkiye özelinde belirlenmiştir. Bunlar 1000 kişiye düşen hekim sayısı, popülasyondaki kadın oranı, toplam yaş bağlılık oranı (%), okuma yazma bilmeyen sayısı, ortalama hanehalkı büyüklüğü, hastahane sayısı, Gayri Safi Yurtiçi Hâsıla (GSYH bin TL), taşkın koruma tesisinin varlığı ve nüfus yoğunluğudur. Tüm veriler Türkiye İstatistik Kurumu (TÜİK) veritabanından elde edilmiştir. Birbirinden farklı birimlere sahip olan etkilenebilirlik parametrelerini Temel Bileşen Analizi yöntemiyle birleştirebilmek için maksimum-minimum normalizasyonu prosedürü uygulanmıştır. Temel Bileşen Analizi, temelde çok boyutlu bir verisetinin dağılımın anlamının korunacağı şekilde daha düşük boyutlu bir veri setine indirgenmesini sağlayan bir analiz çeşididir. Bu analiz yapılmadan önce bahsekonu verisetinin analize uygunluğunu değerlendirme olanağı veren Bartlett's Test of Sphericity and Kaiser-Meyer Olkin's measure of sampling adequacy testleri verisetine uygulanmış ve test sonuçları Temel Bileşen Analizi prosedürünün uygulanmasında herhangi bir sorun olmadığını göstermiştir. Bu testlerden sonra etkilenebilirliği arttıran parametreler ve azaltan parametreler ayrı ayrı hesaplanıp daha sonra birleştirilmiştir. Bununla birlikte her bir şehir 0 ila 1 arasında bir etkilenebilirlik değeriyle ifade edilmiştir. Fakat Türkiye genelinde yapılan ve kuraklığa etkilenebilirliği analiz eden diğer bir çalışmada (Türkeş 2017) İzmir ve Ankara çok yüksek etkilenebilirlik derecesine sahip olarak ifade edilmişken, bu çalışmada en düşük etkilenebilirlik seviyesine sahip olarak belirlenmiştir. Bunun sebebinin ise her iki çalışmada kullanılan etkilenebilirlik parametrelerinin farklı olmasından kaynaklandığı düşünülmektedir. Ayrıca, 2017 yılında gerçekleştirilen çalışmadaki verilerin bu çalışmadaki veriler kadar güncel olmaması nedeniyle böyle bir farkın ortaya çıkmış olabileceği öngörülmüştür. Ayrıca bu çalışmada kullanılan etkilenebilirlik parametreleri ayrı ayrı incelendiğinde de Ankara ve İzmir'in GSYH, 1000 kişiye düşen hekim sayısı ve taşkın tesisi sayılarının tüm verisetindeki en yüksek değerlere sahip olduğu görülmektedir.

Sosyal Etkilenebilirlik Endeksi analizi sonucunda Adıyaman, Ağrı, Ardahan, Bartın, Batman, Bingöl, Çankırı, Iğdır, Kastamonu, Muş, Siirt, Sinop ve Şırnak olmak üzere 13 şehir çok yüksek derecede etkilenebilir olarak nitelendirilmiştir. Sinop, Bartın, Kastamonu illerinde yüksek yaşlı bağımlılık ve kadın popülasyonu oranı ve düşük taşkın tesisi sayısı, Ardahan, Ağrı, Çankırı, Iğdır, Muş illerinde yüksek okuma yazma bilmeyen nüfus oranı ve düşük doktor ve hastane sayısı, Batman, Bingöl illerinde ise düşük Gayrisafi Yurtiçi Hasıla (GSYİH) oranı yüksek etkilenebilirlik oranına sahip olma nedenleridir.

Türkiye genelinde yapılan bir başka çalışmada (Türkeş 2017) hesaplanan Sosyal Etkilenebilirlik Endeksi'nin ülke genelindeki dağılımının bu çalışmayla tam olarak uyumlu olmadığı belirlenmiştir. Şırnak, Batman, Muş ve Adıyaman şehirleri her iki çalışmada da en yüksek etkilenebilirlik seviyesine sahip olmuştur. İzmir ise Sosyal Etkilenebilirlik Endeksine göre Türkiye'de etkilenebilirlik değerininin en düşük olduğu il olarak belirlenmiştir. İzmir ilinin bu değere sahip olmasında taşkın tesis sayısının ve 1000 kişiye düşen hekim sayısının fazlalığı ile üçüncü en yüksek GSYİH değerine sahip olmasının etkili olduğu tespit edilmiştir.

Taşkın riskinin biyofiziksel katmanı ise tarihi taşkın sayılarıyla tanımlanmıştır. 1960 ve 2021 yılları arasındaki tarihi taşkınlar il bazında analiz edilmiştir. Balıkesir ili 1960 yılından beri kaydedilen 264 taşkın olayı ile Türkiye genelinde en fazla sayıda taşkına maruz kalmış il olmuştur. Sosyal Etkilenebilirlik Analizi ve tarihi taşkınların değerlendirilmesi sonucunda bu 13 şehirden yalnızca Sinop, Kütahya ve Ordu Taşkın Sosyal Etkilenebilirlik Endeksi'nde en yüksek dereceyi almıştır. Balıkesir ili ise orta derecede sosyal etkilenebilirlik değerine sahip olduğu için Taşkın Sosyal Etkilenebilirlik derecesinde düşük bir değere sahip olmuştur. En fazla taşkına maruz kalmış il olan Balıkesir, daha az derecede sosyal etkilenebilir bir popülasyona sahip olduğu için düşük bir risk değerine sahiptir. Taşkın Sosyal Etkilenebilirlik Endeksi analizi sonuçları yalnızca riskin sosyal veya biyofiziksel katmanlarının yeterli olmadığı, riskin kapsamlı şekilde ifade edilebilmesi için bu iki katmanın birlikte değerlendirilmesi gerektiğini ortaya koymuştur. Bu çalışmada uygulanan ve önerilen yöntem karar vericiler için kullanışlı bir metot olmakla beraber tüm Türkiye'de taşkın hazırlık yetkinliğini arttırmada rol oynayabilecektir. Taşkın durumlarında ülkedeki toplam riski ifade eden bu sonuçlar, kapasite geliştirmek için kaynak dağıtımının yapılması hususunda karar vericilere altlık olacaktır. Bu çalışmada uygulanan yöntem ülkede daha küçük ölçeklerde daha detaylı olarak çalışılarak bölgesel taşkın risklerini belirlemede kullanılabilir. Ayrıca, başka ülkelerde ülke çapında yürütülecek çalışmalar içinde metodolojik bir referans olarak kullanılabilir.

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Research Article

Length-Weight Relationships and Condition Factors of Eight Exotic Fish Species from Türkiye

Türkiye'de Bulunan Sekiz Egzotik Balık Türünün Boy-Ağırlık İlişkisi ve Kondisyon Faktörü

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Abstract

Length-weight relationships and condition factors were estimated for eight exotic fish species, including *Oreochromis niloticus*, *Coptodon zillii*, *Carassius auratus*, *C. gibelio*, *Pseudorasbora parva*, *Gambusia holbrooki*, *Lepomis gibbosus*, and *Oncorhynchus mykiss* from 10 river basins in Türkiye. A total of 1958 specimens were sampled between 2014 and 2019 from 29 populations, and their length-weight relationships, Fulton's relative, and mean condition factors were estimated. The estimated values of the parameter *b* ranged from 2.732 (*C. auratus*) to 3.319 (*C. gibelio*) with the mean and median values estimated at 3.013 and 3.047, respectively. The R^2 values varied from 0.753 to 0.998, indicating a high degree of the positive relationship between length and weight. The Fulton's condition factor ranged between 0.882 (*P. parva*) and 2.002 (*L. gibbosus*) with the mean and median values of 1.397 and 1.453, respectively. This situation reveals that the condition values of all alien species except *P. parva* are quite high. In addition, the condition factor values of exotic fish species and native species live with in Lake Çıldır were compared to observe their competition with indigenous fishes of the lake. As a result of this comparison, it was found that *C. gibelio* has the highest condition factor value.
Keywords: *condition factor, exotic fish species, river basin, growth pattern*

Öz

Bu çalışmada Türkiye'nin 10 farklı nehir havzasından, *Oreochromis niloticus*, *Coptodon zillii*, *Carassius auratus*, *C. gibelio*, *Pseudorasbora parva*, *Gambusia holbrooki*, *Lepomis gibbosus* ve

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Oncorhynchus mykiss olmak üzere sekiz egzotik balık türünün boy-ağırlık ilişkileri (L-WRs) ve kondisyon faktörü değerleri tahmin edilmiştir. 2014, 2017, 2018 ve 2019 yılları arasında 29 populasyondan 1958 birey örneklenmiştir. Boy-ağırlık ilişkisi sabitlerinden *b* değerinin 2,732 (*C. auratus*) ile 3,319 (*C. gibelio*) arasında değişim gösterdiği belirlenmiş olup çalışılan populasyonlar için ortalama ve ortanca değerler sırasıyla 3,013 ve 3,047 olarak hesaplanmıştır. Regresyon analizi sonucunda boy-ağırlık değerleri arasında yüksek bir pozitif ilişki belirlenmiş olup R^2 değeri 0,753 ile 0,998 arasında bulunmuştur. Fulton'un kondisyon faktörü değerinin 0,882 (*P. parva*) ile 2,002 (*L. gibbosus*) arasında değişim gösterdiği belirlenmiş ve ortalama ve ortanca değerler sırasıyla 1,397 ve 1,453 olarak hesaplanmıştır. Bu durum *P. parva* dışında diğer tüm egzotik türlerin kondisyon değerlerinin oldukça yüksek olduğunu ortaya koymaktadır. Bunun yanı sıra Çıldır Gölünde egzotik balık türleri ile birlikte yaşadıkları yerli türlerin kondisyon faktörü değerleri de karşılaştırılmıştır. Bu karşılaştırma sonucunda *C. gibelio*'nun en yüksek kondisyon faktörü değerine sahip olduğu belirlenmiştir.

Anahtar sözcükler: *kondisyon faktör, egzotik balık türleri, nehir havzası, büyüme paterni*

Introduction

Exotic species in new environments can threaten native species due to resource competition, predation, and disease, driving them to decline or even extinction. Their adverse effects are seen not only in the aquatic environments where they enter but also in the local economies. Exotic species' influence on biodiversity is rising and becoming a global threat. To date, 39 exotic fish species have been reported from Turkish inland waters (Çetinkaya, 2006; Innal & Erkakan, 2006; Innal, 2012; Tarkan et al., 2015; Çiçek et al., 2021), of which 19 of them have established populations in the wild (Çiçek et al., 2020, 2022). So, it is important to keep an eye on the spread of exotic species and how they affect the freshwater ecosystem in Türkiye.

The length-weight relationships (LWRs) are a valuable tool for estimating the weight of a given length, biomass from length data, comparing them to relative conditions among species, regions, even years and life histories, and population dynamics of given species (da Costa et al., 2014). The condition factor of fish indicates the degree of food source availability, environmental condition and stress, state of sexual maturity, age, and sex (Anibeze, 2000; Liang & Cai, 2020). Therefore, estimations of population biology traits are a crucial part of fisheries biology and management (Froese et al., 2011). These estimations for exotic species may help us to take measures to prevent their effects on native biodiversity and conservation biology.

The knowledge on the length-weight relations of the exotic freshwater fishes in Türkiye is limited (Innal & Gianetto, 2017; Kurtul & Sarı, 2020). Therefore, this study aimed to investigate the length-weight relationships and condition factors of exotic fish species collected from some freshwater habitats in Türkiye.

Materials and Methods

Fish samples were collected in the spring, summer, and fall of the years 2014, 2015, 2017, 2018, and 2019 from 10 river basins (West and East Mediterranean, Çoruh, Seyhan, Aras, Asi, East Black Sea, Fırat, Konya and North Aegean) in Türkiye. Fish were caught using a backpack electrofishing device (SAMUS 1000) in lotic waters and gillnets in lentic aquatic ecosystems. The collected fish specimens were fixed into 10% formaldehyde solutions after anaesthesia and then transferred to the laboratory for further study. In the laboratory, total length (L) and total weight (W) were measured to the nearest 0.01 cm and 0.01 g, respectively.

