Sustainable Kuwait Index (SKI)

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***Abstract*—** Sustainable development has become the main framework to promote natural resources systems for urban cities in multi-dimensions. Economic, environmental, and social components form the structure of sustainable development. They are characterizing the positive or negative trend in sustainability which is defined by many indicators in a unique sustainable index. Many urban Cities were developed under a certain constraints guided by efficient indicators and comprehensive assessment frameworks to achieve the optimum level of sustainability. Efficient water supply systems play an important role in achieving the ultimate goal of sustainability. Kuwait water system is considered a case study to develop a methodology for identifying sustainable water systems indicators that measure the sustainability status, especially in terms of high water demand per capita and high supply of desalinated water. The water system of Kuwait suffers from a lack of a comprehensive framework for management and planning. Therefore, the triple bottom line of sustainable development (environmental, economic, and social) should be integrated with the infrastructure plans in the same framework to provide optimal and up-to-date results to decision-makers. The purpose of this study to bring different indicators that suitable to test the sustainability of urban water system to provide a simple number that can compare with others global indices. Sustainable Kuwait Index (SKI) for integrated and assessment water system is composed of 16 indicators that are classified into 4 sub-categories, which are resources, infrastructure, capacity, and socio-economic. These indicators were applied to urban areas in Kuwait to determines the sustainable identity and maintain easily the deficits. A. Almubarak urban area was selected to be as initial case study to test the applicability of SKI. The scores of SKI indicators demonstrate that some water system aspects need intervention action from decision makers to improve them and make system more sustainable for future.

***Keywords*—** Sustainable development, urban Cities, triple bottom line, Indicator, Index, water system.

I. Introduction

SUSTAINABLE infrastructure is not only a reflection of a community's long term resilience, but also evidence of its value across the areas of environment, economics and society. With population growth, limited natural resources, and increases in economic resources and technology, it is necessary to have engineering tools and techniques to integrate all the components together without compromising any of them. Stress is increasing on the world's finite resources such as land, water, materials, food, and energy due to increasing population and economic development. To preserve and improve the quality and quantity of our resources, we need to develop a sustainable framework in which our developments meet our requirements for natural resources, energy, food, transportation, waste recycling and decrease the growing social and economic inequities.

Sustainability is the main framework which has emerged as a planning and management concept and has commonly been applied to urban development in the fields of environmental, social, and economic planning which they are the triple bottom line of sustainability. In addition, sustainable development has become a tool in engineering with the most popular and clear definition of sustainable development (SD) coming from the Brundtland report as the development that meets the demands of the current generation without compromising the ability of future generations to meet their own demands [2]. Sustainable infrastructure provides and maintains physical infrastructure (water supply systems in our case) to enable reliable and accurate consumer use for the predictable future with attention on the infrastructure systems themselves, taking into account the adequacy of these systems to serve an increasing population, satisfy public service demands, remain in satisfactory working order, and be supported by reliable economic resources.

Looking toward a future with increasing demands on water resources, it is clear that coordinated water planning will be an ongoing need. Sustainable development refers to a wide range of issues, which involve an integrated approach to the management of the economy, the environment, and concerns areas of human and institutional capacity [4]. In order to manage a water system and its distribution network, the decision-maker needs information to use sustainable development as a planning vision: on the current stage of progress, on trends, pressure points, and on the impact of interventions. Indicators enable decision-makers and policy-makers to see if they are on the right track and to help them monitor progress towards sustainable development.

The water system of Kuwait suffers from a lack of a comprehensive framework for management and planning. Therefore, the triple bottom line of sustainable development (environmental, economic, and social) should be integrated with the infrastructure plans in the same framework to provide optimal and up-to-date results to decision-makers. The Sustainable Index provides a simple number instead of complicated information for decision makers to use as a basis for sustainability assessment [12]. Developing a sustainability index that empowers decision makers and researchers to know the trends of sustainability for each specific area and let them characterize how close or far they are from a desired sustainability level. Indicators give a unique numeric value that simplifies complicated information and allows exploration

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of the deficits in each factor in order to reach the sustainability level. This index has been adopted and adjusted based on previous studies of creating indicators to be appropriate for the Kuwait water system framework.

