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Development of a novel water efficiency sustainability index framework for analysis and monitoring of water efficiency in schools

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ABSTRACT

Climate change, urbanization and increasing water demand cause serious pressure on water resources. Efficient use of water, planning and sustainable implementation of water efficiency practices are quite important for sustainable water management. The aim of this study is to develop a novel water efficiency sustainability index framework for evaluating and monitoring water efficiency practices in schools. A total of 123 components were defined under the sub-sustainability indexes of Education and Capacity Development (EKG-index) (47 components), Water Consumption Analysis and Monitoring (STA-index) (50) and Audit, Control and Maintenance (DKB-index) (26). The weights of indices and components were determined by the best worst method. The highest weight was calculated as 0.394 for EKG. The weights of the DKB and STA indices were 0.307 and 0.299, respectively. The scores of components were obtained from 35 schools based on field data. The highest and lowest OSVS index scores were obtained as 3.90 and 2.14, respectively. In pilot schools, the scores of the DKB sub-index were higher than those of the EKG and STA indices. This comprehensive framework for water efficiency with a hierarchical calculation methodology is the novelty of this study. This framework will make significant contributions to monitoring water efficiency in schools.

Key words: best worst method, public schools, sustainable urban water management, sustainability index, water efficiency

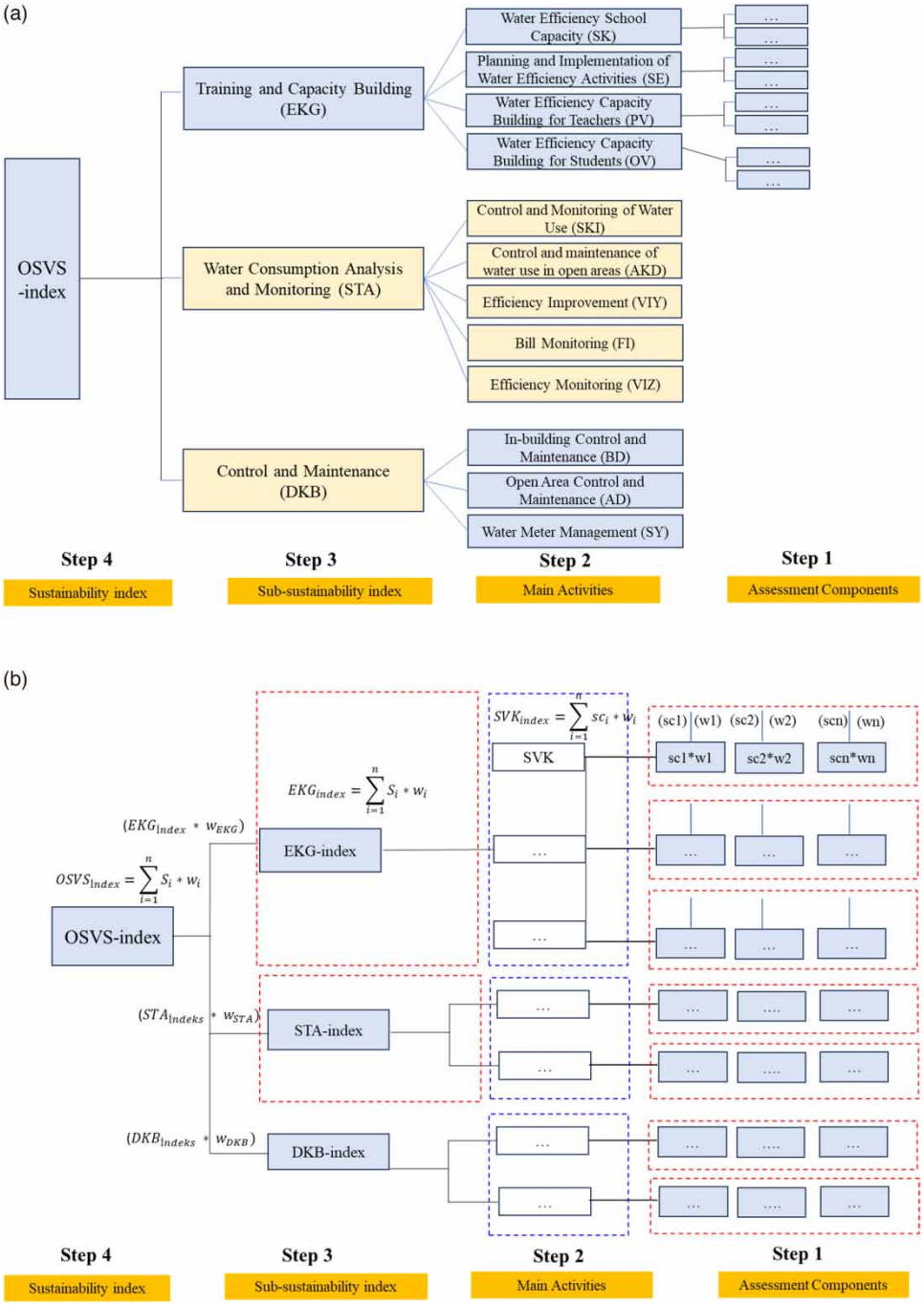
HIGHLIGHTS

- A novel water efficiency sustainability index framework structure was developed.
- A total of 123 assessment components were defined.
- The weights of components were determined using the best worst method.
- The water efficiency sustainability index was applied to 35 schools.
- A weighted index score was calculated according to the current status of each school.

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GRAPHICAL ABSTRACT



INTRODUCTION

Preventing leaks and excessive consumption in water distribution systems is critical for water efficiency in urban water management. Especially, high-consumption users (schools, universities, hotels, swimming pools, sports facilities, industry, etc.) have the potential to make significant contributions to water efficiency. Therefore, water efficiency practices for high-consumption users should be planned and implemented systematically (El-Nwsany *et al.* 2019; Liu *et al.* 2020). In Türkiye, the Water Efficiency Regulation that includes the targets, actions and recommendations for water efficiency in all sectors, was published. This regulation covers analyzing the current situation, planning, implementation and reporting of water efficiency activities that provide greater water efficiency for high-consumption users (schools, hotels, industry, public, etc.). Regular inspection of installations and equipment, planning of education and awareness activities and ensuring participation of students will contribute to water efficiency.

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In the literature, the studies on water efficiency in schools generally cover the analysis of consumption data with a limited scope at the pilot level (Almeida *et al.* 2015; Nunes *et al.* 2019a; Antunes & Ghisi 2020; Morote *et al.* 2020; Schultt *et al.* 2022; Amahmid *et al.* 2019; Cheng & Hong 2004). Barua *et al.* (2016) proposed a prediction model with multiple regression to analyze the water use in schools using the water consumption and climate data (precipitation, temperature, humidity) in 375 schools. El-Nwsany *et al.* (2019) published a guide document that includes the sustainability methods in the interior and exterior design of schools, to ensure the sustainable water efficiency and management in schools. Nunes *et al.* (2019b) evaluated the water consumption metrics and indicators to compare water consumption per student in pilot schools. Flores & Ghisi (2022) calculated the unit water consumption indicators based on monthly water usage data in pilot schools.

However, sustainability indices that include the calculation of the sustainability index by considering the environmental, economic and social indicators (Brito *et al.* 2021), building stock and safety, user experience, energy efficiency, digital infrastructure and equipment and the environment (Primc *et al.* 2023), have been proposed. Adas *et al.* (2024) developed a tool that covers the rainwater harvesting variable under water productivity, using the analytical hierarchy process (AHP) to evaluate social, environmental and economic sustainability in schools. Baba *et al.* (2024) proposed an evaluation framework that considers the energy, social, environmental, quality, site management, water consumption components, rainwater harvesting and grey water use criteria in schools.

It is seen that the sustainability indices proposed in the literature generally cover the environmental, energy, waste management and economic criteria. However, the components of water efficiency, education and activity planning, maintenance and control of installations and equipment in open/closed areas were not considered. A sustainability index may provide an opportunity to analyze and monitor the sustainability of water efficiency activities in schools in a holistic way. Moreover, water efficiency practices should be monitored by considering the basic headings of the water consumption, awareness and consciousness-raising activities, training, maintenance and inspection. Therefore, a water efficiency sustainability index that analyzes and monitors the sustainability of water efficiency activities in schools should be defined. The aim of this study is to develop a water efficiency sustainability index framework for monitoring and evaluating water efficiency activities in schools. This water efficiency sustainability index basically includes defining the components of water efficiency with hierarchical processes, determining water efficiency evaluation criteria, defining weights, testing in pilot schools and determining and evaluating the current situation.