The LWRs function was fitted with a simple linear regression model using log-transformed data:

$$W=a*L^b \qquad (1)$$

where a is the intercept and b is the allometric coefficient (LeCren, 1951). The 95% confidence interval (CI) was determined for parameters a and b (Froese, 2006). Before to regression analyses, log-log plots of the length-weight pairs were performed to identify outliers (Froese et al., 2011). Outliers perceived in the log–log plots of all these eight species were eliminated from the analysis. Fulton's condition factor (K_F) was estimated using the formula (Ricker, 1975; Froese, 2006):

$$K_F=(W/L^3) \times 100 \qquad (2)$$

The relative condition factor (K_R) was calculated using the equation (Froese, 2006):

$$K_R = W/(a \times L^b) \qquad (3)$$

The mean condition factor (K_M) for a given length was derived from the respective WLR (Froese, 2006) using the formula:

$$K_M = 100 \times a \times L^{b-3} \qquad (4)$$

The form factor (a3:0) was used to assess if a population's or species' body shape differs significantly from that of others, which was calculated using the formula (Froese, 2006):

$$a_{3:0}=10^{\log a\text{-}S(b\text{-}3)} \qquad (5)$$

where S was the slope of the regression of log a vs b. This value was used as a -1.358 proxy for estimating the form factor (Froese, 2006).

All statistical analyses were performed in Excel 2016 and Past 3.26 software.

Results and Discussion

During the study period, a total of eight exotic fishes, *Oreochromis niloticus* (Linnaeus, 1758), *Coptodon zillii* (Gervais, 1848), *Carassius auratus* (Linnaeus, 1758), *C. gibelio* (Bloch, 1782), *Pseudorasbora parva* (Temminck & Schlegel, 1846), *Gambusia holbrooki* Girard, 1859, *Lepomis gibbosus* (Linnaeus, 1758), and *Oncorhynchus mykiss* (Walbaum, 1792) were collected. *C. auratus* is the first exotic fish introduced into Türkiye's inland waters (Deveciyan, 1926), followed by *G. holbrooki* for biological control of mosquitos (Geldiay & Balik, 2007). Aquaculture, as the main reason for introducing egzotic fish species with a relatively short history in Türkiye, was began with the farming of rainbow trout (Food and Agriculture Organization of United Nations [FAO], 2005) and then seven tilapia species such as *C. zillii* and *O. niloticus* were imported to improve aquaculture production (Çetinkaya, 2006; Innal & Erkakan, 2006). All of these eight species have been successfully naturalized and become exotic in the freshwater basins of Türkiye (Özcan, 2007; Tarkan et al., 2012; Yerli et al., 2014; Özcan & Tarhan, 2019, Çiçek et al., 2022).

The distribution of fish populations and total number fish caught from each basin and and year classes are given in Table 1. Their descriptive statistics including the length, weight, and LWRs parameters are indicated in Table 2. Estimated values of b varied from 2.732 (*C. auratus*) to 3.319 (*C. gibelio*) with a mean and median of 3.013 and 3.047, respectively. A total of 18 populations displayed isometric growth (b = 3), 2 populations had negative allometric growth (b < 3) and 9 populations had positive allometric growth (b < 3) patterns. For the studied populations, the b values ranged within the expected range of 2.5–3.5 (Froese, 2006). All relationships were highly significant (P < 0.005), with R^2 values being greater than 0.75, indicating a high degree of a positive relationship between length and weight.

Table 1

Information of Eight Exotic Species from 29 Populations

ID	Species	Basins	Habitat	Sampling Year	n
CICHLIFORMES (1 family)					
Cichlidae (2 species)					
1	*Oreochromis niloticus* (Linnaeus, 1758)	Asi	Lotic	2019	20
2	*Coptodon zillii* (Gervais, 1848)	Batı Akdeniz	Lotic	2014	206
CYPRINIFORMES (1 family)					
Cyprinidae (2 species)					
3	*Carassius auratus* (Linnaeus, 1758)	Çoruh	Lotic	2019	26
4	*Carassius auratus* (Linnaeus, 1758)	Fırat	Lotic	2019	71
5	*Carassius auratus* (Linnaeus, 1758)	Seyhan	Lotic	2019	13
6	*Carassius gibelio* (Bloch, 1782)	Aras	Lotic	2014	233
7	*Carassius gibelio* (Bloch, 1782)	Asi	Lotic	2019	34
8	*Carassius gibelio* (Bloch, 1782)	Batı Akdeniz	Lotic	2014	95
9	*Carassius gibelio* (Bloch, 1782)	Çoruh	Lotic	2019	38
10	*Carassius gibelio* (Bloch, 1782)	Doğu Akdeniz	Lotic	2019	19
11	*Carassius gibelio* (Bloch, 1782)	Fırat	Lotic	2019	159
12	*Carassius gibelio* (Bloch, 1782)	Fırat	Lotic	2014	12
13	*Carassius gibelio* (Bloch, 1782)	Konya	Lotic	2017	29
14	*Carassius gibelio* (Bloch, 1782)	Seyhan	Lotic	2019	32
Gobionidae (1 species)					
15	*Pseudorasbora parva* (Temminck & Schlegel, 1846)	Aras	Lotic	2014	94
16	*Pseudorasbora parva* (Temminck & Schlegel, 1846)	Batı Akdeniz	Lotic	2014	97
17	*Pseudorasbora parva* (Temminck & Schlegel, 1846)	Konya	Lotic	2017	15
18	*Pseudorasbora parva* (Temminck & Schlegel, 1846)	Kuzey Ege	Lotic	2014	35
CYPRINODONTIFORMES (2 families)					
Poecilidae (1 species)					
19	*Gambusia holbrooki* Girard, 1859	Batı Akdeniz	Lotic	2014	122
20	*Gambusia holbrooki* Girard, 1859	Fırat	Lotic	2014	71
PERCIFORMES (2 families)					
Centrarhidae (1 species)					
21	*Lepomis gibbosus* Linnaeus, 1758	Batı Akdeniz	Lentic	2014	48
22	*Lepomis gibbosus* Linnaeus, 1758	Batı Akdeniz	Lotic	2014	182
SALMONIFORMES (1 family)					
Salmonidae (1 species)					
23	*Oncorhynchus mykiss* (Walbaum, 1792)	Aras	Lentic	2014	21
24	*Oncorhynchus mykiss* (Walbaum, 1792)	Aras	Lotic	2014	12
25	*Oncorhynchus mykiss* (Walbaum, 1792)	Ceyhan	Lentic	2014	19
26	*Oncorhynchus mykiss* (Walbaum, 1792)	Çoruh	Lotic	2019	22
27	*Oncorhynchus mykiss* (Walbaum, 1792)	Batı Akdeniz	Lentic	2014	5
28	*Oncorhynchus mykiss* (Walbaum, 1792)	Ceyhan	Lentic	2019	41
29	*Oncorhynchus mykiss* (Walbaum, 1792)	Doğu Karadeniz	Lentic	2018	67

Note. ID: Species Identification Number; n: Number of Specimens

Table 2

Descriptive Statistics of Eight Exotic Fish Species from 29 Populations in Türkiye (Froese & Pauly, 2022)

ID	Species	Total Length				Total Weight			
		Min	Max	Mean	SD	Min	Max	Mean	SD
1	*Oreochromis niloticus*	3.8	17.5	8.60	3.29	0.98	117.06	15.48	25.60
2	*Coptodon zilli*	6.6	15.3	10.74	1.45	4.92	58.23	23.23	8.30
3	*Carassius auratus*	8.3	13.5	10.25	1.37	6.60	28.90	14.87	5.57
4	*Carassius auratus*	8.3	23.7	13.15	3.94	7.71	232.62	41.14	40.71
5	*Carassius auratus*	10.3	16.8	12.76	1.86	14.51	69.14	33.89	16.29
6	*Carassius gibelio*	4.7	32.5	17.09	8.68	1.44	727.45	183.03	221.11
7	*Carassius gibelio*	16.2	21.6	19.06	1.29	66.82	167.14	119.41	25.39
8	*Carassius gibelio*	5.1	27.2	14.41	4.32	2.15	280.25	65.40	59.26
9	*Carassius gibelio*	8.1	21.8	9.22	2.14	8.34	143.45	14.67	21.52
10	*Carassius gibelio*	7.4	23.0	14.44	6.66	6.14	222.04	89.12	96.66
11	*Carassius gibelio*	7.6	25.5	13.23	4.41	7.60	246.43	49.55	48.13
12	*Carassius gibelio*	5.4	20.0	13.51	5.28	1.69	140.73	59.48	52.31
13	*Carassius gibelio*	9.4	24.2	18.53	3.49	12.06	240.80	112.56	51.57
14	*Carassius gibelio*	10.0	20.3	14.28	2.93	14.58	140.97	50.03	35.05
15	*Pseudoraspora parva*	4.8	10.2	7.81	1.41	0.87	11.10	5.19	2.42
16	*Pseudoraspora parva*	4.2	6.5	5.46	0.62	0.68	2.80	1.48	0.50
17	*Pseudoraspora parva*	6.0	10.4	8.27	1.55	2.12	12.00	6.63	3.64
18	*Pseudorasbora parva*	5.0	9.8	7.69	1.53	1.16	9.94	4.62	2.67
19	*Gambusia holbrooki*	2.3	5.3	3.07	0.50	0.11	1.67	0.41	0.26
20	*Gambusia holbrooki*	2.3	4.4	3.21	0.46	0.12	1.36	0.45	0.22
21	*Lepomis gibbosus*	2.7	10.7	6.54	1.54	0.20	23.54	6.60	4.42
22	*Lepomis gibbosus*	3.9	13.2	6.74	2.21	0.93	42.70	7.16	7.97
23	*Oncorhynchus mykiss*	11.0	19.1	15.15	2.65	17.05	89.97	46.24	24.82
24	*Onchorhyncus mykiss*	14.2	27.0	18.27	3.38	41.55	297.20	88.83	69.72
25	*Onchorhyncus mykiss*	9.0	30.0	19.31	5.96	7.56	393.03	103.44	92.26
26	*Onchorhyncus mykiss*	12.9	29.7	20.81	3.16	25.50	285.87	100.95	44.09
27	*Oncorhynchus mykiss*	9.8	25.8	17.67	3.76	12.36	205.57	82.45	47.93
28	*Onchorhyncus mykiss*	6.7	22.8	16.45	3.78	4.80	196.42	73.30	44.04
29	*Onchorhyncus mykiss*	8.5	18.5	13.86	2.00	7.82	90.76	35.31	14.41

Note. min: minimum; max: maximum; SD: standard deviation

Table 3

Estimated Parameters of the Length–Weight Relationships for Eight Exotic Fish Species from 29 Populations in Türkiye