II. The Methodology of SKI Indicators

The vision of creating a sustainability framework is reached by managing, conserving and improving the physical infrastructure interconnecting economic, social, and environmental aspects with solutions for the current and future states. Sustainability in this research is focused on water systems and their surrounding factors. Sustainable development needs a system of indicators to characterize the progress towards sustainability. Environmental, economic, and social components are the three bottom lines of sustainability; they are used to create the Sustainable Kuwait Index (SKI) to measure the sustainability level. SKI contains 16 indicators that are classified into 4 sub-categories, which are resources, infrastructure, capacity, and socio-economic.

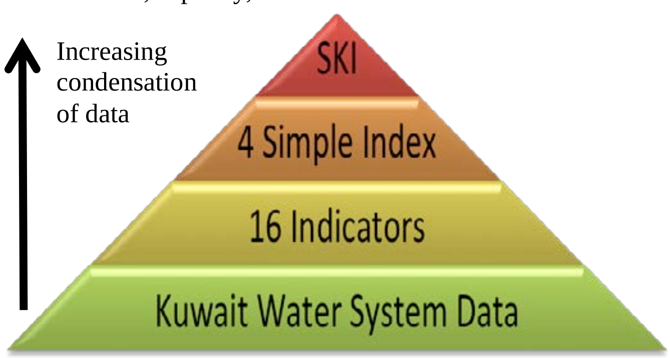

Fig. 1 Sustainable Kuwait Index (SKI) Pyramid

Depending on the scenario results; the sustainability indicators are synthesized to provide a holistic sustainability profile of the water system in Kuwait and indicate the percent achievement of the sustainable level in terms of the economic, social and environment aspects of the system. The SKI score is the average of the four sub-category (simple index) scores (resources, infrastructure, capacity, socio-economic). Each sub-category can be computed by dividing the sum of value indicators by the number of indicators. The range of all indicators is between 0 and 100, where higher scores indicate higher sustainability for that indicator. Some of the indicator equations have been adopted and adjusted from previous studies that have used a similar approach of measuring the sustainability of water systems. While for others indicators, mathematical techniques have been used for the evaluation criteria such as liner transformation, standardized score range transformation, and fuzzy logic transformation. The SKI indicators aim to improve the sustainability of water system in Kuwait by looking at local, national, and global standard value of sustainability.

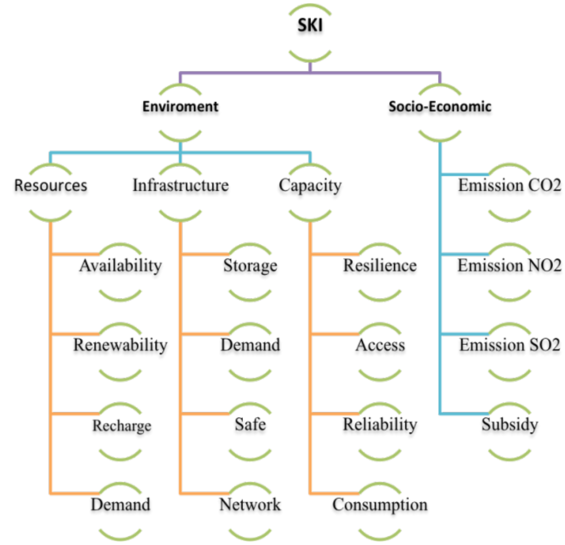

Fig. 2 SKI Index Structure

A. Environmental Category

This category contains indicators that are related to resources, infrastructure, and capacity of water systems in Kuwait. Environmental category includes 12 indicators that aim to measure the sustainability of water systems. A high score for an indicator means that it has potential to improve sustainability.

- *Resources*

The availability, renewability, recharge, and demand indicators are components of the resources subcategory. Each of these indicators measures some significant aspects of the water system. The *resources* score is determined by taking the average score of the four indicators that make up this subcategory.

(1) Availability

This indicator measures the percent of water production capacity remaining before the system reaches maximum production. It represents the ratio of water production to total installed capacity for desalination plants. The method used in this indicator is linear transformation to measure the sustainability of water availability.

(2) Renewability

This indicator uses the Falkenmark water stress indicator compared to the amount of renewable freshwater resources per capita to determine the score of renewability [6]. The amount of renewable freshwater assigned by Falkenmark is 1700 m3/cap/yr to meet water requirements. This indicator considers renewable surface and groundwater flow in the whole country. The renewability indicator is determined by equation 2. The renewability score is calculated based on a standardized score evaluation, which uses the renewable water resources per year-capita (T) as input [12].