The weights of the water efficiency components that should be determined with an appropriate method could be different. The multi-criteria decision methods, such as the AHP, analytical network process (ANP), entropy, DEMATEL, Delphi and best worst (BWM), have been applied in determining the weights (Namavar *et al.* 2023; Pokhrel *et al.* 2023; Bhatta *et al.* 2024). These methods have different features, advantages and disadvantages. The AHP method, which is based on expert opinions, has a hierarchical structure and is simpler to apply (Domínguez *et al.* 2019; Mvongo *et al.* 2021; Mvongo *et al.* 2022). The applicability of AHP becomes more difficult when the evaluation sensitivity decreases as the number of components in the problem increases (Murad *et al.* 2022). The expert opinions are consulted more than once in the Delphi method. It becomes difficult for experts to score multiple items with complex problems (Wright & Giovinazzo 2000).

In this study, the linear programming-based BWM, which is an easy-to-implement, flexible and powerful tool (Rezaei 2020; Akbari *et al.* 2021), was preferred to calculate the weights. The BWM performs better than other multi-criteria decision-making methods (Gupta *et al.* 2017; Mi *et al.* 2019) and requires less comparison data. The BWM offers a lower consistency rate to verify the reliability of pairwise comparisons and produces reliable results with higher consistency (Rezaei 2015; Karimi *et al.* 2019; Darestani *et al.* 2020; Akbari *et al.* 2021). The BWM has been applied to determine the weights of components of industrial water supply security (Zhou *et al.* 2022; Majumder *et al.* 2023; Chao *et al.* 2024), dam safety assessment (Celik & Gul 2021), water quality assessment (Khiavi *et al.* 2023) and basin-based water security assessment (Alvandi *et al.* 2021; Tavosi *et al.* 2024).

It was observed in the literature that the BWM has not been applied to urban water efficiency, water efficiency assessment in schools. The novelty of this study could be listed as follows: (i) proposing a comprehensive and integrated sustainability index framework for the evaluation of water efficiency in schools, (ii) establishing a hierarchical calculation methodology, (iii) defining evaluation criteria, (iv) defining the scoring class for water efficiency components and (v) applying the BWM to determine the weights of water efficiency components.

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MATERIAL AND METHOD

Development of water efficiency sustainability index framework

In this study, the '*Water Efficiency Sustainability Index (OSVS-Index) Framework in Schools*' was proposed to assess and monitor the water efficiency sustainability. This framework has a hierarchical computing methodology (Figure 1).

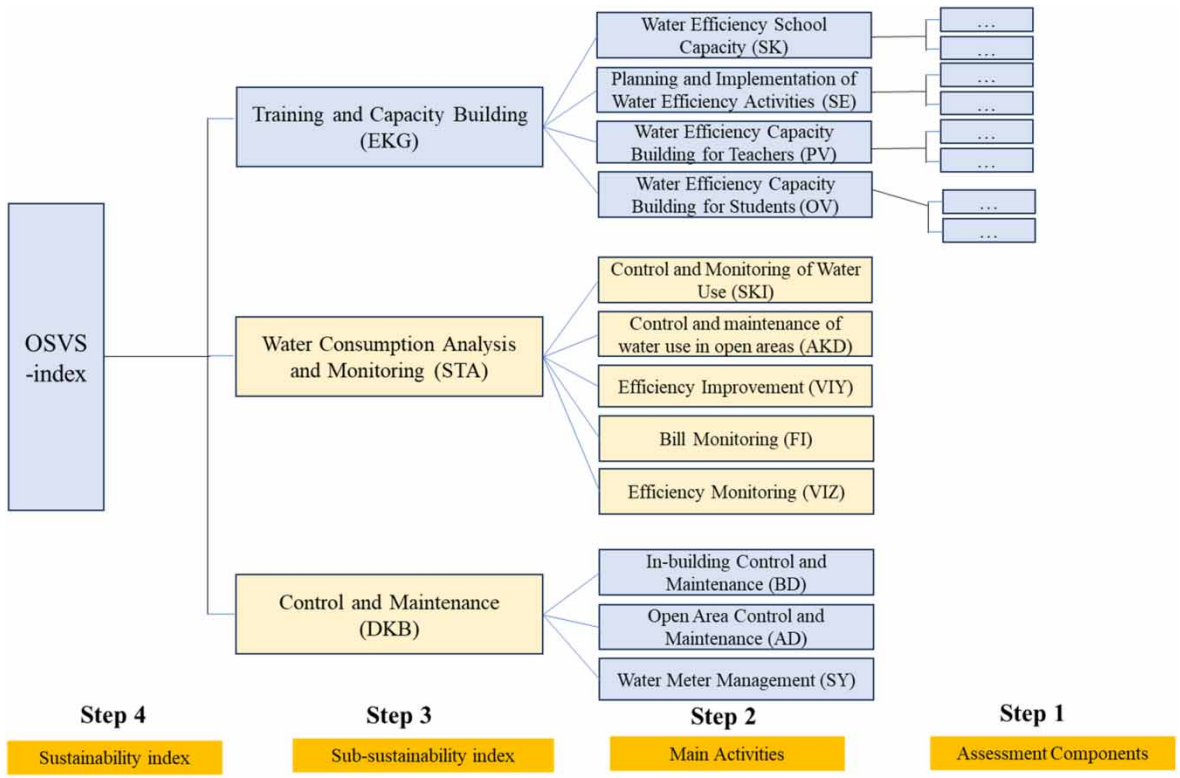


Figure 1 | Water efficiency index framework in schools (Güngör 2025).

In this framework, three *Water Efficiency Sub-Sustainability Indexes* that are Training and Capacity Development (EKG-index), Water Consumption Analysis and Monitoring (STA-index) and Audit, Control and Maintenance (DKB-index) under the OSVS-index, were defined. Moreover, the *Main Activity Category (MAC)* is created under each sub-sustainability index (Figure 1).

Finally, the '*Assessment Components*' category that includes 123 components (Table 1) and enables the evaluation of the current status and implementation frequency of water efficiency practices in schools under Main Activities, was defined. Güngör (2025) proposed a '*current status assessment system for water efficiency in schools*' to analyze the current level of water efficiency practices in schools and to determine the weaknesses and strengths. The scoring structure and classes created for the evaluation criteria in this framework were taken from Güngör (2025). In this system, the current implementation levels of water efficiency activities and components in schools were analyzed according to the gradual scoring scale.

The *EKG-index* includes the components of increasing the knowledge level of students, teachers and staff within the scope of water efficiency, informing about the journey of water and participation in water efficiency activities. The *STA-index* covers the components of the audit and control of water usage areas, monitoring of invoices and water use in open and closed areas in the school, selection and management of water efficiency equipment, improvement and monitoring of water efficiency, equipment maintenance and control strategy. The *DKB-index* comprises the collection of equipment inventory information, monitoring, control, maintenance and repair, creation of maintenance and monitoring forms and reports and control and management of meters.