ID	Species	Length-weight relationship parameters					Growth Type	In FishBase	
		a	***b***	R^2	**SE of *b***	**CI of *b***		***a***	***b***
1	*Oreochromis niloticus*	0.013	3.061	0.967	0.133	2.751-3.404	I	0.0257	2.93
2	*Coptodon zilli*	0.014	3.093	0.978	0.033	3.031-3.159	A+	0.0245	2.99
3	*Carassius auratus*	0.025	2.732	0.952	0.125	2.474-2.967	A-	0.0145	3.06
4	*Carassius auratus*	0.019	2.886	0.964	0.067	2.731-3.29	I	0.0145	3.06
5	*Carassius auratus*	0.009	3.191	0.954	0.212	2.476-3.483	I	0.0145	3.06
6	*Carassius gibelio*	0.009	3.259	0.998	0.010	3.239-3.778	A+	0.0151	3.09
7	*Carassius gibelio*	0.014	3.070	0.863	0.217	2.806-3.424	I	0.0151	3.09
8	*Carassius gibelio*	0.016	3.034	0.990	0.032	2.966-3.106	I	0.0151	3.09
9	*Carassius gibelio*	0.023	2.830	0.978	0.071	2.661-3.268	I	0.0151	3.09
10	*Carassius gibelio*	0.011	3.156	0.998	0.031	3.103-3.211	A+	0.0151	3.09
11	*Carassius gibelio*	0.013	3.060	0.971	0.043	2.983-3.129	I	0.0151	3.09
12	*Carassius gibelio*	0.007	3.319	0.998	0.048	3.238-3.491	A+	0.0151	3.09
13	*Carassius gibelio*	0.017	2.982	0.981	0.080	2.862-3.235	I	0.0151	3.09
14	*Carassius gibelio*	0.009	3.171	0.949	0.133	2.971-3.378	I	0.0151	3.09
15	*Pseudoraspora parva*	0.013	2.884	0.962	0.060	2.729-3.026	I	0.0085	3.11
16	*Pseudoraspora parva*	0.012	2.823	0.901	0.096	2.643-3.008	I	0.0085	3.11
17	*Pseudoraspora parva*	0.006	3.253	0.996	0.058	3.151-3.363	A+	0.0085	3.11
18	*Pseudorasbora parva*	0.007	3.135	0.981	0.076	2.970-3.256	I	0.0085	3.11
19	*Gambusia holbrooki*	0.012	3.063	0.753	0.160	2.664-3.406	I	0.0087	3.32
20	*Gambusia holbrooki*	0.009	3.270	0.956	0.084	3.183-3.559	A+	0.0087	3.32
21	*Lepomis gibbosus*	0.008	3.491	0.950	0.103	3.199-4.013	A+	0.0120	3.18
22	*Lepomis gibbosus*	0.013	3.138	0.987	0.027	3.091-3.185	A+	0.0120	3.18
23	*Oncorhynchus mykiss*	0.013	2.970	0.897	0.279	2.325-3.334	I	0.0100	3.02
24	*Onchorhyncus mykiss*	0.014	2.972	0.907	0.301	2.435-4.217	I	0.0100	3.02
25	*Onchorhyncus mykiss*	0.007	3.138	0.980	0.062	3.026-3.252	A+	0.0100	3.02
26	*Onchorhyncus mykiss*	0.018	2.831	0.927	0.084	2.632-3.045	I	0.0100	3.02
27	*Oncorhynchus mykiss*	0.025	2.788	0.990	0.061	2.603-2.999	A-	0.0100	3.02
28	*Onchorhyncus mykiss*	0.018	2.917	0.973	0.139	2.467-3.280	I	0.0100	3.02
29	*Onchorhyncus mykiss*	0.021	2.814	0.967	0.066	2.683-3.001	I	0.0100	3.02

Note. I: Isometric growth; A+: positive allometry: A-: negative allometry; SE: standard error; CI: Confidence intervals

Table 4

Estimated Parameters of Condition Factors and Form Factor for Eight Exotic Fish Species from 29 Populations in Türkiye

ID	Species	Fulton's Condition Factor (K_F)				Relative Condition Factor (K_R)				Mean Condition Factor (K_M)				Form Factor (F_F)
		Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	
1	*Oreochromis niloticus*	1.03	2.18	1.52	0.31	0.67	1.40	1.02	0.20	1.42	1.56	1.49	0.03	0.0159
2	*Coptodon zilli*	1.52	2.09	1.78	0.12	0.84	1.18	1.01	0.07	1.69	1.83	1.77	0.02	0.0190
3	*Carassius auratus*	1.15	1.57	1.33	0.12	0.82	1.17	1.00	0.08	1.23	1.40	1.33	0.05	0.0107
4	*Carassius auratus*	1.02	1.85	1.44	0.22	0.72	1.39	1.01	0.16	1.32	1.49	1.42	0.05	0.0133
5	*Carassius auratus*	1.29	1.86	1.53	0.16	0.85	1.21	1.00	0.10	1.47	1.61	1.53	0.04	0.0171
6	*Carassius gibelio*	1.19	2.53	1.76	0.31	0.77	1.25	1.01	0.09	1.28	2.12	1.75	0.25	0.0193
7	*Carassius gibelio*	1.30	2.02	1.70	0.14	0.76	1.19	1.00	0.08	1.68	1.71	1.70	0.01	0.0172
8	*Carassius gibelio*	1.30	2.04	1.71	0.15	0.77	1.20	1.00	0.09	1.65	1.74	1.71	0.02	0.0173
9	*Carassius gibelio*	1.38	1.82	1.58	0.11	0.90	1.15	1.00	0.07	1.36	1.61	1.58	0.04	0.0135
10	*Carassius gibelio*	1.41	1.94	1.69	0.16	0.88	1.12	1.01	0.06	1.53	1.83	1.68	0.12	0.0182
11	*Carassius gibelio*	0.72	2.21	1.56	0.26	0.47	1.47	1.01	0.17	1.49	1.60	1.54	0.03	0.0159
12	*Carassius gibelio*	1.07	1.84	1.58	0.23	0.89	1.11	1.00	0.07	1.20	1.82	1.58	0.22	0.0190
13	*Carassius gibelio*	1.28	1.90	1.62	0.15	0.79	1.18	1.00	0.09	1.61	1.63	1.61	0.01	0.0161
14	*Carassius gibelio*	0.96	1.82	1.48	0.21	0.65	1.21	1.01	0.14	1.38	1.56	1.46	0.05	0.0159
15	*Pseudoraspora parva*	0.79	1.27	1.01	0.12	0.74	1.29	1.00	0.11	0.97	1.06	1.00	0.02	0.0088
16	*Pseudoraspora parva*	0.61	1.17	0.88	0.10	0.71	1.37	1.01	0.11	0.85	0.92	0.88	0.02	0.0068
17	*Pseudoraspora parva*	0.94	1.14	1.05	0.06	0.95	1.08	0.99	0.04	0.98	1.12	1.05	0.05	0.0137
18	*Pseudorasbora parva*	0.76	1.16	0.89	0.09	0.85	1.26	1.00	0.09	0.84	0.92	0.89	0.02	0.0104
19	*Gambusia holbrooki*	0.69	3.76	1.31	0.49	0.54	3.04	1.05	0.39	1.23	1.30	1.25	0.01	0.0142
20	*Gambusia holbrooki*	0.87	1.60	1.26	0.14	0.70	1.25	1.00	0.10	1.15	1.37	1.26	0.05	0.0214
21	*Lepomis gibbosus*	0.92	2.36	2.00	0.35	0.64	1.29	1.02	0.16	1.29	2.53	1.97	0.24	0.0367
22	*Lepomis gibbosus*	1.31	3.04	1.65	0.23	0.82	1.92	1.01	0.13	1.53	1.81	1.64	0.07	0.0196
23	*Oncorhynchus mykiss*	0.82	1.48	1.22	0.20	0.68	1.22	1.01	0.17	1.20	1.22	1.21	0.01	0.0119
24	*Onchorhyncus mykiss*	1.10	1.86	1.30	0.23	0.85	1.43	1.01	0.18	1.28	1.30	1.29	0.01	0.0128
25	*Onchorhyncus mykiss*	0.86	1.70	1.07	0.19	0.81	1.51	1.01	0.17	0.96	1.14	1.06	0.05	0.0109
26	*Onchorhyncus mykiss*	0.79	1.66	1.06	0.15	0.77	1.60	1.01	0.14	0.99	1.14	1.05	0.03	0.0103
27	*Oncorhynchus mykiss*	1.20	1.71	1.36	0.11	0.86	1.17	1.00	0.06	1.25	1.53	1.36	0.06	0.0128
28	*Onchorhyncus mykiss*	1.31	1.70	1.45	0.12	0.90	1.18	1.01	0.08	1.40	1.55	1.45	0.04	0.0140
29	*Onchorhyncus mykiss*	1.01	1.53	1.26	0.11	0.84	1.21	1.00	0.08	1.19	1.38	1.26	0.04	0.0115

Note. min: minimum; max: maximum; SD: standard deviation

The length-weight relationship parameters depend on food availability, environmental conditions, environmental stress, geographic region, and climatic changes (Matos et al., 2019; Prestes et al., 2019; Sampaio et al., 2019; Oliveira et al., 2020). Our results revealed that the parameters of the exotic fishes collected from Türkiye fall within the range of previous reports (Çetinkaya, 2006; Innal & Erkakan, 2006; Innal, 2012; Tarkan et al., 2015; Çiçek et al., 2021, 2022) indicating that likely inhabit ecosystems that are suitable for them, e.g., cichlid species were discovered in the Mediterranean region during field surveys conducted between 2014 and 2019 due to their preference for tropical climates. In addition, *G. holbrooki* is found in a range of water bodies, demonstrating its high tolerance for aquatic conditions. Other successful exotic fishes such as *C. auratus*, *C. gibelio*, *P. parva*, and *L. gibbosus* were collected in lentic waters and used to release common carps into natural environments for stocking programs, demonstrating that restocking programs are the primary cause of exotic species spread in many Turkish waters.

Fulton's, relative and mean condition factors, and form factors were calculated for the 29 studied populations (Table 4, Figure 1). The values of K_F were in the range of 0.875 (*P. parva*) to 1.973 (*L. gibbosus*) with a mean and median of 1.376 and 1.445, respectively. We found out that Fulton's and mean condition factors were similar. As is seen from Table 4, the values of K_R varied from 0.993 (*P. parva*) to 1.047 (*G. holbrooki*). Le Cren (1951) proposed the relative condition factor (K_R), which is considered changes in form or condition as length increases and assesses an individual's divergence from the sample's average weight for length. The condition factor for all species was found to be high, except for *P. parva* (Table 5). This shows that the studied exotic species have been established successfully, i.e., they are in good condition in the new habitats.

Figure 1

Box Plot of (A) Allometric Co-Efficient b Values, (b) Fulton's Condition Factor (K_F) for 29 Population Belongs to Eight Exotic Fish Species from Türkiye

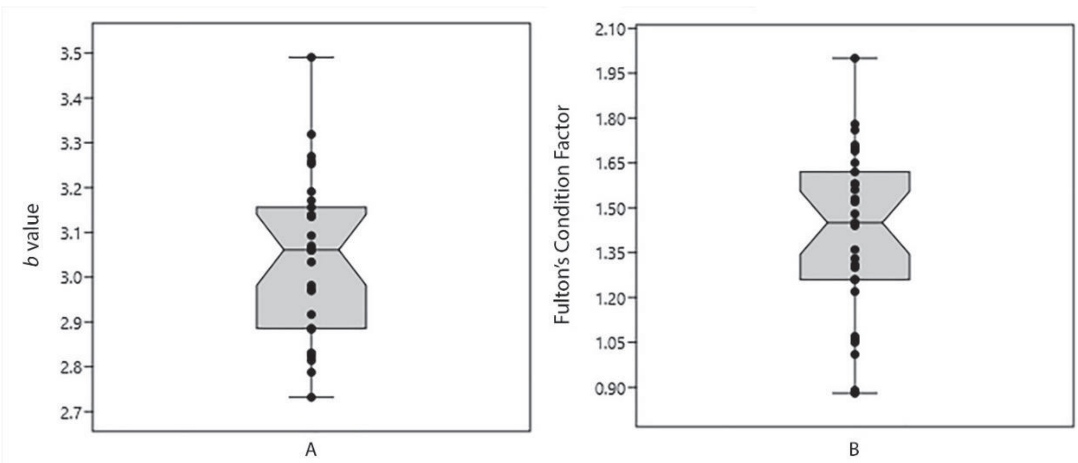

Table 5

Fulton's Condition Factor (K_F) for Eight Exotic Fish Species from Türkiye

Species	Range	Mean	SD
Oreochromis niloticus (n: 1)		1,52	
Coptodon zilli (n: 1)		1,78	
Carassius auratus (n: 3)	1.33-1.53	1,43	0,12
Carassius gibelio (n: 9)	1.48-1.76	1,63	0,09
Pseudoraspora parva (n: 4)	0,88-1,05	0,96	0,08
Gambusia holbrooki (n: 2)	1.26-1.31	1,29	0,04
Lepomis gibbosus (n: 2)	1.65-2.00	1,83	0,25
Oncorhynchus mykiss (n: 7)	1.06-1.45	1,25	0,14

Note. SD: standard deviation; n: number of population

As an example, we compared the condition factor of *C. gibelio* with other coexisting indigenous species in Çıldır Lake (Table 6) to observe their competition with indigenous fishes of this lake. Based on our findings, the highest K_F value was calculated as 1.76 for *C. gibelio* as well as *C. carpio*. There was a strong positive relationship between Fulton's and the mean condition factors. Froese (2006) and Clark (1928) showed that if *b* is not significantly different from 3, K_F can be compared directly. Additionally, to make such comparisons easier, Le Cren (1951) proposed the relative condition factor (K_R). The values of K_R were generally close to 1, showing an overall state of well-being for the studied species. However, the K_R value of *C. gibelio* is significantly higher than that of other species. Therefore, it can be argued that the condition of the natural species is negatively affected by the occurrence of *C. gibelio*. Indeed, with the introduction of *C. gibelio* to lake Çıldır, the catch composition changed by increasing the catch value of *C. gibelio* and declining those indigenous species sharply (A. Ağbulak, personal communication, August 13, 2014).