(3) Recharge

This indicator (R_{ASR}) represents the sustainable water supply that called Aquifer storage and recovery (ASR). The recovery efficiency (RE) is the ratio of volume of water recovered with TDS less than 1500 mg/L to the volume of water injected in ASR operation [1]. This indicator used the recovery efficiency of ASR variable as sustainable indicator.

(4) Demand

This indicator measures the condition of sustainable demand for an area. By looking at the daily water per capita based on the standard approach of consumption per capita at the country scale (D_{STD}.), demand indicator can be computed. The standard daily per capita of water consumption is 250 L/day/c. It was assigned by the policy makers in MEW in Kuwait. The water per capita for area i is D_i (D_i =Demand$_i$/Populationi) and represents the water consumption measured from water sensors built into pipelines serving this area (i). The demand indicator is 100 if D_i is less than D_{STD}.

TABLE I
LIST OF SKI INDICATORS IN RESOURCES CATEGORY

Indicators	Indicator Equation
Availability	R_{av} =[$\frac{\text{(Total Supply per day)}}{\text{(total installed capacity per day)}}$] * 100
Renewability	$R_r = \begin{cases} 100 & if\ T > 1700 \\ \frac{T-500}{1700-500} * 100 & if\ 1700 < T \leq 500 \\ 0 & if\ T = 0 \end{cases}$
Recharge	$R_{ASR} = [\frac{\text{(volume of water recovered with TDS less than 1500 mg/L)}_{Cycle}}{\text{(volume of water injected)}_{\text{Cycle}}}] *$ 100
Demand	R_D = [($D_{STD.}$/D_i)] *100

- *Infrastructure*

This subcategory evaluates the water infrastructure at the local (area) scale. It has four indicators, each of which examines the ability of infrastructure to provide freshwater of appropriate quality and quantity. The indicators are dependent on the capacity of water storage tanks. The final simple index score for the sub-category is the average of the four indictors' scores.

(1) Storage

The Storage indicator focuses exclusively on supply from surface reservoirs and elevated tanks. In case a desalination plant is shut down for some critical reason, the storages that are distributed over the country have to cover the water demand for each area. The indicator measures the days that an area can survive with only water from storage. The types of water storage in Kuwait are surface reservoir and elevated tank. Equation 5 determines storage indicator by dividing the number of days that the storage can supply the specific area to 30 days. The maximum days that are required to restore a desalination plant to work, based on data from the Ministry of Electricity and Water (Energy), is 30 days [9]

(2) Demand

This indicator looks at the capacity to supply water demand considering population growth and future demand. It measures the number of years before the capacity to supply water will be exceeded due to population growth. It has adjusted the number of years to construct new water infrastructures in case of population growth to ten years instead fifty years that used in Canadian water sustainability index [12].

(3) Access to Safe Drinking water

This indicator measures the percent of unsafe drinking water reported from the Environmental Protection Agency in Kuwait EPA [8]. EPA in Kuwait has certain criteria to classify unsafe drinking water. These criteria involves concentration of total dissolved solid (TDS), percentage of chlorine (Cl) and PH of water. The numbers of days with unsafe water for drinking and sanitation for each area in Kuwait are used in calculating the score.

(4) Network

This indicator characterizes how the water network is distributed. There are many types of water networks, such as: series; branches; single loop; multi-loops; multi-loops with single redundant pipeline; and multi-loops with redundant pipelines. The percent of each type of network is given from the Department of Network and Maintenance of the Ministry of Electricity and Water. To determine the network indicator score (I_N), we have to find how many pipelines deliver water from sources to an area and the type of distribution of the main pipelines within the area. Table (I) an assigns score for each type of water network.

TABLE II
THE SCORE OF NETWORK INDICATORS [10]

Water Network	**Score of sustainable network (%)**
Series	8
Branches	25
Single loop	50
Multi-loops	70
Multi-loops with single redundant pipeline	90
Multi-loops with redundant pipelines	100

- *Capacity*

This subcategory measures the overall capacity of the community to access potable water, demand over capacity, and percent of sustainable demand per capita from the basic daily water requirement, and water services disruption. The capacity score is the average of the four indicators in the sub-category.