The *performance class (sc)* of the water efficiency components was defined in order to apply the evaluation components in schools and reveal the current status of water efficiency in schools. For this purpose, a scoring

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Table 1 | Assessment components defined for the water efficiency framework

EKG-index		STA-index	
SK main activity	**ID**	**SKI main activity**	**ID**
Establishing a water efficiency team	SK1	Average consumption per capita	SKI1
Establishing a water efficiency club	SK2	Frequency of checking water usage areas in the building	SKI2
Representation rate of classes in a water efficiency club	SK3	Frequency of monitoring the meter reading status	SKI3
The rate of students participating in a water efficiency club	SK4	Frequency of monitoring water use volume	SKI4
Frequency of organizing water efficiency club events	SK5	Frequency of analysis of changes in water use	SKI5
The rate of teachers participating in a water efficiency club	SK6	Frequency of analysis of water use per student	SKI6
Frequency of reporting water efficiency club activities	SK7	Frequency of fire hydrant use in the building	SKI7
Annually planned water efficiency competitions	SK8	Frequency of monitoring water use in laboratories	SKI8
Frequency of sharing about water efficiency on the school website	SK9	Frequency of monitoring water use in the cafeteria	SKI9
Inclusion of water efficiency in the curriculum	SK10	Monitoring water usage in the canteen	SKI10
Frequency of reporting water efficiency activities	SK11	Sensor tap usage rate	SKI11
SE main activity	**ID**	**AKD main activity**	**ID**
Creation of water efficiency labels in water usage areas	SE1	Water efficiency applications in the landscape	AKD1
Update the status of the water board/corner for water efficiency	SE2	Control the frequency of water use in open areas	AKD2
Frequency of publishing water efficiency events in the water corner	SE3	Frequency of measurement of water use in the landscape	AKD3
Frequency of organizing painting, composition and poetry competitions	SE4	Seasonal adjustment frequency of landscape irrigation	AKD4
Frequency of organizing slogan and cartoon contests	SE5	Innovative irrigation system in the landscape	AKD5
Frequency of theatre activity for water efficiency	SE6	Landscape rate with an irrigation plan based on weather conditions	AKD6
Organizing a special presentation event for World Water Day	SE7	Water usage rate per unit area	AKD7
Frequency of organizing events with stakeholder institutions	SE8	Frequency of monitoring water use in the gym	AKD8
Frequency of preparing posters, brochures and information notes	SE9	Valve/plumbing inspection frequency	AKD9
Frequency of creating corridors for water efficiency	SE10	Water-sensitive plant usage rate	AKD10
Frequency of showing water efficiency promotional films	SE11	Knowledge level about rainwater harvesting	AKD11
Frequency of organizing training for the maintenance team	SE12	Knowledge level about rainwater harvesting systems	AKD12
PV main activity	**ID**	**VIY main activity**	**ID**
The percentage of teachers who know the importance of water	PV1	Frequency of efficiency analysis and monitoring	VIY1
The percentage of teachers who know water resources	PV2	Frequency of monitoring water efficiency in an open area	VIY2
The percentage of teachers who know water efficiency	PV3	Frequency of water efficiency monitoring in buildings	VIY3
Percentage of teachers who know efficient water use	PV4	Rainwater harvesting application status	VIY4

(*Continued.*)

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Table 1 | Continued

The percentage of teachers who know the journey of water	PV5	Water efficiency cost analysis status	VIY5
The percentage of teachers who know the water footprint	PV6	Analysis status of water efficiency gains	VIY6
Frequency of water efficiency training for teachers	PV7	Water-saving equipment ratio in sinks and taps	VIY7
Frequency of teachers' participation in external water efficiency training	PV8	An equipment ratio that reduces water consumption in flushes	VIY8
Frequency of teachers preparing water efficiency projects with stakeholders	PV9	Adequacy of the number of repair and maintenance teams	VIY9
Frequency of teachers examining water efficiency practices	PV10	Repair and maintenance equipment capacity adequacy	VIY10
Frequency of school management in informing about water efficiency	PV11	Water-saving equipment rate in open areas	VIY11
OV main activity	**ID**	**FI main activity**	**ID**
The percentage of students who know the importance of water	OV1	Activities to reduce water bills	FI1
The percentage of students who know of the water resources	OV2	Frequency of comparing invoices with previous periods	FI2
The percentage of students who know water efficiency	OV3	Compliance of invoices with usage habits	FI3
The percentage of students who know efficient water use	OV4	Compliance of bills with water-saving policies	FI4
The percentage of students who are aware of reporting broken taps	OV5	Frequency of efficiency analysis of water-saving equipment	FI5
The percentage of students who know the journey of water	OV6	**VIZ main activity**	**ID**
The percentage of students who know the water footprint	OV7	The status of implementing staff efficiency studies	VIZ1
Frequency of water efficiency training for students	OV8	Efficiency policy update status	VIZ2
Frequency of students' participation in external water efficiency training	OV9	Implementation status of activities based on data analysis	VIZ3
Frequency of students examining water efficiency practices	OV10	The performance improvement status of the efficiency policy	VIZ4
Frequency of water efficiency information for parents at school	OV11	Use of metrics in monitoring water efficiency	VIZ5
Frequency of water efficiency briefings to students by external experts	OV12	Efficiency of rainwater harvesting	VIZ6
		Monitoring the status of rainwater harvesting	VIZ7
		Monitoring rainwater harvesting costs and benefits	VIZ8
		The ratio of rainwater harvesting to water demand	VIZ9
DKB-index			
BD main activity	**ID**	**AD main activity**	**ID**
Frequency of piping and equipment data updates in the building	BD1	Pipe and equipment data update frequency in an open area	AD1
Frequency of inspection and audit of urinals	BD2	Layout plan of pipes and equipment in an open area	AD2
Frequency of control and inspection of flush tanks in toilets	BD3	Frequency of leak checks for installations and pipes	AD3
Frequency of control and inspection of taps	BD4	Frequency of leak check for fire hydrants/ connections	AD4

(*Continued.*)

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Table 1 | Continued

Frequency of leakage control and inspection of installations and pipes	BD5	Frequency of checking the leakage of installations in open areas	AD5
Frequency of water use control in cleaning classrooms	BD6	Open area installation repair time	AD6
Consideration of water efficiency in classroom cleaning	BD7	Reporting frequency of inspections and repairs in an open area	AD7
Tap and siphon repair time	BD8	Monitoring form for control of equipment in an open area	AD8
Frequency of reporting of installation inspections and repairs	BD9	Monitoring form for the repair of equipment in an open area	AD9
Frequency of checking the leakage status of taps	BD10	**SY main activity**	**ID**
Monitoring form for control of equipment in a building	BD11	Frequency of checking the physical condition of water meters	SY1
Monitoring form for the repair of equipment in a building	BD12	Protection status to prevent meters from freezing	SY2
Status of equipment required for plumbing repair in a building	BD13	Water meter accuracy	SY3
		Water meter installation location suitability	SY4

scale that groups the assessment components gradually between 1 and 5 points was used. This performance scale is 1 point (*Low Performance Class*), 2 (*Insufficient Performance Class*), 3 (*Average Performance Class*), 4 (*High Performance Class*) and 5 (*Quite High Performance Class*) (Güngör 2025).

Best worst method

The BWM, which is a linear programming-based method based on the binary comparison vector and proposed by Rezaei (2015), was applied to determine the weights. In this method, the most appropriate solution is produced by minimizing the largest absolute differences between comparisons (Ghoushchi & Sarvi 2023). The BWM is a flexible and powerful tool and compares only the best and worst components. The number of pairwise comparisons is less $(2n-3)$ than in other methods. The best (most important) and worst (least important) components among the components (C_1, C_2,…C_n) are determined by considering the objectives of the problem. These components are scored by pairwise comparison with other components (1: equal importance, 3: moderate importance, 5: high importance, 9: extremely high importance) (Rezaei 2015; Ghoushchi & Sarvi 2023). The scoring vectors, A_B and A_W, are obtained by Equations (1) and (2), respectively (Rezaei 2015).

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \tag{1}$$

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T \tag{2}$$

a_{Bj} is the preference of the best component B over the other criterion j. The result of comparing the preference status with the best component itself is equal to 1 ($a_{BB}=1$). a_{Wi} is the preference of the worst component W over the other criterion i ($a_{WW}=1$). In the next step, the optimum weights (w_1^*, w_2^*,…,w_n^*) and the optimum values of the confidence level (ξ) are calculated with the optimization model (Equations (3) and (4), respectively).

$$\text{minmax}_j = \{|(W_B/W_j) - a_{Bj}|, |(W_j/W_w) - a_{jw}|\} \tag{3}$$

$$\begin{aligned} &\text{Min } \xi \\ &|(W_B/W_j) - a_{Bj}| \le \xi, \quad \text{for all } j \\ &|(W_j/W_w) - a_{jw}| \le \xi, \quad \text{for all } j \\ &w_j \ge 0, \quad \text{for all } j \end{aligned} \tag{4}$$

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$\sum w_j = 1$. W_B and Ww are the weights of the best and worst components, respectively. The consistency index (CI) and K_{si} (if it is 0 or close to 0, it is fully consistent). Higher values indicate low consistency in pairwise comparisons.