Table 6

Condition Factor and Form Factor Values for Sampled Species in Lake Çıldır

Species	O	K_F		K_M		K_R		Form Factor
		Range	Mean	Range	Mean	Range	Mean	
Acanthobrama microlepis	N	0.58-1.11	0.80±0.09	0.73-0.85	0.80±0.03	0.74-1.41	1.00±0.10	0.0084
Alburnoides eichwaldii	N	0.63-1.34	0.96±0.14	0.65-1.16	0.95±0.08	0.79-1.44	1.01±0.12	0.0152
Alburnus filippii	N	0.65-0.92	0.77±0.07	0.72-0.85	0.77±0.03	0.83-1.18	1.00±0.09	0.0087
Capoeta capoeta	N	0.63-1.58	0.91±0.13	0.80-1.02	0.90±0.04	0.69-1.60	1.01±0.14	0.0087
Luciobarbus mursa	N	0.74-1.33	1.01±0.13	0.95-1.05	1.00±0.02	0.75-1.32	1.00±0.13	0.0103
Squalius turcicus	N	0.79-1.44	1.11±0.11	0.98-1.21	1.09±0.05	0.71-1.24	1.01±0.09	0.0111
Cyprinus carpio	T	0.94-2.48	1.76±0.34	1.56-2.02	1.73±0.09	0.57-1.49	1.02±0.20	0.0165
Carassius gibelio	E	1.19-2.53	1.76±0.31	1.13-1.48	1.33±0.10	0.99-1.74	1.32±0.15	0.0140
Pseudoraspora parva	E	0.79-1.27	1.01±0.12	0.97-1.06	1.00±0.02	0.74-1.29	1.00±0.11	0.0088

Note. O: Occurrence; N: Natural; T: Translocated; E: Exotic; K_F: Fulton's Condition Factor; K_R: Relative Condition Factor; K_M: Mean Condition Factor

Therefore, the possible impacts of the introduced fishes on the native fish biodiversity in Türkiye are yet unknown and further research is crucial.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Türkiye'de Bulunan Sekiz Egzotik Balık Türünün Boy-Ağırlık İlişkisi ve Kondisyon Faktörü

Bu çalışma egzotik balık türlerinin bazı popülasyon dinamiği parametrelerinin belirlenmesi amacıyla yapılmıştır. Bu kapsamda örnekler 2014, 2015, 2017, 2018 ve 2019 yıllarında Türkiye'deki 10 farklı havzadan (Batı ve Doğu Akdeniz, Çoruh, Seyhan, Aras, Asi, Doğu Karadeniz, Fırat, Konya ve Kuzey Ege) toplanmıştır. Örnekler, Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğünün finansal desteği ile gerçekleştirilmiş olan iki projenin (Project on Establishment of Ecological Assessment System of Water Quality Specific for Türkiye" ve "Project on Establishment of Reference Monitoring Network in Türkiye) alan çalışmaları esnasında toplanmıştır.

Örnekleme çalışmaları akarsularda elektroşoker (SAMUS 1000) ile durgun su ekosistemlerinde ise uzatma ağları (12 farklı göz açıklığına sahip) kullanılarak yapılmıştır. Toplanan örnekler %4'lük formaldehit solüsyonu içerisinde muhafaza edilerek laboratuvara taşınmıştır. Laboratuvarda muhafaza edilen örnekler bir gün süre ile çeşme suyu altında tutulduktan sonra total boy 0,1 cm ve total ağırlık ise 0,01 g hassasiyetle belirlenmiştir. Örneklemeler sonucunda *Oreochromis niloticus*, *Coptodon zillii*, *Carassius auratus*, *C. gibelio*, *Pseudorasbora parva*, *Gambusia holbrooki*, *Lepomis gibbosus* ve *Oncorhynchus mykiss* türlerinin bulunduğu sekiz egzotik balık türüne ait 29 populasyondan incelenen toplam 1958 adet birey için boy-ağırlık ilişkileri (L-WRs) ve kondisyon faktörü değerleri hesaplanmıştır. Boy-ağırlık ilişkisi sabitlerinden *b* değerinin 2,732 (*C. auratus*) ile 3,319 (*C. gibelio*) arasında değişim gösterdiği belirlenmiş olup çalışılan populasyonlar için ortalama ve ortanca değerler sırasıyla 3,013 ve 3,047 olarak hesaplanmıştır. Regresyon analizi sonucunda boy-ağırlık değerleri arasında yüksek bir pozitif ilişki belirlenmiş olup R^2 değeri 0,753 ile 0,998 arasında bulunmuştur. Fulton'un kondisyon faktörü değerinin 0,882 (*P. parva*) ile 2,002 (*L. gibbosus*) arasında değişim gösterdiği belirlenmiş ve ortalama ve ortanca değerler sırasıyla 1,397 ve 1,453 olarak hesaplanmıştır. Fulton'un kondisyon faktörü değerleri ile ortalama ve nispi kondisyon faktörü değerlerinin de benzer bir özellik sergilediği görülmüştür. Hesaplanan değerlere bakıldığında *P. parva* dışında diğer tüm egzotik türlerin kondisyon değerlerinin oldukça yüksek olduğu ortaya çıkmaktadır.

Bunun yanı sıra Çıldır Gölü'nde egzotik balık türleri ile birlikte yaşadıkları yerli türlerin kondisyon faktörü değerleri karşılaştırılmıştır. Karşılaştırma sonucunda yerli türlere göre *C. gibelio*'nun türünün en yüksek kondisyon faktörü değerine sahip olduğu belirlenmiştir. Çıldır Gölünde tespit edilmiş olan *P. parva*'nın kondisyon faktörünün ise bazı doğal türlerden yüksek olsa da genelde benzer olduğu görülmüştür. Bu durum yerli türlerin büyümeleri üzerinde *C. gibelio*'nun olumsuz etkilere sahip olduğunun işareti olarak değerlendirilebilir. Türkiye'de yerli balık çeşitliliği ile tanıştırılan yabancı türlerin etkileri hala bilinmemekte olup bu alanda çalışmalar yapılması kritik önem taşımaktadır.

Research Article

Assessing the Potential Resistance of Floating Vegetation against Different Flow Rates

Yüzer Halde Bulunan Bitkilerin Farklı Hız Akış Oranlarına Karşı Potansiyel Dirençlerinin Değerlendirilmesi

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Abstract

Constructed Floating Wetlands have been rising an innovative and environmentally friendly water treatment technology for both stormwater and wastewater over the decades. For the sustainability of these systems, hydraulic components of wetlands should be carefully monitored and properly managed. With this study, the root resistance of *Baumea rubiginosa* and *Phragmites australis* grown in the drinking water and a synthetic water mix representing stormwater and domestic wastewater with low and high nutrient content against different flow rates was examined. With the nutrient uptakes from intermediate bulk container water tanks, two plant species had reached at harvest stage over the period of 35 weeks, and then they were subjected to flume test experiment. Two plant species from five different water types showed different growth levels in roots and shoots, and thanks to their stronger and denser root structures, plant species of *Baumea rubiginosa* and *Phragmites australis* in domestic wastewater with low nutrient were found more resistant to the flow by pushing water deeper and cause a higher hydraulic head loss between upstream and downstream in comparison to the rest of plant types. The relationships between three different components: Root volume, flow rate and head loss were also analysed through correlation test in SPSS Statistics and the relationship between root volume and head loss was found positive at the higher flow rate(s). The results demonstrate that these native plant species in constructed floating wetlands could be used to reduce extreme flow rates in upstream side and provide a safe environment during extreme flood events.

***Keywords**: constructed floating wetlands, stormwater, domestic wastewater, root resistance, floating vegetation*

Öz

İnşa edilen yapay sulak alanlar son yıllarda hem hasat edilen yağmur suyu hem de atık-su için yenilikçi ve çevre dostu bir su arıtma teknolojisi olarak ortaya çıkmıştır. Bu sistemlerin sürdürülebilirliği için, bu sistemlerin parçası olan hidrolik bileşenlerinin dikkatlice izlenilmesi ve düzenli olarak yönetilmesi gerekir. Bu çalışma ile birlikte içme suyu, yağmur suyu ve evsel atık-suyu temsil eden sularda yetişen *Baumea rubiginosa* ve *Phragmites australis* bitki türlerinin kök dirençlerinin farklı akış miktarlarına gösterdiği dirençler araştırılmıştır. Su tanklarında yetiştirilip 35 hafta da olgunluğa erişen bu iki bitki türü akışkanlar mekaniği testine maruz bırakılmıştır. Beş farklı su türünde yetişen iki bitki türü köklerinden ve gövdelerinden farklı oranlarda gelişim göstermişlerdir. Düşük besin maddesi ile simüle edilen evsel atık-suda yetişen bitkilerin daha güçlü ve yoğun kök yapısına sahip olduğu ve bu sayede bu bitkilerin su akışına gösterdikleri direncin daha fazla ve yapay su kanalın memba ve mansap kısmı arasında daha fazla bir yük kaybı meydana getirdikleri belirlenmiştir. Kök hacmi, akış oranı ve hidrolik yük kaybı arasındaki ilişki SPSS de korelasyon yaklaşımıyla incelenmiş ve yüksek akışkan oranlarında hacimce büyük köklerin meydana getirdiği hidrolik yük kayıplarının daha fazla olduğu bulunmuştur. Sonuç olarak, söz konusu iki lokal bitkinin kök dirençleri sayesinde havza bazında aşırı hız akışını azaltma ve aşırı sel taşkınlarının olduğu durumda güvenli bir ortam sağlayabilecekleri bulunmuştur.