TABLE III
LIST OF SKI INDICATORS IN INFRASTRUCTURE CATEGORY

Indicators	Indicator Equation
Storage	$I_s = \left[\frac{\left[\frac{(\text{Reservoir or Tank volume for area})_i}{(\text{water per capita for area} * \text{population})_i}\right]}{30}\right] * 100$
Demand	$\text{FV} = (1+\text{r})^{t_d} * PV$ $\text{I}_\text{d} = \text{I}\begin{cases} 100 & if\ t_d > 50 \\ \frac{t_d}{50} * 100 & if\ 0 < t_d \le 50 \\ 0 & if\ t_d = 0 \end{cases}$
Safe Water	Isws = [1- { # of unsafe water (days) / n}] * 100 ; n= month or year
Network	To determine network indicator score (I_N) from table (II) it has to find: 1- How many pipelines that delivers the water from source to area 2- The type of distribution of main pipelines within area.

Where FV: number of consumers that can be served at 100 % of production
PV: number of consumers that can be served at current production
r: rate of population growth

(1) Resilience

Resilience is the probability that the system has failure scenario in certain period; the next period has not failure. Resilience shows the ability of the system to recover from a failure episode [13]. The resilience indicator assesses the drop in water pressure in peak period as failure scenario. In Kuwait, each area has a constant value for water pressure (P_i) in peak period and non-peak period. When the system has no drop in water pressure during peak period, the resilience indicator has score of 100 %.

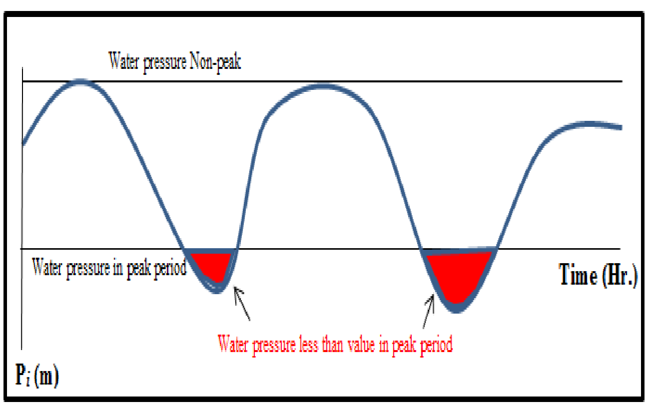

Fig. 3 Water pressure in WDN in Peak and Non-Peak periods

Figure 2 illustrates water pressure (P_i) when is below the normal condition during peak period. The water pressure value in non-peak period is the upper boundary of system, while water pressure value in peak period (normal condition) is the lower boundary of system. Any water supply with water pressure less than the upper boundary consider deficit in the system.

(2) Access

The access indicator assesses the ability of the community to receive an amount of freshwater per day-capita for domestic use. The minimum value for acceptable access per capita for domestic freshwater is 50 L/Cap/day to satisfy personal requirements excluding water for cleaning, cooking, and bathing. If these other requirements are included, the basic personal requirement is 150 L/Cap/day [14]. The access indicator (C_a) is adopted from the Canadian water sustainability index report (Policy Research Initiative, 2005).

(3) Reliability

The reliability indicator measures the fraction of time service is disrupted in certain period. Service disruption may occur as a result of: poor water quality or contamination; human error; or infrastructure issues (breakage pipelines or shut down pump). The Reliability Equation measures the number of times that service disruption occurs (Di) per certain period [7]. The value of reliability score has cubed to consider even small service distribution as significant concern.

(4) Consumption

This indicator assesses the trend of water consumption per capita per day (D_i) for area i relative to the basic requirement for water. The goal to sustainable daily water per capita is 150 L/Cap/day. To increase the accuracy of this indicator, it also considers the minimum personal requirement value of water (50 L/Cap/day). When indicator has a high value, which means there is a reduction in water consumption to reach the desired value (150 L/cap/day) for domestic potable water.