Water efficiency sustainability index framework

OSVS-index is calculated step by step, starting from the assessment component category in a hierarchical structure by considering performance classes and weights. The index scores are also determined for the MAC and sub-sustainability indexes (Figure 2). The performance class (*sc*) of each component according to the assessment scale (1–5) was determined as a result of examinations conducted in 35 schools (Figure 2, step 1). Then, the weight of each assessment component is multiplied by the *performance class (sc)* to obtain the weighted score for the MACs (Figure 1(b), step 2). The score of SK is calculated using Equation (5). In the next step, the weighted score of each sub-sustainability index is calculated (Figure 1(b), step 3). The weighted score for the sub-sustainability index (e.g. EKG-index) is obtained by multiplying the performance class and weight of each MAC (Equation (6)).

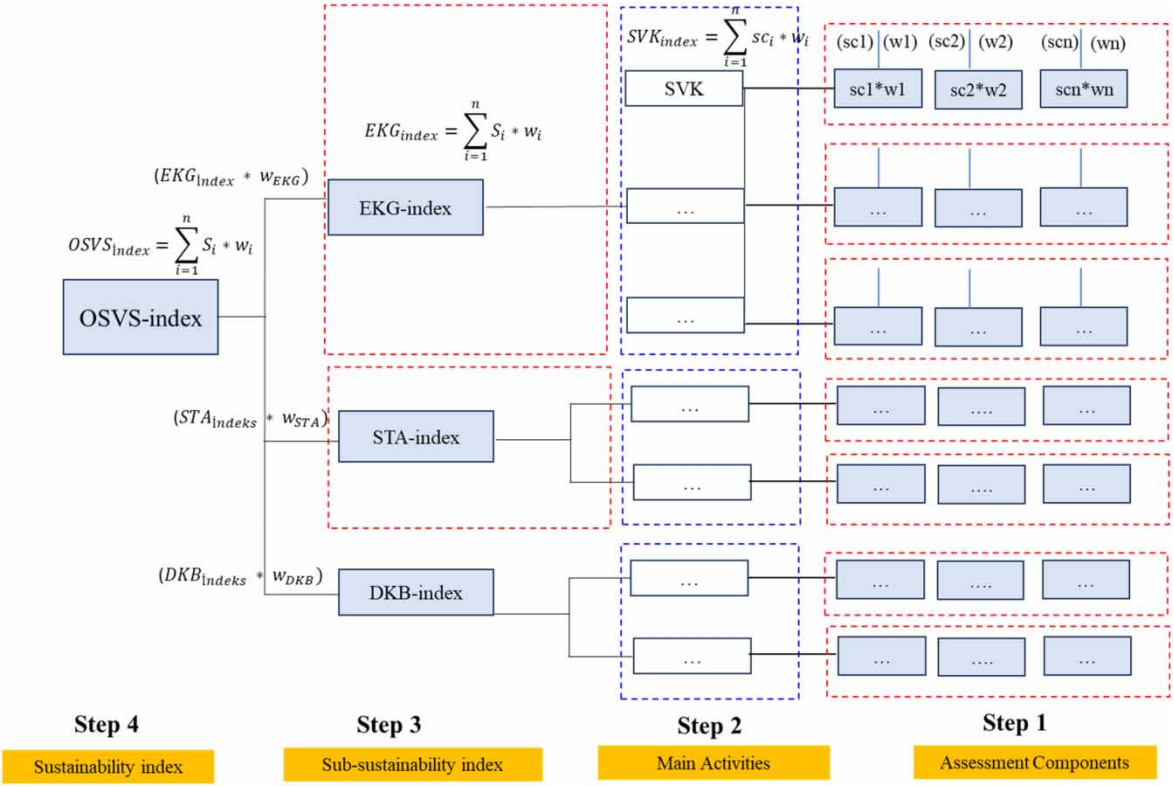


Figure 2 | Calculation steps of water efficiency sustainability index in schools.

$$\mathrm{SK}_{\mathrm{index}} = \sum_{i=1}^{n} sc_i * w_i = sc_1 * w_1 + sc_2 * w_2 + \cdots + sc_n * w_n \tag{5}$$

$$\mathrm{EKG}_{\mathrm{index}} = \mathrm{SK}_{\mathrm{index}} * w_{\mathrm{SK}} + \mathrm{SE}_{\mathrm{index}} * w_{\mathrm{SE}} + \mathrm{PV}_{\mathrm{index}} * w_{\mathrm{PV}} + \mathrm{OV}_{\mathrm{index}} * w_{\mathrm{OV}} \tag{6}$$

In the last step, the OSVS-index score in schools is calculated (Figure 1(b), step 4) using the performance class and weight (w) of each sub-sustainability index (Equation (7)).

$$\mathrm{OSVS}_{\mathrm{index}} = \mathrm{EKG}_{\mathrm{index}} * w_{\mathrm{EKG}} + \mathrm{STA}_{\mathrm{index}} * w_{\mathrm{STA}} + \mathrm{DKB}_{\mathrm{index}} * w_{\mathrm{DKB}} \tag{7}$$

A sustainability assessment scale was defined to evaluate the calculated index scores. The sustainability classes of the indexes and MACs are evaluated separately according to this assessment scale. If the index score is less

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than or equal to 1, the sustainability class is defined as '*Low Sustainability Class*'. If the score is greater than 1 and less than or equal to 2, it is evaluated as '*Inadequate Sustainability Class*'. If the score is greater than 2 and less than or equal to 3, the assessment class is defined as '*Average Sustainability Class*'. If the score is greater than 3 and less than or equal to 4, it is evaluated as '*High Sustainability Class*'. If the score is greater than 4, the evaluation class is defined as '*Quite High Sustainability Class*'.

RESULTS AND DISCUSSION

Determination of weights with BWM

The weights of the EKG-index, STA-index and DKB-index, MACs and components in each step were calculated with the BWM separately. The best and worst components in each category on water efficiency were defined by experts. The superiority level of these best and worst components over other components was determined using a scoring scale (Table 2).

The weights of the STA and DKB were 0.2989 and 0.3075, respectively. The highest weight was obtained for the EKG-index (0.3936), which includes training and capacity-building components within the scope of water efficiency in schools. The involvement and active participation of students in activities and training will make a significant contribution to ensuring water efficiency in schools. Therefore, the fact that the EKG-index has the highest weight is compatible with the natural structure of the problem. The weights of MACs and all assessment components were calculated separately (Tables 3). Students' awareness and active participation in activities are critical to ensuring water efficiency in schools. The EKG-index, which includes student education, awareness and activity, is given the highest weight and defined as the most important index, consistent with the nature of the problem.

The weight of SK is 0.2539. The highest and lowest weights were determined for the SK1 (0.1707) and SK11 (0.0526), respectively. Under the PV, the highest and lowest weights were calculated for the PV3 (0.1203) and PV5 (0.0475), respectively. Under the OV, the highest weight was calculated for the OV1 (0.1409) and the lowest weight was obtained for OV6 (0.046). The highest weight under the EKG-index was calculated for the SE (0.3345) component. Under the SE, the assessment components with the highest and lowest weights are SE12 (0.1467) and SE6 (0.0416), respectively. The SE12 recommends that the team required for the implementation of water efficiency practices be trained at certain periods. The assessment components defined under SE control the creation of water efficiency boards and the organization of competitions related to water efficiency. The SE was determined as the most important main activity under the EKG-index by emphasizing the importance of awareness-raising and planning implementation within the scope of water efficiency.

Under the STA-index, the MCA with the highest weight is the SKI that covers the control and supervision of water use and could make a significant contribution to monitoring and controlling water usage in school buildings. The fact that the SKI has the highest weight is compatible with the natural structure of the problem within the scope of water efficiency. Under the SKI, the highest weight was calculated for SKI2 (Frequency of water usage control in the building). Regular inspection will contribute to preventing losses. This component aims to learn water consumption in all areas, consumption habits and average water consumption per capita. The SKI2 considers whether water use areas are regularly controlled or not. The regular control of water use areas directly helps to prevent factors that will lead to water loss. The weights of the other four MACs under the STA-index are close to each other. The VIY component has the second-highest weight (0.1602). The highest weight was calculated for the VIY3 (Frequency of productivity analysis and monitoring in the institution) component. Finally, the lowest weight under the STA-index was obtained for the FI (0.1182).