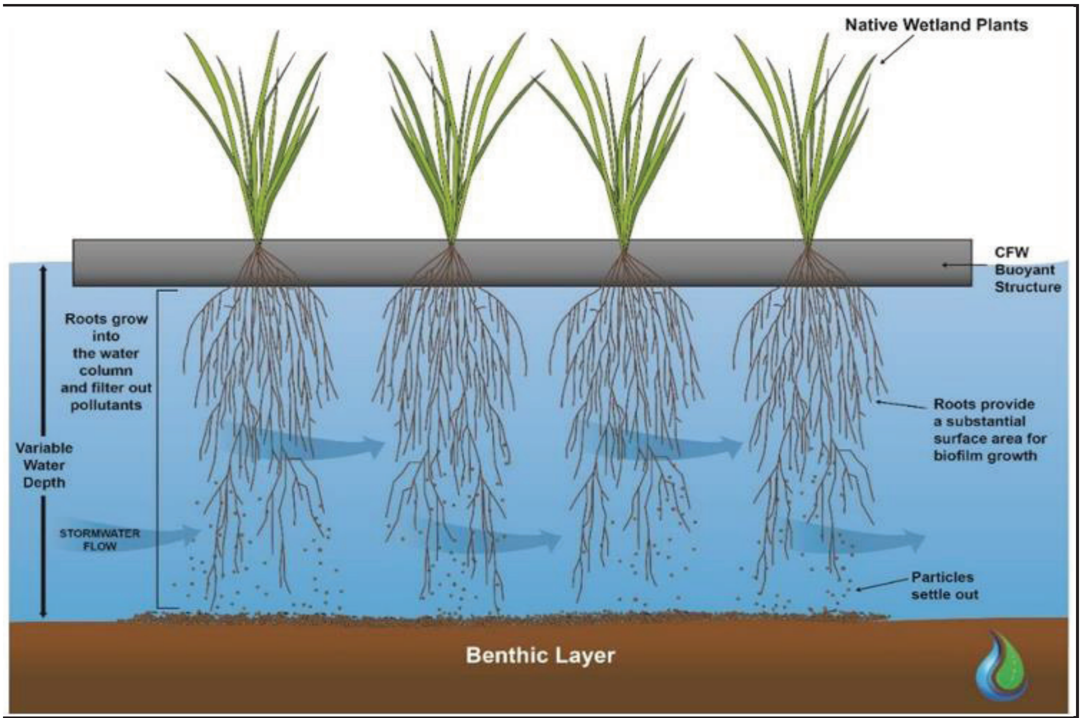
Anahtar sözcükler*: yapay sulak alanlar, yağmur suyu, evsel atık-su, kök direnci*

Introduction

Urban waterways are under the threat of pollution mostly coming from wastewater and pollutants washed off from impervious urban landscapes during the stormwater events (Chance & White, 2018; Kumari & Tripathi, 2014; Nuruzzaman et al., 2021). Though, the concentration of pollutants such as Total Nitrogen (TN), Total Phosphorous (TP) and organic matter in stormwater is lower than in wastewater, a much larger area must be designed and much more attention should be paid to treating stormwater because of high volume of runoff, especially during rainy seasons (Liu et al., 2009). So far, several policies, standards, guidelines and treatment technologies have been set up by the governments, scientists and engineers to mitigate pollution problems in waters across the world (Daly et al., 2012). Water control and treatment strategies under the different names are developed in cities (Nuruzzaman et al., 2021), and these initiatives are generally termed as Best Management Practices (BMPs) that are stood out as stormwater control measures (SCMs) including treatment, green infrastructure (GI), low impact design (LID) in USA and New Zealand, sustainable urban drainage systems (SUDS) in England, water sensitive urban design (WSSUD) in Australia (Yang & Lusk, 2018). As one of the best management practices, Constructed Floating Wetlands (CFWs) that are defined innovative and environmentally friendly water treatment technology (Lucke et al., 2019; Stefanakis, 2020), are successfully implemented to treat and manage the polluted water types including stormwater runoff (Tanner & Headley, 2011), sewerage water (Van de Moortel et al., 2011), natural lake/river water (Kato et al., 2009), nutrition-rich agricultural/farm manure water (Sooknah & Wilkie, 2004), eutrophic water (Olguín et al., 2017), and paper mill wastewater (Ayres et al., 2019). CFWs in Figure 1, can be detailed through the presence of macrophytes over the floating beds taking a place of soil base that is supportive of terrestrial macrophytes for the sustainability, as well as economic, environmental and ecological water treatment methods in the water bodies (Ge et al., 2016).

Figure 1

Design of Constructed Floating Wetlands (Lucke et al., 2019)



Several factors including plant species, temperature, detention time, and pollutant loading rate play a significant role in evaluating the treatment efficiency of CFWs in addition to the hydraulics of CFWs that has also a substantial impact on the treatment by affecting the amount of inflow through root zone and residence time (Nuruzzaman et al., 2021). Moreover, vegetation acts as a principal source of hydraulic resistance against flow in wetlands (Kadlec, 1990), affects the flow in several ways (Piercy, 2010), and would bring about some difficulties in hydraulic design (Järvelä, 2005). As a result, the hydraulic components of these systems should be very well understood to manage these systems properly.

As reviewed from the recent studies, it is found that there are few experiments based on wetland hydrology since a majority of studies are mostly focused on water treatment performance, plant and root development and changes in water quality in wetland conditions. Schwammberger et al. (2017; 2019) are set up their experiments on CFWs with two different studies in Queensland, Australia. Through these studies, the investigation on monitoring changes in water quality parameters and plant development are done. Moreover, Ge et al. (2016) briefly point out Floating Treatment Wetlands referring that CFWs can improve the health of the aquatic environment and contribute to the life of other organisms by slowing down the velocity, which facilitates the settlement of suspended solids. However, there is no real implementation to find out the relation between flow and wetland vegetation.

A few studies have been found to determine the hydraulics of water bodies and the resistance of roots to different flows in CFWs. In addition to experiments carried out at the field-scale with different applications, a flume test experiment widely takes place in the laboratory to assess the impact of roots to flow in the laboratory.

As a matter of fact, the majority of flume test experiments are conducted via artificial vegetation that is made of either wood or synthetic material rather than real vegetation at varying flow velocity values (Chang et al., 2015). For instance, Liu et al. (2019) set up a flume test experiment through a staggered array of rigid dowels to examine the impacts of the floating treatment island FTI spacing on the flow. In this study, the approach of simulation of floating macrophyte roots is considered. Chang et al. (2015) test the effects of vegetation on the flow by placing artificial vegetation to identify the performance of the automatic pulse tracer velocimeter (APTV) in the lab, followed by the adaptation of obtained results into wetland conditions.

Despite a number of studies with a similar approach, it is believed that neither artificial dowels nor other artificial rigid materials of vegetation as mentioned create an environment below the water surface similar to the real root structures since the emerged roots cannot remain motionless below the water surface and are freely shaped in parallel to the flow when immersed them in water. A further step is taken by West (2016), the real plant roots belonging to Typha and Carex are grown in wetland conditions and artificial root structures are used to identify transverse mixing coefficients through a flume test experiment. However, the hydraulic performance of wetland plants through flow condition should be assessed considering several factors together.

Therefore, this research project is undertaken to identify the resistance of real root structures against a range of flow velocities through a flume test experiment and calculate the hydraulic performance of wetland conditions with the presence of real vegetation.

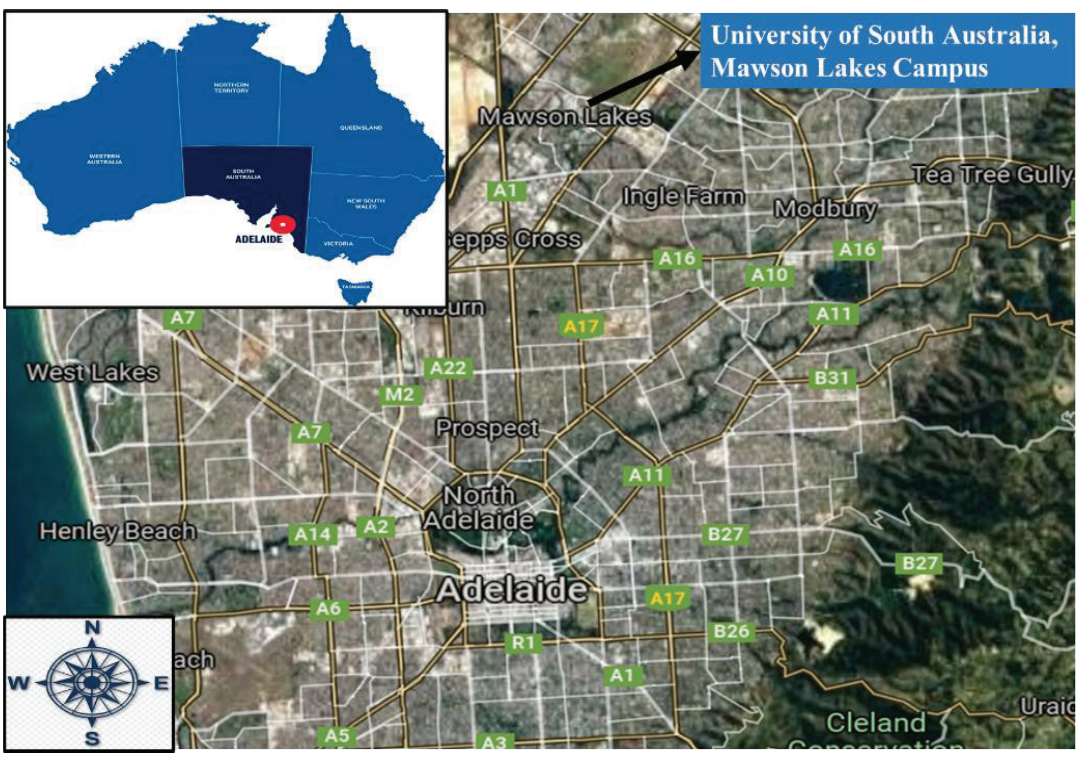
Method

System Information

The simulation of CFW was designed with 10 intermediate bulk container (IBC) water tanks at the University of South Australia on Mawson Lakes Campus in Adelaide, South Australia (34° 48´´ S 138° 37´´ E) and carried out between October 2019 and June 2020. The location of the conducted experiment can be seen in Figure 2.

Figure 2

Location of Mawson Lakes Campus at the University of South Australia

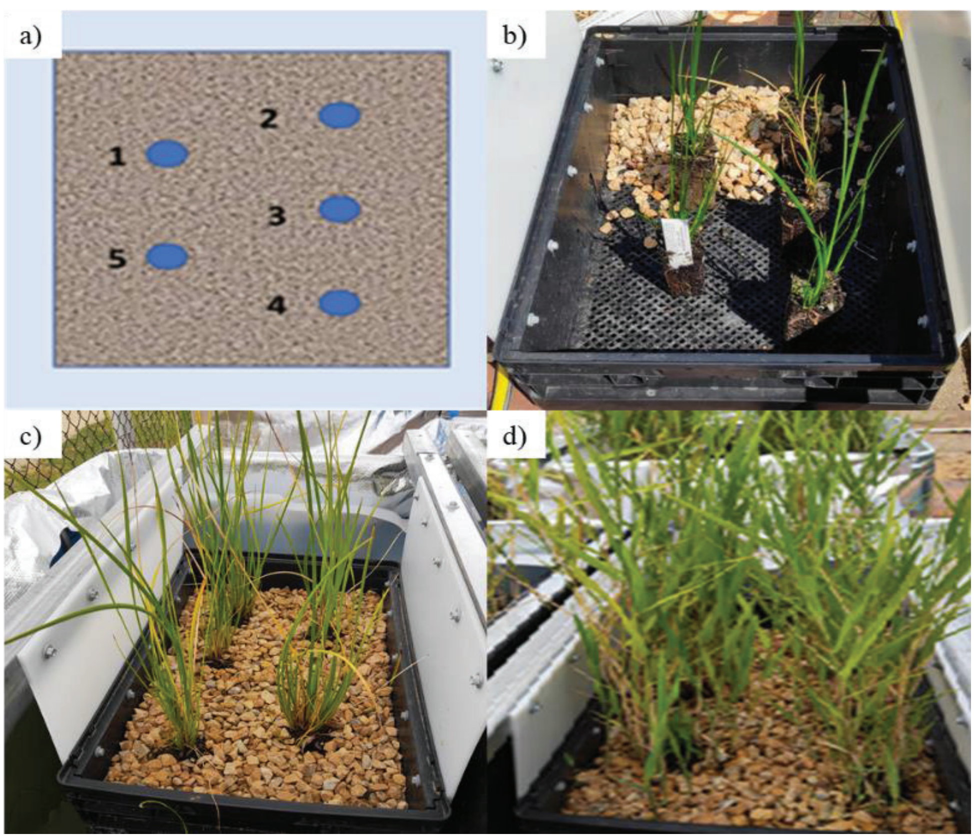


The system was split into two groups represented by *Baumea rubiginosa* (PA) and *Phragmites australis* (PB) plant species. Each tank was then filled with 950 L of potable water so that the plant baskets can be half soaked in order to simulate the CFW environment. The simulation components of each IBC tank consisted of two polypropylene baskets (57 cm * 38 cm * 17 cm) filled with almost 10 cm depth aggregate (Figure 3). Additionally, each tank was wrapped by aluminium insulation foil to limit light penetration from outside, which prevents the growth of cyanobacteria in the tank throughout the experiment.