TABLE IV
LIST OF SKI INDICATORS IN CAPACITY CATEGORY

Indicator	Indicator Equation
Resilience	$C_{rs} = \left[\frac{[\text{No of times water pressure } (Pi) \text{back to normal condition in peak period}]_i}{[\text{No. of times water pressure } (Pi) \text{ in WDN below normal condition}]_i}\right]$
Access	$C_a = \begin{cases} 100 & if\ D_i > 150 \\ \left[1 - \frac{150 - D_i}{150 - 50}\right] * 100 & if\ 0 < D_i \le 50 \\ 0 & if\ D_i < 50 \end{cases}$
Reliability	$Risk_i = \left[\frac{\sum_t^n D_i}{n}\right]$; $C_r = [1 - Risk_i]^3 * 100$
Consumption	$C_{Capita} = \begin{cases} 100 & if\ 50 < D_i \le 150 \\ \left(1 - \left[\frac{(D_i - 150)}{(D_i - 50)}\right]\right) * 100 & if\ D_i > 150 \\ 0 & if\ D_i < 50 \end{cases}$

B. Socio-Economic Category

This category has 4 indicators to demonstrate the social and economic impacts of water system demand on sustainable development. The SKI indicators score in socio-economic category consider the pollutant emissions from desalination plants and percentage of government subsidy for water price. The score of socio-economic category is computed by the average of its indicators. The indicators in the social field usually are not related to the water system with a direct relation [8]. So the SKI indicators provide the percentage of consequences of water over consumption by measuring the pollutants emissions. The pollutants emissions applicable standards based on measurement EPA in Kuwait are the following:

CO_2 (Million M.Tons)	SO_2 (Thousand M.Tons)	NO_2 (Thousand M.Tons)
91.75	778.41	458.75

The pollutants emissions should not exceed the standard mass of the environment to absorb or reduce their harm.

(1) Emission CO_2

This indicator serves as a proxy for water consumption of the community by looking at the CO_2 emissions per capita from burning fossil fuel to produce water. Carbon dioxide (CO_2) is the primary greenhouse gas emitted from combustion of fossil fuels. This indicator shows the responsibility of consumers in the society for released CO_2 emission from desalination plants due to water consumption.

(2) Emission SO2

Determining the SO_2 emission as a consequence of water production is step toward a higher sustainability level. By identifying the SO_2 emission per capita, society may take action to decrease the emissions that result from water over-consumption.

(3) Emission NO2

The third emission indicator that reflects the role of society in increasing the quantity of pollutants released to the atmosphere is the NO_2 emission indicator that is the amount of emitted pollutants per capita due to water production from desalination plants reflects the consumption behavior of the community. A low score for this indicator indicates less sustainable water consumption.

(4) Subsidy

This indicator addresses the subsidy received from the government. When the government increases the support to water price it decreases the sustainability of the water system. The role of water price is important in reducing water over-consumption. When the water price is relatively small in terms of water production cost, then the consumption will be increased.

TABLE V
LIST OF SKI INDICATORS IN SOCIO-ECONOMIC CATEGORY

Indicators	Indicator Equation
Emission CO_2	$S_{co_2} = \left[1 - \frac{\left(\frac{CO_2\,Emission}{Population}\right)_i}{\left(\frac{CO_2\,Emission}{Population}\right)_{STD.}}\right] * 100$
Emission SO_2	$S_{So_2} = \left[1 - \frac{\left(\frac{SO_2\,Emission}{Population}\right)_i}{\left(\frac{SO_2\,Emission}{Population}\right)_{STD.}}\right] * 100$
Emission NO_2	$S_{No_2} = \left[1 - \frac{\left(\frac{NO_2\,Emission}{Population}\right)_i}{\left(\frac{NO_2\,Emission}{Population}\right)_{STD.}}\right] * 100$
Government Subsidy	$S_S = \left[\frac{Water\ price}{water\ production\ price}\right] * 100$

III. SKI PROFILE FOR A. AL-MUBARAK AREA

An area called A. Al-Mubarak was a case study to provide SKI indicators scores and then determined SKI index value. Sustainability profile was created for A. Al-Mubarak to provide information about area, water facilities, and SKI indicators. Based on 2011 data, the total population was 38981 and total houses were 5643. In Kuwait there are two types of water tower tanks: (1) balancing towers that are used if the demand is low (between 11 pm and 6 am), and (2) is a water supplier to a community. Abdullah Al-Mubarak area has 8 elevated towers (D14) that supply the entire area. Elevated towers (D14) have a total capacity of 5.288 MIG (24.04 thousand m^3). Ground water storage (E 13) is the water source for elevated towers (D14) and the length of main pipeline between them is 27500 m. Water consumption per day was 19210 m^3 and daily water use per capita in Kuwait was 493 L/d per capita in November 2011.