The highest and lowest weights were calculated for the BD (0.4305) and SY (0.2546) MACs under the DKB-index, respectively. The BD covers the inspection and control of equipment, installations and water usage equipment in buildings. Regular inspection and maintenance of equipment will minimize leaks and losses. Therefore, the fact that this MAC has the highest weight is compatible with water efficiency activities. Regularly checking the leakage of sinks, WCs, urinals and lines in the building, where water is consumed, is quite important in water saving. Checking the taps frequently will contribute greatly to water saving and prevent water waste. Similarly, the AD covering the control and maintenance of outdoor water use equipment has the second-highest weight. Regular maintenance and inspection in open areas, as well as in buildings, contribute significantly to water efficiency. Therefore, it is compatible with the structure of the problem that these two MACs are the heaviest. The results show that the weights calculated with the BWM were generally compatible with the natural structure of

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Table 2 | Selection of the best and worst components in the water efficiency framework

Expert (E)	B&W	Sub-index	EKG	SK	SE	PV	OV	STA	SKI	AKD	VIY	FI	VIZ	DKB	BD	AD	SY
E1	B	EKG	SE	SK1	SE2	PV3	OV3	SKI	SKI12	AKD2	VIY3	FI1	VIZ2	BD	BD4	AD3	SY3
	W	STA	SK	SK7	SE11	PV11	OV11	FI	SKI7	AKD7	VIY9	FI2	VIZ5	SY	BD6	AD7	SY1
E2	B	STA	SE	SK10	SE1	PV1	OV1	SKI	SKI1	AKD1	VIY1	FI1	VIZ1	SY	BD5	AD3	SY2
	W	EKG	PV	SK3	SE6	PV9	OV9	AKD	SKI8	AKD8	VIY12	FI2	VIZ7	AD	BD12	AD8	SY4
E3	B	EKG	SK	SK2	SE12	PV1	OV1	SKI	SKI4	AKD3	VIY1	FI1	VIZ2	AD	BD10	AD2	SY3
	W	DKB	OV	SK9	SE6	PV6	OV7	AKD	SKI2	AKD12	VIY12	FI2	VIZ7	SY	BD6	AD9	SY2
E4	B	DKB	OV	SK5	SE8	PV9	OV1	SKI	SKI1	AKD3	VIY1	FI1	VIZ2	BD	BD1	AD2	SY1
	W	EKG	PV	SK9	SE10	PV8	OV6	FI	SKI12	AKD10	VIY12	FI3	VIZ8	SY	BD6	AD8	SY2
E5	B	DKB	ÖV	SK1	SE12	PV1	OV1	SKI	SKI2	AKD2	VIY7	FI1	VIZ1	BD	BD10	AD3	SY1
	W	EKG	SK	SK3	SE6	PV5	OV6	VIZ	SKI3	AKD12	VIY5	FI2	VIZ6	SY	BD6	AD1	SY4

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Table 3 | The weights of water efficiency components

#ID	Weight	#ID	Weight	#ID	Weight	#ID	Weight		
EKG	**0.3936**								
SK	0.2539	SE	0.3345	PV	0.1137	OV	0.2979		
SK1	0.1707	SE1	0.1046	PV1	0.1188	OV1	0.1409		
SK2	0.1181	SE2	0.1016	PV2	0.0784	OV2	0.0847		
SK3	0.0656	SE3	0.0745	PV3	0.1203	OV3	0.1224		
SK4	0.0850	SE4	0.0635	PV4	0.0964	OV4	0.0900		
SK5	0.0959	SE5	0.0635	PV5	0.0475	OV5	0.0780		
SK6	0.0725	SE6	0.0416	PV6	0.0672	OV6	0.0460		
SK7	0.0491	SE7	0.0770	PV7	0.0900	OV7	0.0708		
SK8	0.1015	SE8	0.1174	PV8	0.0820	OV8	0.0776		
SK9	0.0652	SE9	0.0779	PV9	0.0868	OV9	0.0734		
SK10	0.1240	SE10	0.0670	PV10	0.0739	OV10	0.0755		
SK11	0.0526	SE11	0.0647	PV11	0.0604	OV11	0.0631		
		SE12	0.1467	PV12	0.0782	OV12	0.0776		
#ID	**Weight**	**#ID**	**Weight**	**#ID**	**Weight**	**#ID**	**Weight**	**#ID**	**Weight**
STA	**0.2989**								
SKI	0.4314	AKD	0.1466	VIY	0.1602	FI	0.1182	VIZ	0.1436
SKI1	0.1123	AKD1	0.1155	VIY1	0.1363	FI1	0.4333	VIZ1	0.1688
SKI2	0.1395	AKD2	0.1504	VIY2	0.1046	FI2	0.1022	VIZ2	0.2055
SKI3	0.0869	AKD3	0.0966	VIY3	0.1161	FI3	0.1446	VIZ3	0.1261
SKI4	0.1214	AKD4	0.0709	VIY4	0.0652	FI4	0.1571	VIZ4	0.1074
SKI5	0.0801	AKD5	0.0825	VIY5	0.0580	FI5	0.1628	VIZ5	0.0755
SKI6	0.0650	AKD6	0.0675	VIY6	0.0626			VIZ6	0.0839
SKI7	0.0704	AKD7	0.0737	VIY7	0.0937			VIZ7	0.0803
SKI8	0.0612	AKD8	0.0525	VIY8	0.0793			VIZ8	0.0688
SKI9	0.0695	AKD9	0.1073	VIY9	0.0739			VIZ9	0.0836
SKI10	0.0695	AKD10	0.0545	VIY10	0.0815				
SKI11	0.0746	AKD11	0.0704	VIY11	0.0921				
SKI12	0.0497	AKD12	0.0583	VIY12	0.0368				
#ID	**Weight**	**#ID**	**Weight**	**#ID**	**Weight**				
DKB	**0.3075**								
BD	0.4305	AD	0.3149	SY	0.2546				
BD1	0.0709	AD1	0.0897	SY1	0.3075				
BD2	0.0773	AD2	0.1547	SY2	0.1421				
BD3	0.0753	AD3	0.1914	SY3	0.3148				
BD4	0.1119	AD4	0.1041	SY4	0.2355				
BD5	0.1068	AD5	0.1469						
BD6	0.0344	AD6	0.1076						
BD7	0.0636	AD7	0.0733						
BD8	0.0800	AD8	0.0663						
BD9	0.0614	AD9	0.0660						
BD10	0.1272								
BD11	0.0543								
BD12	0.0476								
BD13	0.0891								

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the problem. The results suggest that the BWM provides good results in evaluating water efficiency components and defining their impact levels. The CI and ratios calculated to test the consistency of the BWM model are given in Table 4.

Table 4 | The consistency index and consistency rates of the BWM model

OSVS index	a_{BW}	ξ	CI	CR
Sub-indexes	4.6	0.1137	2.3	0.0494
EKG	6.6	0.1001	3.73	0.0268
SK	6.6	0.0942	3.73	0.0253
SE	5.8	0.0851	3	0.0284
PV	6	0.0752	3	0.0251
OV	5.6	0.0723	3	0.0241
STA	5.2	0.0809	2.3	0.0352
SKI	7	0.1019	3.73	0.0273
AKD	6.4	0.0768	3	0.0256
VIY	6.8	0.0817	3.73	0.0219
FI	4.8	0.0625	2.3	0.0272
VIZ	5	0.0513	2.3	0.0223
DKB	4.6	0.1944	2.3	0.0845
BD	7	0.0857	3.73	0.0229
AD	5.2	0.0878	2.3	0.0382
SY	5	0.0634	2.3	0.0276

The a_{BW} column was obtained by taking the arithmetic average of the scores given for the preference level of the best component over the worst component in the expert's evaluation forms. Consistency indexes were calculated for all ratings, and the averages were presented in the ξ column (Rezaei 2015). Consistency indexes corresponding to the closest scores to the a_{BW} values were selected using the BWM. Consistency values were obtained with the ξ/CI ratio. The results show that CR rates are in the range of 0–1 and the evaluations are consistent.

Case study in pilot schools

The water efficiency index framework structure was implemented in pilot schools. A total of 35 schools (primary, secondary and high schools) in the Malatya province in Türkiye were selected as pilot application areas. The Malatya province is one of the cities where the earthquake centered in Kahramanmaraş occurred on 6 February 2023. The water resources were damaged; pollution was observed, and a decrease in flow occurred due to the earthquake. Moreover, failure rates in the transmission and distribution system have reached serious levels. As a result, leaks have increased, and more efficient use of water resources has become necessary. Water saving becomes even more important for users with high water consumption in urban areas. Water efficiency activities, especially in schools, make a significant contribution to the efficient use of existing resources (Güngör 2025). The student age range in the pilot primary schools varies between 7 and 10. In secondary schools, the age range is between 11 and 14 and in high schools, it is between 14 and 18. The performance classes for each assessment component were determined as a result of the examinations conducted in the pilot schools and interviews with school managers. The duration of this process varies depending on the size of the school (open and closed areas). The index scores of main activity components were calculated using the weights and *performance classes (sc)* of each assessment component determined based on-site inspections at schools according to the hierarchical calculation methodology in the framework structure.