For each group, four different synthetic waters environment named as W2: Low strength stormwater, W3: High strength stormwater, W4: Low strength domestic wastewater and W5: High strength domestic wastewater were prepared in addition to W1 which was filtered potable water without additional nutrients. Studies through comprehensive review were taken into account to add chemicals such as potassium nitrate (KNO_3) and potassium dihydrogen phosphate (KH_2PO_4) into mesocosm tanks to obtain required nutrient levels (Table 1).

Figure 3

Seedling Setup in the IBC Tanks



Note. The simulation of CFWs in IBC water tanks were made of two polypropylene baskets filled with ~10 cm depth with aggregate (a) and (b). The progress of plant development for *Baumea rubiginosa* (c) and *Phragmites australis* (d) as planted.

Table 1

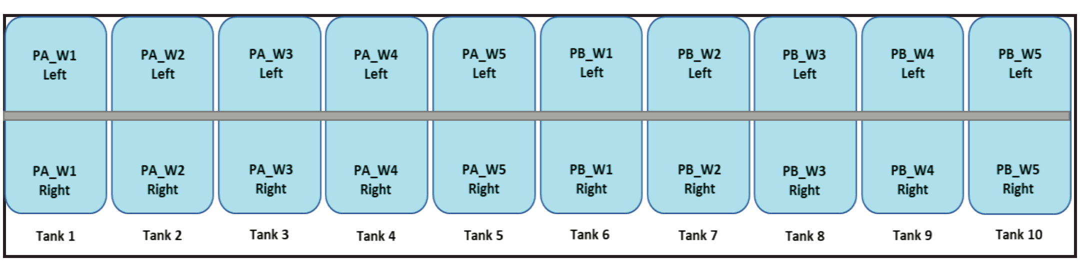
Additional Nutrient Concentrations to IBC Tanks for The Simulation of Water Types (Awad et al., 2022; Carey & Migliaccio, 2009; Duncan, 2005)

Type	Description of Replica	Nitrogen (N) in mg/l	Phosphorus (P) in mg/l	Potassium (K) in mg/l
W1	Potable water	No addition of nutrient		
W2	Low strength stormwater	0.4	0.2	1.3
W3	High strength stormwater	3.7	1.3	11.9
W4	Low strength domestic wastewater	8.0	2.0	24.8
W5	High strength domestic wastewater	25.0	7.0	78.5

To avoid any complexity over the samples, the following naming mechanism was taken into account: Each basket was named based on plant type, water type and location, and they were placed on the IBC tank. If PA_W1 Right or PB_W1 Right is taken as an example, PA stands for "Plant A", representing *Baumea rubiginosa*, and PB stands for "Plant B" representing *Phragmites australis.* W1 reflected the potable water, and the right specified the basket on the right side of the system when facing eastwards. The layout of the IBC tanks with the naming of each basket is as illustrated in Figure 4.

Figure 4

The Drawing of the Entire System on the Site



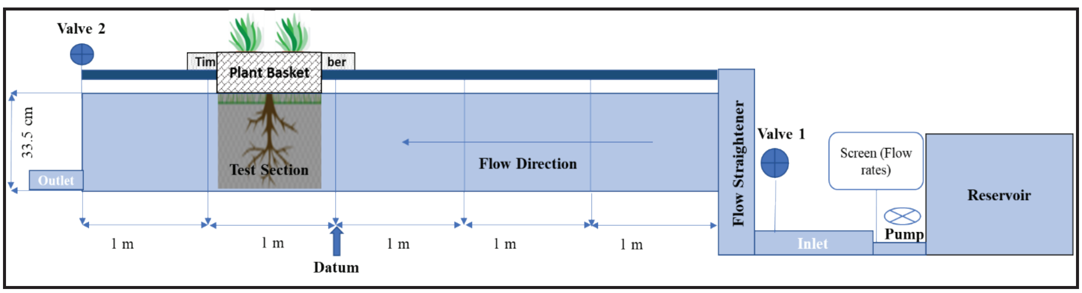
Note. PA: Plant A (*Baumea rubiginosa*), PB: Plant B (*Phragmites australis*), W1: Filtered water without additional nutrients, W2: Low strength stormwater, W3: High strength stormwater, W4: Low strength domestic wastewater, W5: High strength domestic wastewater.

Flume Test

The flume test station on Mawson Lakes Campus was utilized to gain a better understanding of the resistance of root systems of grown plants against variable flow rates. The artificial water channel is 5 metres long, 0.66 metres wide, and 0.50 metres deep, with an effective depth of almost 0.4 metres (observable side-glass) (Figure 5).

Figure 5

The Layout of the Flume Test Station Located on Mawson Lakes Campus



The artificial water channel for flume test was installed with blue painted stainless-steel pillars one metre away from one another and equipped with observable side-glass placed in between. To create a stable one-directional flow, a pump with the adjustable flow was used. While Valve 1 was used to increase or decrease the flow rate provided by the pump, Valve 2 was used to adjust the water level to the desired level just below the basket in a water channel. For this experiment, the desirable flow speed going through an artificial channel was determined as low as 0.05, 0.10 and 0.15 m/s accordingly. As a result, the flow rate generated by the pump should be set as:

$$Q = h * d * V \quad \text{(Equation 1)}$$

Where, Q is flow rate generated by the pump ($m^3.s^{-1}$), V is desired flow speed ($m.s^{-1}$), h is water level in the channel (m), and d is the width of water channel (0.66 m).

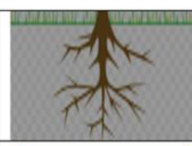
During the test, optimal water height was measured at 0.335 m when the majority of the roots were immersed in water and the bottom of the baskets was not contacted with water, resulting in a flow condition undisturbed by the baskets.

With the theoretical height and channel width, the flow rate from the pump was expected to be 11, 22, and 33 $L.s^{-1}$. However, the pumping rate was not measured as consistent as required owing to uncontrolled variables such as fluctuation of pump power output, and delay after adjusting water gate. In the actual test, the ultimately achieved channel flow rate was accordingly $Q1 = 10.00 \pm 0.19$ L.s^{-1}, $Q2 = 20.00 \pm 0.39$ L.s^{-1}, and $Q3 = 30.00 \pm 0.61$ L.s^{-1}; thus, the height of the water was adjusted accordingly to achieve the design flow speeds.

In order to monitor the placement of baskets on the flume, and the position of water level measured, the pillar on the upstream of the basket was set as the datum reflecting point zero, thus any measurement along the flume can be referenced in accordance with it. Hence, there were nine water levels marked; six on the upstream side 0.25 m, 0.5 m, 0.75 m, 1.25 m, 1.5 m and 1.75 m, and three on the downstream side at 1.25 m, 1.5 m and 1.75 m away from the datum. As shown in Figure 6, the negative sign indicates the orientation of the side in relation to point zero.

Figure 6

Distance of Measured Water Levels from Datum at Different Locations

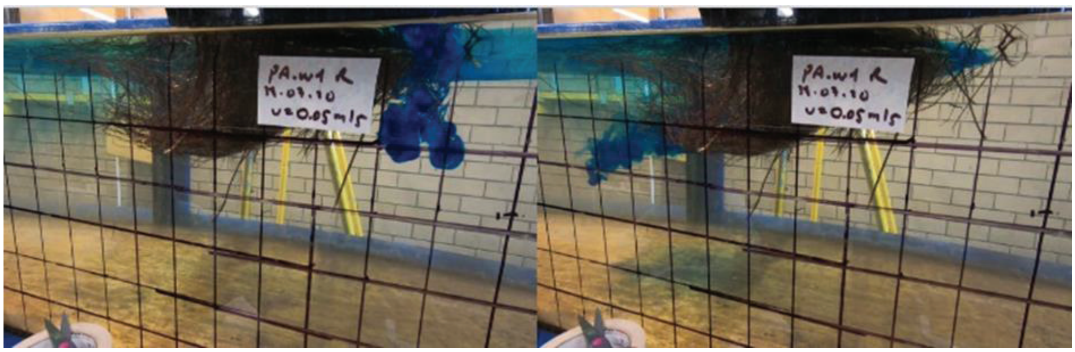
	Downstream Side				Upstream Side					
Water level (cm)										
Locations away from datum (m)	-1.75	-1.50	-1.25	1 m	0.25	0.50	0.75	1.25	1.50	1.75

Water levels at both sides were measured before placing plants at once and after emerging each plant into the water at each flow rate. There were changes in water level at the beginning of the test area just after the flow straightener, which was inconstantly conveyed into both upstream and downstream sides of the channel; as a result, the alarm was set for approximately 15 minutes before commencing each flume experiment to ensure water level literally settled down and there was no up and down movement in water level at both sides.

There is no coincidence that denser roots are able to reduce water flow; yet, owing to continuity, a portion of the flow would be driven to the channel's edges or bottom (Liu et al., 2019). In order to visualise the water flow through the streamline, the dye test was implemented. Once the basket from each IBC tank was placed on the top of the flume test channel one by one, regular food colouring kept in plastic pipettes was injected into the water from just right ahead of the basket at varying flow rates (Figure 7). Time taken to travel for food colouring droplet throughout 1 metre distance was recorded, and in the meantime, the trajectory of dye was recorded by GoPro HERO model camera from glass side in time series. To minimize any possibility of human error, dye injection for one basket was repeated three times even more at each single flow rate.

Figure 7

The Footage for the Dye Test through the Channel in the Presence of the Plant Roots
(PA_W1, V= 0.05 m. s^{-1})



In the end of the flume tests experiment for all plant groups, plant roots were cut off and yielded to examine the effects of magnitude of root volume on flow. Basically, a scissor was used to separate the roots from the plant; following that, the volume of roots was determined using 1000 ml cylinder. For this purpose, the cylinder with 1000 ml capacity was clogged with plant roots and compacted all the way by iron, then excess water was poured into the room of cylinder remained from the roots. The volume of root structures was calculated by subtracting 1000 ml from the quantity of water placed in the cylinder.

A correlation test in SPSS was used to evaluate the effect of the magnitude of root volume and flow rate on hydraulic head loss between upstream and downstream. This approach was determined after applying ANOVA not applicable due to limited data taken from the experiment. For the different cases, p-values < 0.01 and < 0.05 were taken into account as evidence of statistical significance.

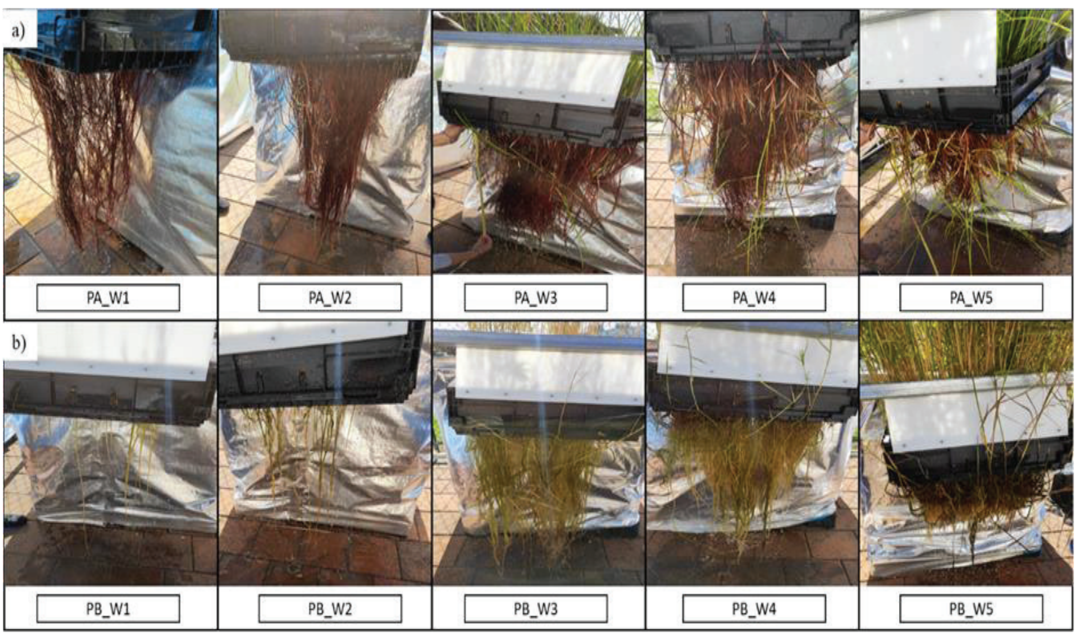
Results and Discussion

Based on observation and experiment, it was concluded that two plant species: PA and PB through normal (control) water and synthetic stormwater and municipal wastewater reached out the harvest level over a 35-week period (Figure 8).