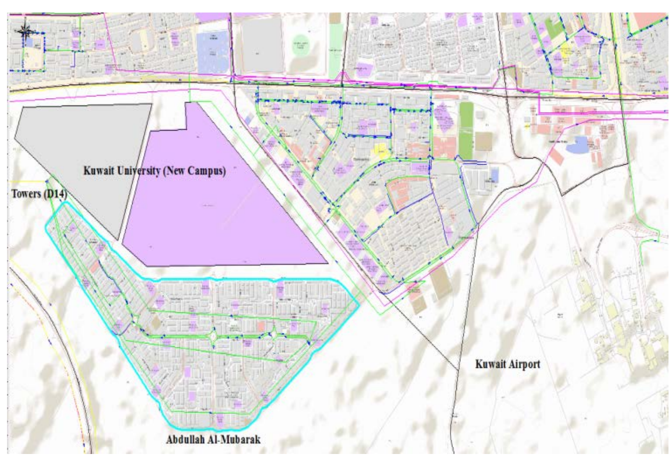

Fig. 4 A. Al-Mubarak Location from ArcGIS

IV. Calculation of SKI Indicators and Final Index Value

SKI index score for Abdullah Al-Mubarak area overall was 60.2 %. Resources indicators have scores at the national (Kuwait) and local levels. *The Availability indicator* has a value of 13%, indicating the amount by which desalination plants can increase supply. Kuwait has only one conventional renewable water resource, groundwater, that is equal 0.02 Km^3 per year. The *Renewability indicator* has a zero value because it is less than 500 Km^3 per year. The score for *Indicator 3* (*Recharge*) was 77.42%; it is the percentage of recovery efficiency by using ASR as sustainable water source and long-term supply of freshwater. The standard water per capita was assigned by policy makers in Kuwait equal 250 L/d per capita. While the water demands in November 2011, measured by sensors in pipelines of the Abdullah Al-Mubarak area, was 493 L/d per capita. The value of *Indicator 4 (Demand)* is 50.71 % which mean that is the sustainable demand score for the area. Overall, the Resources Category has a score of 35.3% based on the 4 indicators in this subcategory.

The *Storage Indicator* in the Infrastructure category has a value of 4.17% indicating how long tanks can supply water to the area in case of a shut-down of the desalination plants. The scores for *Indicators 6* and *7* (*Demand* and *Safe Water*) (65% and 100%, respectively) indicate the sustainable demand score of number of years before the system reaches 100% capacity and water quality. *Safe Water* indicator was 100% due to the fact that there were no issues regarding water quality reported. *Indicator 8 (Network)* has a score of 90% based on the type of water network in area. Generally, Infrastructure score was 64.8 % and that indicates to increase the maintainability and management for WDN.

The *Resilience indicator* designates to determine the system recovery score due to failure scenario. There is no data for pressure in WDN but by developing MUC then *Resilience indicator* can computes the number of times that the pressure in WDN has dropped below the designed peak pressure. In Kuwait, the percentage of access to freshwater is 100% except when there is a critical situation. As result, the score of *Access Indicator* is 100%. The *Reliability indicator* has a value of 100 % since the water demand is less than water supplied. 150 L/d per capita is the goal to achieve the sustainable consumption per capita. *Indicator 12* (*Consumption*) has a value of 22% indicating how far the daily water consumption per capita is from the sustainable goal. The capacity category illustrates the engineering sustainability aspects of water system. The category index score was 74%.

Indicators 13, 14, and *15* (*Emissions*) have values of 88.5%, 83% and 85%, respectively, and reflect the pollutants emitted from desalination plants due to water consumption. The score of *Subsidy Indicator* was 8.9% indicating the low water price in terms of the cost of water production. The socio-economic index score (66.35 %) was relatively small due to high pollution emissions per capita and low economic value of water in Kuwait.

V. Conclusion

Sustainable Kuwait Index (SKI) provides an unified code to measure sustainability in terms of environment and socio-economic criteria. There are 16 indicators that characterize the percentage of sustainability of areas in Kuwait. SKI indicators were applied to Abdullah Al-Mubarak area as a case study. SKI index overall score was 60.2 % and determined to provide the sustainability of Abdullah Al-Mubarak area. So, SKI attempts to support decisions related to water demand and supply management by illustrating the effectiveness of applying policies such as water price policy for water conservation or need for new storage due to population growth. The benefits of applying a new water management policy can be judged positive if the SKI score is increased. The ideal sustainability level can be achieved by applying effective water management tools that consider improvements to the triple bottom line of sustainability.

VI. Acknowledgement

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