The index scores of the main activity components SK, SE, PV and OV (defined under the EKG) were obtained by considering the weights (Table 3) and performance classes (Figure 3). Similarly, the index scores of the main activity components SKI, AKD, VIY, FI and VIZ (defined under the STA) were calculated using weights (Table 3)

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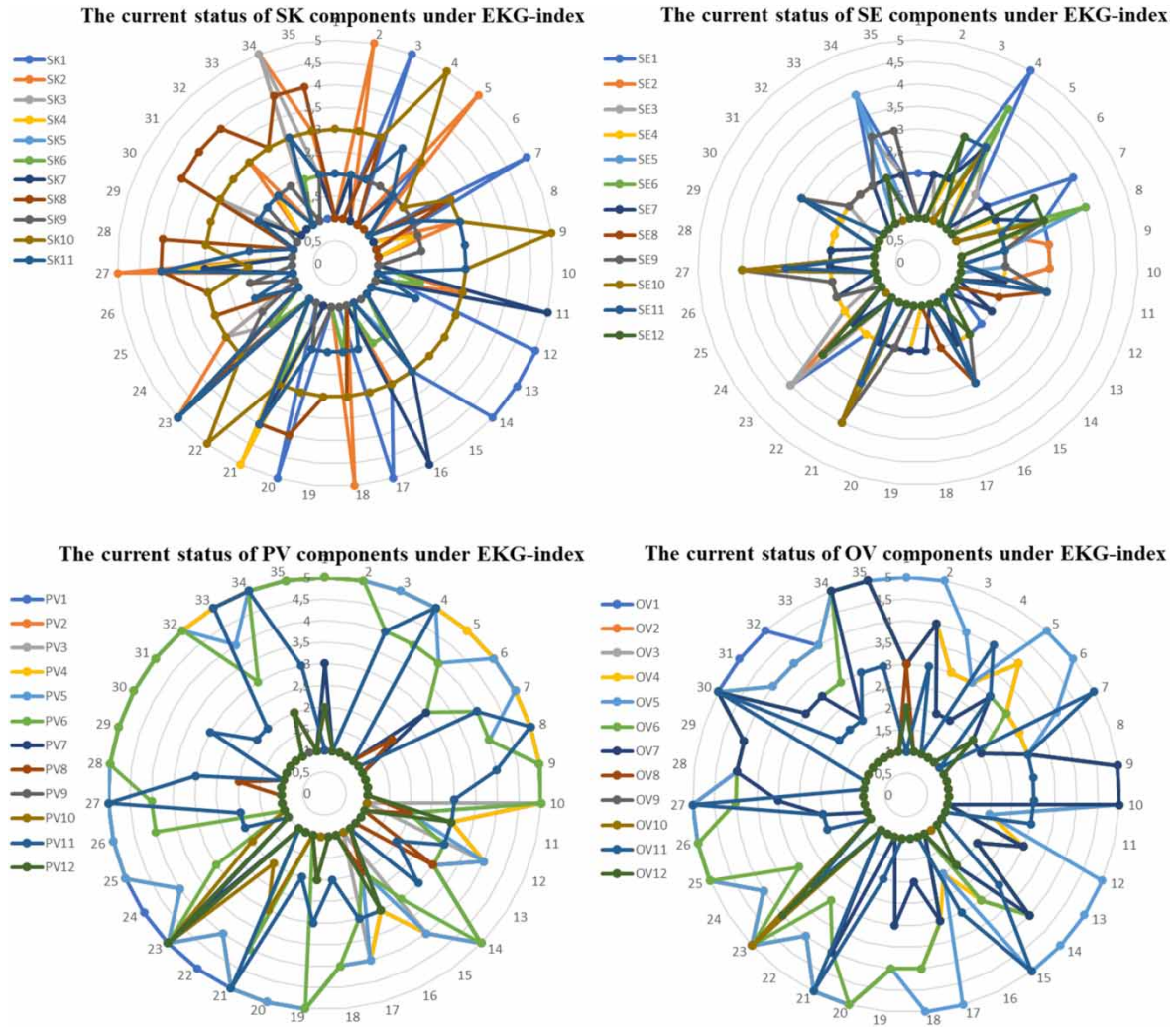


Figure 3 | Current status of the evaluation components under EKG.

and performance classes (Figure 4). Finally, weights (Table 3) and performance classes (Figure 5) were used for the index scores (defined under the DKB) of the main activity components BD, AD and SY.

The accuracy of component scores in schools generally depends on accurate on-site inspections. Therefore, each component must be evaluated in detail. Adequate records are essential, particularly for monitoring and evaluating maintenance and control activities. Incomplete or inaccurate performance scores directly impact index scores. The sustainability level for each main component was defined based on the index score (Table 5).

The sustainability level of the components under the DKB-index in schools is generally in good or quite good condition. The sustainability of the MCA under the EKG-index and STA-index is generally insufficient. In particular, the main activities of SK and SE (under EKG-index) and AKD and VIY (under STA-index) need to be improved. Planning and systematic implementation of water efficiency activities, including awareness and capacity building, play a critical role in improving these components. Moreover, water efficiency activities should be planned regularly with the participation of students. In order to improve the AKD and VIY indexes, water efficiency practices in open areas should be organized, an audit and control policy should be established and the frequency of water efficiency activities should be monitored. It is at a good level in a significant part of these activities, while the sustainability of PV and OV main activities is at an average level in a certain part of the schools.

Regular planning and implementation of these activities, which include capacity-building activities for students and teachers, will contribute to the improvement of index scores. Moreover, the FI sustainability index is at a good or quite good level in some of the schools, while it is at an inadequate level in some of them. This

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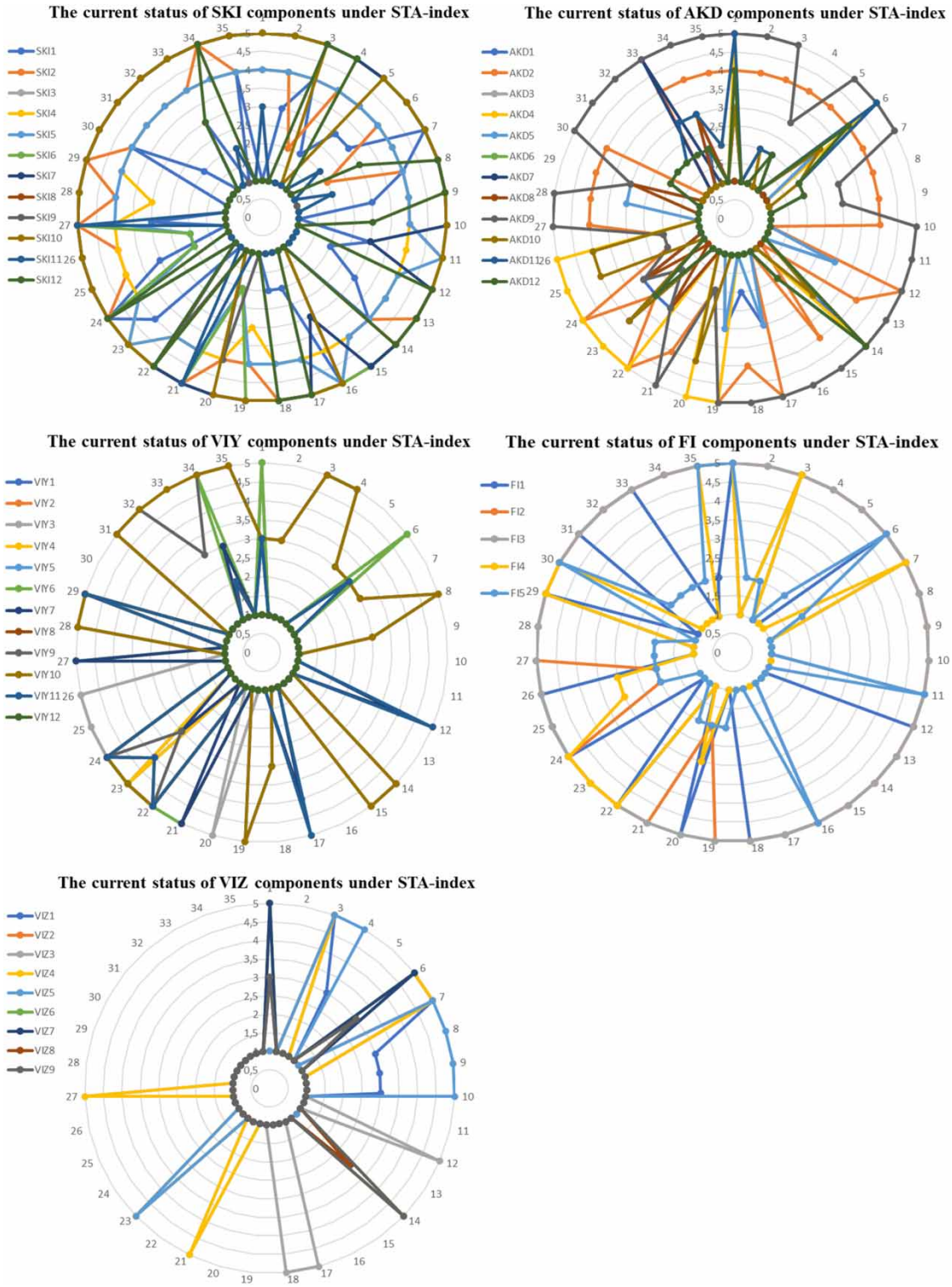