In the dye test, it was predicted that root structures would have no effect on the change in actual velocity if the density of the root was less, which means dye velocities equal to the designed velocity. However, regardless of having a low or high dense root, all root structures influenced the actual flow velocity in some way. With the measurement and video recording of the dye test, those plant species developed in synthetic stormwater and domestic wastewater both at low and high nutrient levels showed greater resistance against flow than the control group thanks to additional nutrients and possession of dense root structures (Figure 9).

Figure 8

*A Caption of Root Structure Looks for Baumea rubiginosa (*a) and *Phragmites australis* (b) *Just before Commencing the Flume Test Experiment*



From the synthetic domestic wastewater with low nutrient levels (W4), both PA and PB created such a greater block in the middle of water body at 30 $L.s^{-1}$ out and pushed dye and water mixture much deeper, resulting in an accelerated dye transmission throughout roots. Hence, the time taken by dye to travel along 1m was less than expected, which increased water velocity up to 16% for PA and 52% for PB respectively. In contrast, the plant types coming from the control group, even though PA has a denser root structure than PB due to characteristics of plant species, the flow after injection of dye in water easily passed throughout roots of both because of less intense root occurrence (Table 2).

Emerged macrophytes are defined as the dominant factor that affects flow conditions along the channel where they are placed (Green, 2005). These influences should be considered not only in terms of variations in flow direction and speed through the channel, but also in terms of hydraulic head loss between upstream and downstream. To develop a better understanding of how emerged roots depending on the magnitude of their volume would influence water level throughout the upstream-downstream line, initially head loss due to channel shape and the slope was measured at 0.75, 0.70 and 0.75 cm at Q = 10, 20 and 30 L.s^{-1} respectively before placing plants in the artificial channel.

Figure 9

Dye Test for Baumea rubiginosa (a; control group, and c; domestic waste-water with low nutrient) and Phragmites australis (b; control group, and d; domestic waste-water with low nutrient)

Note. At Q= 10 L.s^{-1}; V= 0.05 m. s^{-1}, Q=20 L.s^{-1}; V=0.10 m.s^{-1}, Q=30 L.s^{-1}; V= 0.15 m. s^{-1}

From the synthetic domestic wastewater with low nutrient levels (W4), both PA and PB created such a greater block in the middle of water body at 30 $L.s^{-1}$, thus they pushed dye and water mixture much deeper, resulting in an accelerated dye transmission throughout root. Hence, the time taken by dye to travel along 1m was less than expected, which increased water velocity up to 16% for PA and 52% for PB respectively (Table 2).

Table 2

The Response of Dye Transmission to Adjusted Flow Rates

		Q = 10 $L.s^{-1}$		Q = 20 $L.s^{-1}$		Q = 30 $L.s^{-1}$	
Plant Species	Water Types	Time (s)	V(m/s)	Time (s)	V(m/s)	Time (s)	V(m/s)
PA	W1	16.54	0.06	9.35	0.11	5.46	0.18
	W2	17.64	0.06	9.22	0.11	6.46	0.15
	W3	17.00	0.06	9.82	0.10	5.66	0.18
	W4	16.31	0.06	8.79	0.11	5.51	0.18
	W5	15.51	0.06	7.78	0.13	6.28	0.16
PB	W1	17.73	0.06	9.35	0.11	6.11	0.16
	W2	16.51	0.06	8.72	0.11	6.28	0.16
	W3	18.15	0.06	9.06	0.11	5.97	0.17
	W4	14.52	0.07	6.80	0.15	4.76	0.21
	W5	14.20	0.07	6.80	0.15	5.22	0.19

Table 3

Obtained Hydraulic Head Losses between Upstream and Downstream After Flume Test in Response to Root Volume of Two Plant Species in Five Different Water Types and Different Flow Rate

			Q=10 $L.s^{-1}$ Average Water Level(cm)			Q=20 $L.s^{-1}$ Average Water Level(cm)			Q=30 $L.s^{-1}$ Average Water Level(cm)		
Plant Species	Water Types	Root Volume (cm^3)*	Upstream	Downstream	Hydraulic Head Loss (cm)	Upstream	Downstream	Hydraulic Head Loss (cm)	Upstream	Downstream	Hydraulic Head Loss (cm)
Without Plant		-	34.35	33.60	0.75	33.77	33.07	0.70	33.18	32.43	0.75
PA	W1	115.00	33.37	32.60	0.77	33.37	32.50	0.87	32.65	31.90	0.75
	W2	211.50	33.12	32.20	0.92	33.35	32.70	0.65	33.63	32.50	1.13
	W3	311.00	33.73	32.97	0.77	33.27	32.20	1.07	33.32	32.30	1.02
	W4	739.00	33.35	32.30	1.05	33.43	32.50	0.93	34.10	32.80	1.30
	W5	736.00	33.45	32.53	0.92	33.27	32.43	0.83	33.67	32.63	1.03
PB	W1	7.50	33.67	32.83	0.83	33.28	32.43	0.85	33.63	32.73	0.90
	W2	53.50	32.90	32.00	0.90	32.48	31.57	0.92	33.40	32.60	0.80
	W3	293.50	33.43	32.67	0.77	33.67	32.50	1.17	33.30	32.50	0.80
	W4	1324.50	33.55	32.50	1.05	33.05	31.80	1.25	32.62	31.33	1.28
	W5	1569.60	32.90	32.03	0.87	33.15	32.20	0.95	33.20	32.20	1.00

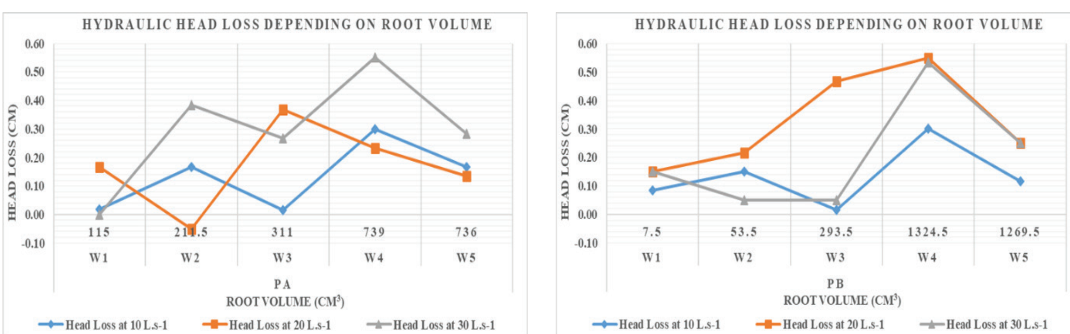
Note. Measurement of root volume was done just after the flume test experiment. The volume of roots for each plant species coming from different types of water was measured by the following method: In the lab environment, the mass of a 1000 ml cylinder filled up with 1000 ml water was measured and noted to determine the mass of 1000 ml water at the lab temperature. Then, the bunch of root biomass for one plant was pushed down to the empty 1000 ml cylinder and the cylinder with roots was filled up with water till the line over 1000 ml. After reaching to 1000 ml, the mass of the cylinder with a mix of both roots and water was measured again. Finally, the difference between the first and second measurements was taken down as the volume of roots belonging to which plant was measured.

The barriers, which consisted of the presence of a distinct volume of roots, produced intriguing results in terms of hydraulic head loss in addition to existence. In parallel to a simultaneous increase in root volume of PA and PB and flow rate, observation of lower water levels in downstream is possible. A close inspection of Table 3 demonstrates that both plant species grown up in synthetic domestic wastewater with low nutrient (W4) brought about a higher head loss at three flow rates in general, and this ratio was up to almost 70 % in addition to constant hydraulic head loss at the highest flow rate 30 L.s^{-1}. Comparing the rest of water level drops in downstream side, those plant types taken from control group illustrated almost the same scenario close to the condition of absence of roots through the flume test channel (Figure 10).

Figure 10

Values Obtained for Additional Hydraulic Head Losses to Existing in Response to Root Structures with Different Magnitude and an Increased Flow Rate

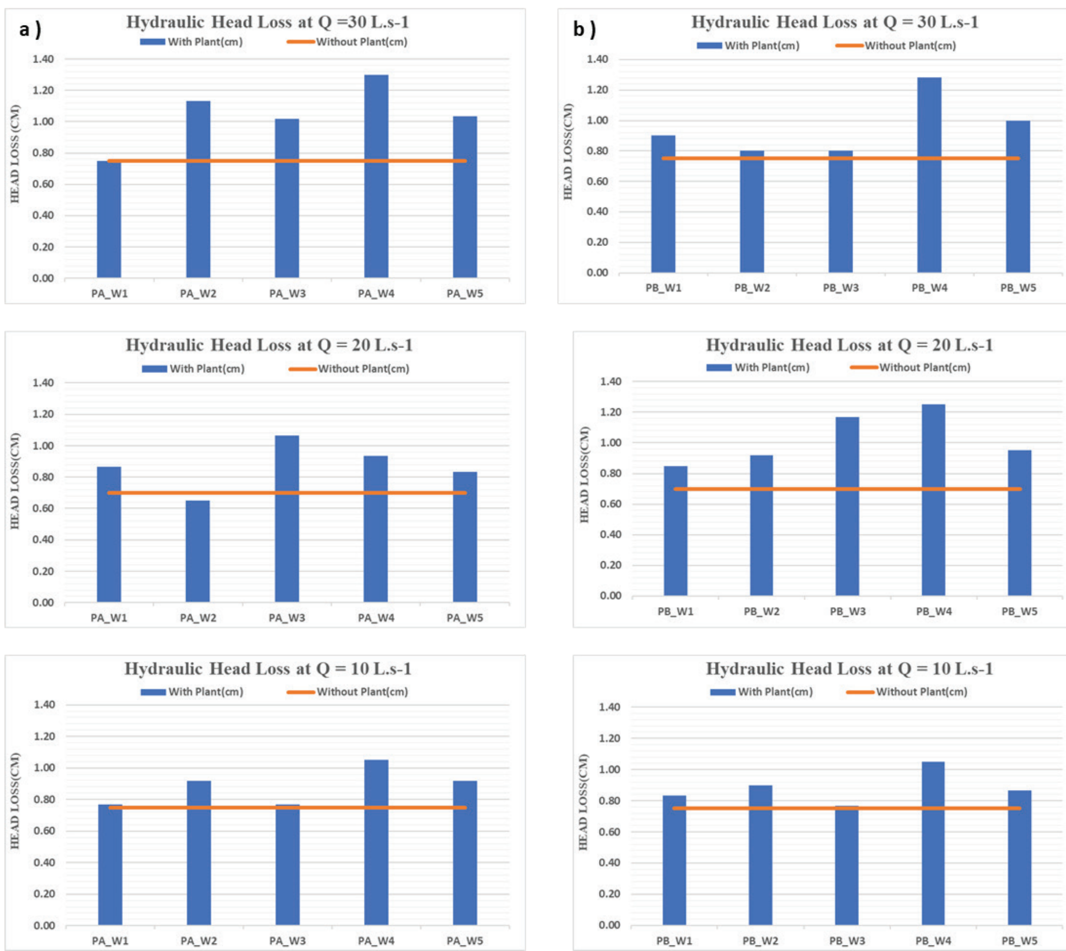
a)   b)



Note. Hydraulic head losses a = *Baumea rubiginosa* and b = *Phragmites australis*

Figure 11

A Comparison between Two Different Hydraulic Head Losses; Existing Due to Channel Shape and Slope and Due to the Presence of Submerged Root Structures



Note. Hydraulic head losses: a = *Baumea rubiginosa* and b = *Phragmites australis*

Figure 11 represents the hydraulic head losses caused by plants as well as the channel geometry at the same time. Regardless of shape, density, or magnitude of root structures, almost every single submerged plant generated head loss between upstream and downstream to some extent except PA grown in synthetic storm water with low nutrient content. Theoretically, the roots of PA were expected to produce head loss whatever flow rate was since it was grown in the environment put additional nutrients. This phenomenon was assumed to happen due to human involvement since every single stage of the flume test through dye was managed by the involvement of a group of people and measurements were done recorded by a group of researchers instead of devices such as flow meters and so on. Therefore, any error because of human involvement in the flume test cannot be prevented.

According to the results of the correlation test, a positive correlation was found between both root volume, discharge and head loss. In accordance with Table 4, the correlation was found higher between an increased root volume and head loss with r = .513, p (.004) <0.01 in comparison with discharge values. In other words, an increase in the volume of roots triggers a more extensive head loss between upstream and downstream of the channel. As discussed by Tavşancıl (2006), the correlation found between two factors can be classified as average, i.e., .50 <.513<.69.

Table 4

Outcomes of Correlation Test in SPSS Applied for Three Inputs; Hydraulic Head Losses Caused by Root Volume and Flow Rate

Variables	n	M	SD	Root Volume (cm^3)	Flow Rate ($L.s^{-1}$)	Hydraulic head loss (cm)
Root Volume (cm^3)	30	506.10	470.08	-	.000	**.513****
				-	1.00	**.004**
Flow Rate ($L.s^{-1}$)	30	0.94	0.16	.000	-	.298
				1.00	-	.109
Hydraulic head loss (cm)	30	20.00	8.31	**.513****	.298	-
				.004	.109	-

** r = .513 and p < .01

Additionally, the effect of increased discharge on the positive and significant correlation between root volume and hydraulic head loss was also interrogated. Hence the increased discharge sent into the flume test channel is evaluated potentially to create a higher head loss (Table 5). In 95% confidence level, when discharge goes up to 30 $L.s^{-1}$ and potentially above to 30 $L.s^{-1}$, and r reaches from .513 to .657 almost a 28% increase (p = .039 < .05). It can be inferred that a large amount of change in hydraulic head loss between upstream and downstream can be generated while keeping root volume as given and flow rate up to 30 $L.s^{-1}$ and above.

Table 5

Outcomes of Correlation Test in SPSS Applied for Three Different Parameters to Evaluate Influence of Magnitude of Flow Rate on Hydraulic Head Loss with the Same Size of Root Structures

			Root Volume (cm^3)	Hydraulic head loss (cm)
Discharge Q = 10 $L.s^{-1}$	Root Volume (cm^3)	Correlation Coefficient	1.000	.462
		Sig (2-tailed)	.	.179
Discharge Q = 20 $L.s^{-1}$	Root Volume (cm^3)	Correlation Coefficient	1.000	.539
		Sig (2-tailed)	.	.108
Discharge Q = 30 $L.s^{-1}$	Root Volume (cm^3)	Correlation Coefficient	1.000	**.657***
		Sig (2-tailed)	.	.039

* $r = .657$ and $p < .05$

Conclusion

The object of this research was to evaluate how different root volumes of Australian native plants *Baumea rubiginosa* (PA) and *Phragmites australis* (PB*)* grown in normal regular water and synthetic water mixing representing stormwater, and domestic wastewater affected hydraulic resistance against flow current in open channel at different discharge values. Two plant species completing the period of their maturity over a 35-weeks were subjected to a flume test experiment using a dye test with flow rates of artificial water channels set at Q = 10, 20, and 30 $L.s^{-1}$. Before emerging the plants into the channel, the examination of hydraulic head loss due to channel shape was done and recorded at 0.75, 0.70, and 0.75 cm, respectively, at the specified flow rates. The dye test was then measured and observed to monitor changes in flow velocity and direction for ten distinct plant types. According to outcomes of dye injection, both plant species grown in low nutrient domestic wastewater simulation accelerated the flow by almost 16% for PA and 52% for PB at Q= 30 $L.s^{-1}$ among the flow rates adjusted. However, this was slightly less when the flow rates were reduced, especially for the plant types in the control group. Moreover, both plant species grown in synthetic domestic wastewater with low nutrients, i.e., W4 generated a larger hydraulic head loss between upstream and downstream in general. When the flow rate was kept at 30 $L.s^{-1}$, these plant species grown in W4 generated the future 0.55 and 0.54 cm hydraulic head loss to the existing one in comparison to the rest of plant types. When the flow rates are decreased, head losses dropped down simultaneously. To support these findings, results were also analysed via correlation approach in SPSS package, which revealed a strong and substantial correlation between larger and denser root structures and hydraulic head loss between upstream and downstream of the channel. This relation became strong when keeping the flow rate up to 30 $L.s^{-1}$ and potentially above.

Based on the experiment and findings, it is considered and suggested that *Baumea rubiginosa* and *Phragmites australis* might represent a feasible solution to remove the contaminants from stormwater and wastewater body. On the other hand, thanks to their strong and dense root structures, they can be useful in the future to mitigate extreme events like flood by slowing down the flow at the basin level.

Due to human involvement and the necessity of more reliable data collection for the flume test experiment, further studies should be done without any intervention of human involvement by adapting technological tools and machines for readings throughout the flume test experiment.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Yüzer Halde Bulunan Bitkilerin Farklı Hız Akış Oranlarına Karşı Potansiyel Dirençlerinin Değerlendirilmesi

Bazen özel amaçlar için geçerli olsa da sürdürülebilirlik açısından dünya genelinde ve ülkemizde kirli suların arıtımı ve tekrar kullanımı oldukça yaygın bir şekilde yapılmaktadır. Su arıtımları geçmişten süre gelen geleneksel arıtma yaklaşım yöntemleriyle beraber son yıllarda yapay olarak inşa edilen sulak alan tipi sistemlerde de yapılmaktadır. Sulak alan tipi yapay olarak inşa edilen arıtma sistemleri, bitkilerin sisteme nasıl entegre edildiğine göre isim almaktadırlar ve bu adlandırmalardan bir tanesi de 2000'li yılların başından itibaren uygulamaya konulan bitkilerin yüzer halde sisteme entegre edildiği yapay sulak alanlardır. Bu tür sistemlerde kirli sularla beraber gelen kirleticiler doğrudan bitkinin biyokütlesine transfer edildiğinden diğer bir ifade ile sistemde besin maddelerini bünyesinde tutacak toprak varlığının olmayışından, bitkiler oldukça hızlı ve güçlü kök ve gövde yapısı göstererek gelişirler (Awad ve ark., 2022). Bu tür su arıtım sistemleri kirletici içeren evsel atık-suyuna ve sanayi atık-suyuna, ayrıca şehirlerde hasat edilen yağmur sularına bu sulardan kirleticilerin uzaklaştırılması amacıyla başarılı bir şekilde uygulanmıştır. Bu tür sistemlerde bitkilerin kirletici maddeleri bünyelerine alabilmeleri için arıtma sistemindeki suyun belli oranlarda hıza sahip olması ve sistemdeki kirletici maddelerini bir noktadan başka bir noktaya hareket ettirmesi sistemin devamlılığı açısından gereklidir. Diğer bir taraftan besin alınımına orantılı olarak sistemdeki bitkilerin kök ve gövdeleri bir gelişim göstermekte, bu proses bitki türüne göre ve kirli suyla beraber kirletici yoğunluğuna göre değişmektedir. Bu açıdan kirli suların arıtımından en iyi performans alınması ve sistemin sürdürebilirliği için sistemin hidrolik parametrelerinin ve bitkilerin ortamdaki su akış hızına gösterecekleri direncin geniş bir şekilde hesaplanıp bulguların sistem tasarımında hesaba katılması gerekir.

Bu araştırmada Avustralya'nın Adelaide şehrinde bulunan Güney Avustralya Üniversitesi'nin Mawson Lakes kampüsünde 10 tane 1000 litrelik su tankı kurulmuş, sisteme A grubu *Baumea rubiginosa* ve B grubu *Phragmites australis* bitkilerinin tank yüzeylerine yüzer bir şekilde adapte edilmesiyle bu bitkilerin su arıtma performansları ve buna bağlı olarak köklerde farklı oranlardaki gelişmenin su akış ortamında su akışına gösterebilecekleri dirençler hesaplanmıştır. 10 adet su tankı 5'erli olarak A ve B şeklinde iki gruba ayrılmış, A grubu *Baumea rubiginosa* ve B grubu *Phragmites australis* temsil edecek şekilde PA (Plant A) ve PB (Plant B) olarak adlandırılmıştır. Daha sonra her iki gruptaki tanklar 950 L su ile doldurularak ve tanklara normal su (W1), az besinli yağmur suyu (W2), zengin besinli yağmur suyu (W3), az besinli evsel atık-suyu (W4) ve zengin besinli evsel atık-su (W5) simülasyonu yapmak için yeterli ve gerekli miktarlarda azot(N), fosfor (P) ve potasyum (K) maddelerini sağlayacak kimyasallar konulup ve tankların alt kısımlarından hava kabarcıkları gönderilerek çalışma başlatılmıştır. Tanklarla kurulan sistemde bitkiler, su gövdesinden kökler yardımıyla alınan besin miktarına, yoğunluğuna ve su kullanım oranına bağlı olarak kök ve gövdelerinden farklı oranlarda gelişim göstermişlerdir. Yaklaşık 35 hafta süren bu çalışmada bitkilerin yeterli erginliğe ulaştığı kanısına varılıp bitkiler kampüs içerisinde bulunan akışkanlar mekaniği test istasyonuna alınmış ve kanala 10, 20 ve 30 $L.s^{-1}$ debilerine sahip akışlar gönderilerek bitkilerin su akışına gösterdikleri direnç ve kanalın memba ve mansap kısmında meydana getirdikleri hidrolik yük kayıpları hesaplanmıştır.

Elde edilen sonuçlara göre her iki bitki türü içinde zengin besinli yağmur suyu ve her iki az ve zengin besinli evsel atık-suyu simülasyonlarında yetişen bitkilerin kök gelişimlerinin ve yoğunluklarının diğer iki su simülasyonuna göre daha fazla olduğu ve su akışına gösterdikleri direncin daha fazla olduğu bulunmuştur. Özellikle *Phragmites australis* bitkisinin *Baumea rubiginosa*

bitkisine göre az besinli evsel atık-su ortamında yetişen türlerinin su akışına gösterdikleri direncin ve yapay su kanalının memba ve mansap kısmında meydana getirdiği hidrolik yük kaybının daha fazla olduğu bulunmuştur. Diğer taraftan ölçümlerin araştırmacılar tarafından yapılması diğer bir ifade ile ölçümlerde insan faktörünün olması bazı durumlarda ölçümlerdeki hassasiyetin düşmesine sebep olmuştur. Örneğin, az besinli atık-su simülasyonu ortamında yetişen *Baumea rubiginosa* bitkisi sistemde kanal şeklinden kaynaklı hidrolik yük kaybı olmasına rağmen sistemde negatif yönlü bir hidrolik yük kaybı meydana getirmiştir. Bu açıdan ilerde yapılacak benzer çalışmalarda bütün ölçümlerin elektronik aletlerle hassas bir şekilde yapılması ve ölçümde düşünülen su kanalının daha büyük ve gerçeğe yakın olarak tasarlanması düşünülmelidir.

Sonuç olarak, her iki bitki türü de hasat edilmiş yağmur suyu ve evsel atık-sulardaki kirleticilerin arıtılmasında başarıyla uygulanmış ve her iki bitki türü de kök gelişmişlik yoğunluğuna bağlı olarak su akışına belirli miktarlarda direnç gösterip ve sistemin memba ve mansap kısımlarında su akışını etkileyerek hidrolik yük kayıpları meydana getirmişlerdir. Bu durum bu bitkilerin ve bunlara benzer bitkilerin havza bazlı su akışını yönetmede ve sel felaketleri gibi ekstrem doğa olaylarında kullanılabileceklerini göstermiştir. Ancak konunun daha geniş açıdan araştırılması ve bulguların geniş alanlarda uygulamaya aktarılması için çalışmaların yapılması önerilmektedir.

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