Figure 4 | Current status of the evaluation components under STA.

component covers activities that analyze the economic impact of water consumption, and especially important for ensuring economic efficiency. However, the sustainability class of the VIZ component that covers efficiency monitoring, rainwater harvesting and performance-monitoring activities, which contribute particularly to the analysis of changes in alternative resource use and water consumption, in schools, is at a low level in a significant part of schools.

In the next step in the hierarchical structure, EKG-, STA- and DKB-index scores were calculated using the scores obtained for each main activity component in the previous step and the weights of these components.

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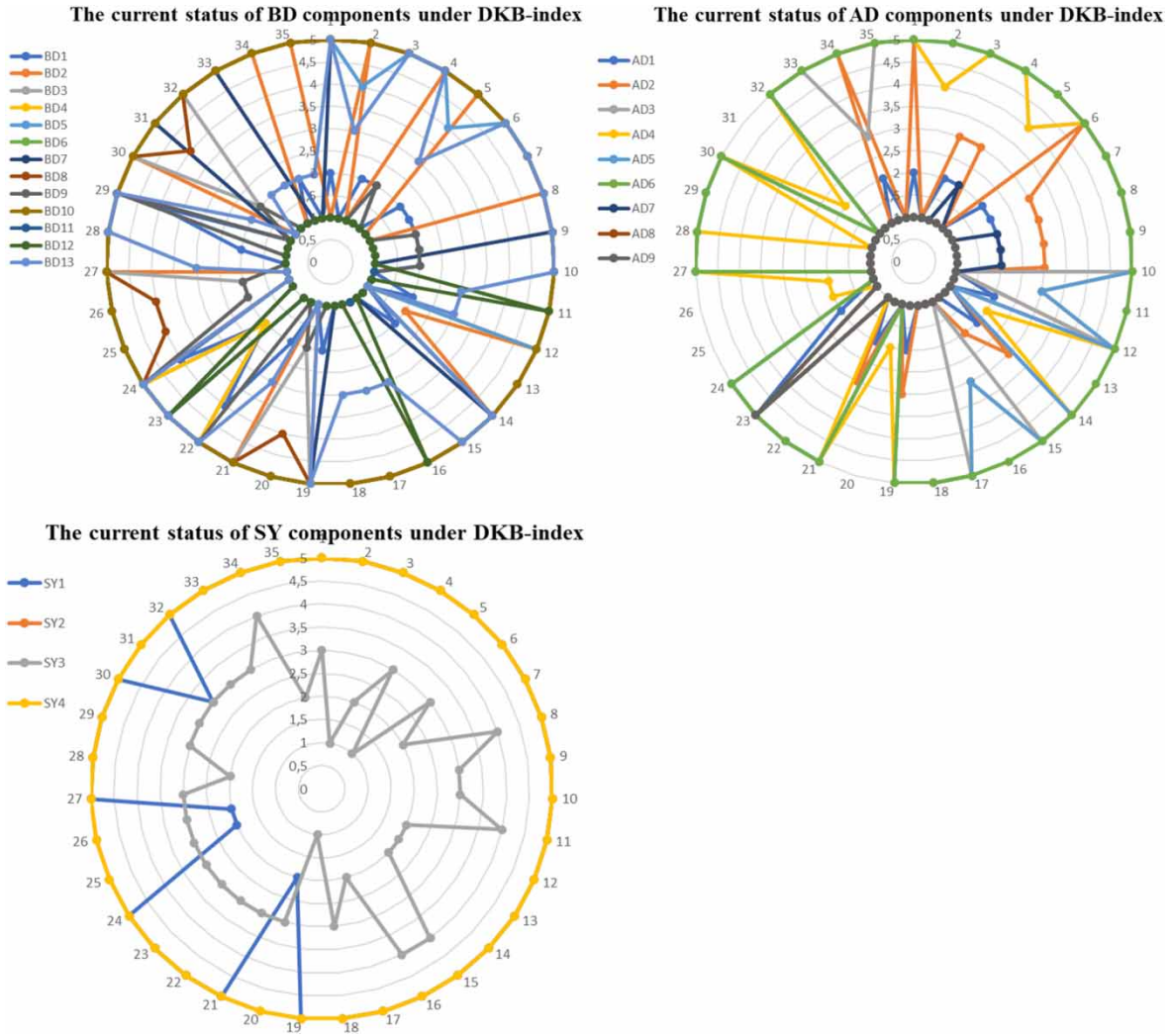


Figure 5 | Current status of the evaluation components under DKB.

The EKG-index score was calculated using the weights (Table 2) and the scores calculated in the previous step for the main activity components SK, SE, PV and OV. Similarly, the STA-index score was obtained by considering the weights (Table 2) and the scores calculated in the previous step for the main activity components SKI, AKD, VIY, FI and VIZ. Finally, the DKB-index score was calculated using the weights (Table 2) and the scores calculated in the previous step for the main activity components BD, AD and SY. The scores of the EKG-index, STA-index and DKB-index are shown in Table 2. In the last step of the hierarchical structure, the OSVS-index score was calculated using the scores calculated in the previous step for each sub-sustainability index and the weights of these indices were considered (Table 6).

The OSVS-index, which is generally between 2 and 3 scores in schools, is at the average sustainability level in a significant number of schools, according to the results. This index is at a good level in seven schools. In particular, improving the activities under EKG and STA will contribute to increasing the OSVS-index score. The EKG-index score is at a good level in just three schools. It is at an average level in a significant number of other schools and at an inadequate level in the remaining schools. Improving the performance classes of the assessment components under the EKG-index, which has the highest weight on the OSVS-index with 0.3936, will make a significant contribution to the OSVS-index score. A similar assessment can be made for the STA-index, which is at a good level in a certain part of the schools (seven schools) and at an average level in a significant part of them. However, the DKB-index, which has the second-highest weight, is at a good level in most of the schools. It is seen that having a good level of this index score in schools has a positive effect on the OSVS-index. Schools generally have high DKB-index scores. This index primarily includes the control and maintenance components of equipment

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Table 5 | The index scores of main activity components

School	EKG				STA					DKB		
	SK	SE	PV	OV	SKI	AKD	VIY	FI	VIZ	BD	AD	SY
1	1.37	1.11	3.45	2.73	3.34	3.32	2.42	5.00	3.57	3.82	3.91	4.36
2	2.06	1.36	3.11	3.10	3.41	1.88	1.31	2.15	1.00	3.78	2.90	3.74
3	2.25	1.67	3.23	2.23	3.45	2.01	1.62	4.51	3.73	3.82	3.60	4.06
4	1.67	2.96	3.29	2.34	3.22	1.79	1.62	1.99	1.64	4.19	3.67	4.37
5	2.40	1.28	3.00	2.99	3.41	1.88	1.31	2.15	1.00	3.78	2.90	3.74
6	1.19	1.18	3.24	2.58	3.49	3.32	2.43	4.37	3.57	3.82	3.91	4.37
7	2.25	2.05	3.23	2.48	3.46	2.06	1.31	4.51	3.73	3.82	3.60	4.06
8	1.81	2.80	3.24	2.39	3.80	1.79	1.62	1.99	1.64	4.19	3.67	4.68
9	1.67	1.83	3.30	3.66	3.61	1.67	1.31	1.99	1.64	4.19	3.67	4.37
10	1.35	1.69	3.24	3.66	3.29	1.88	1.00	1.99	1.64	3.94	3.67	4.37
11	1.90	1.87	2.06	1.29	3.49	1.43	1.00	4.37	1.00	3.82	1.93	4.68
12	1.98	1.12	2.64	2.42	3.64	2.43	1.65	3.72	1.50	3.70	3.91	4.06
13	1.93	1.25	2.28	1.87	3.75	1.88	1.00	1.99	1.00	2.04	1.53	4.06
14	1.93	1.10	3.24	3.10	3.73	2.85	1.62	1.99	2.90	4.13	3.60	4.06
15	2.55	1.57	2.52	2.68	2.91	2.01	1.62	1.99	1.00	3.81	3.35	4.68
16	2.25	1.94	2.06	1.29	3.72	1.43	1.00	4.37	1.00	3.82	1.93	4.68
17	1.98	1.12	2.64	2.42	3.64	2.43	1.65	3.72	1.50	3.63	3.20	4.06
18	2.11	1.08	2.65	2.83	3.64	2.00	1.31	3.72	1.50	3.63	3.20	4.37
19	1.50	1.25	3.40	2.83	3.07	2.71	1.62	2.15	1.00	4.13	3.60	3.74
20	2.35	1.50	2.91	3.31	3.04	1.70	1.46	3.89	1.00	3.15	1.10	3.45
21	3.37	2.53	3.44	3.67	3.35	1.88	1.63	2.15	1.93	3.95	3.60	4.37
22	1.50	1.17	2.58	2.64	3.74	2.60	3.67	4.35	1.00	4.52	2.78	4.37
23	4.11	2.80	4.91	4.80	3.59	2.85	4.35	2.62	2.24	3.99	5.00	4.37
24	1.68	1.24	2.71	2.64	3.98	2.60	3.67	4.35	1.00	4.52	2.87	4.37
25	1.50	1.32	2.91	3.31	3.06	1.70	1.46	3.89	1.00	3.15	1.10	3.45
26	1.52	1.25	3.11	3.38	2.84	1.70	1.46	3.89	1.00	3.15	1.10	3.45
27	2.95	2.35	3.29	3.51	3.85	1.88	1.63	2.15	1.93	3.88	3.20	4.37
28	1.61	1.25	3.32	2.90	3.07	2.05	1.62	2.15	1.00	4.13	3.20	4.06
29	1.25	1.17	3.11	2.90	3.33	1.94	3.67	4.35	1.00	4.52	2.78	4.37
30	2.28	1.66	3.24	3.78	3.53	2.01	1.00	3.27	1.00	3.54	3.20	4.37
31	1.67	1.42	3.17	2.99	3.30	1.56	1.62	3.88	1.00	3.15	1.10	3.75
32	2.06	1.42	3.17	2.99	3.19	1.56	1.62	3.88	1.00	3.49	3.20	4.37
33	1.52	1.50	3.17	2.77	3.51	2.37	1.47	3.88	1.00	3.49	3.20	4.37
34	2.84	2.48	3.68	3.66	3.60	2.47	2.23	2.15	1.00	3.61	3.53	4.68
35	2.27	1.58	3.24	3.66	3.53	1.95	1.62	3.70	1.00	3.54	3.20	4.06

(buildings and outdoors). The components under this index will make a significant contribution, especially to the detection and prevention of leaks.

The OSVS-index scores represent the weighted scores obtained from 123 assessment components and should be calculated annually. Thus, the change in OSVS-index scores in schools over time could be monitored. Additionally, the impact of water efficiency practices implemented in schools on the OSVS-index can also be analyzed.

CONCLUSIONS

In this study, the water efficiency sustainability index framework which consists of 123 components under 3 main headings, was developed to assess and monitor water efficiency practices in schools. This sustainability index was implemented in 35 pilot schools. The results emphasize that the components of measurement accuracy of water meters, control and inspection of their physical condition, training and capacity of the maintenance-repair team, leakage control and inspection of outdoor installations and pipes and inspection of installation conditions in terms of water meter measurement accuracy and accuracy have a greater impact on the water sustainability in schools. The sustainability index framework developed in the study will help analyze the current status of the assessment components within the scope of water efficiency. Moreover, the current status of water efficiency

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Table 6 | The scores of water efficiency sustainability and sub-sustainability indexes

Schools	Water Efficiency Index (OSVS-Index)		Sub-sustainability Indexes					
			EKG		STA		DKB	
	Index	Level	Index	Level	Index	Level	Index	Level
1	3.01	High	1.92	Inadequate	3.42	High	3.99	High
2	2.67	Average	2.25	Average	2.36	Average	3.49	
3	2.95		2.16		3.11	High	3.81	
4	2.94		2.48		2.38	Average	4.07	Quite High
5	2.67		2.27		2.36		3.49	High
6	2.97		1.83	Inadequate	3.41	High	3.99	
7	3.02	High	2.36	Average	3.07		3.81	
8	3.04		2.48		2.63	Average	4.15	Quite High
9	2.98	Average	2.50		2.48		4.07	
10	2.85		2.37		2.33		3.97	High
11	2.50		1.73	Inadequate	2.54		3.45	
12	2.78		1.90		2.85		3.86	
13	2.14		1.72		2.43		2.40	Average
14	2.94		2.15	Average	2.94		3.95	High
15	2.74		2.26		2.19		3.89	
16	2.57		1.84	Inadequate	2.63		3.45	
17	2.71		1.90		2.85		3.60	
18	2.75		2.04	Average	2.73		3.68	
19	2.70	Average	2.03		2.38	Average	3.86	High
20	2.46		2.42		2.40		2.58	Average
21	3.22	High	3.18	High	2.51		3.95	High
22	2.91	Average	1.85	Inadequate	3.24	High	3.94	
23	3.90	High	3.96	High	3.29		4.41	Quite High
24	2.98	Average	1.94	Inadequate	3.34		3.96	High
25	2.36		2.14	Average	2.41	Average	2.58	Average
26	2.34		2.16		2.31		2.58	
27	3.14	High	2.95		2.73		3.79	High
28	2.67	Average	2.06		2.28		3.82	
29	2.85		1.93	Inadequate	2.97		3.94	
30	2.90		2.63	Average	2.51		3.64	
31	2.42		2.15		2.52		2.66	Average
32	2.74		2.25		2.47		3.62	High
33	2.74		2.07		2.70		3.62	
34	3.19	High	3.06	High	2.67		3.86	
35	2.90	Average	2.56	Average	2.65		3.56	

practices is evaluated based on the sub-sustainability index or main activity components. This framework structure allows for a detailed assessment of water efficiency practices in schools. The framework structure developed in this study will make significant contributions to the literature, considering that consumption data obtained from pilot schools are generally analyzed according to various indicators in the literature. This framework will enable monitoring the sustainability of water efficiency activities instead of just calculating water consumption indicators and will enable the identification of strengths and weaknesses and priority components for improvement. Thus, it will provide a road map for school administrations in ensuring water efficiency. The support of school managers is particularly important in the realization of this study. In the examinations conducted in schools, difficulties were experienced in determining the performance classes of the assessment components. These challenges include the lack of sufficient data, evidence and documentation for activities or components in schools. Attention has been paid to the components defined in this framework to cover all aspects of water efficiency. In future studies, the study may be extended by considering components, such as water reuse, rainwater harvesting and smart water management applications. In addition, the study can be taken to a further level by applying multi-criteria decision-making methods for the prioritization of components with defined

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scores and weights. Prioritized components can be implemented in pilot schools, and their impact on water efficiency sustainability index scores can be monitored. Additionally, performance indicators can be defined to monitor water efficiency and sustainability based on this structure. These performance indicators can be calculated at specific intervals and tracked for changes within schools.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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